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Policy runs with the COMPAS model

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ABSTRACT

This paper introduces an activity based (AB) traffic demand model for Copenhagen, called COMPAS. It is European first operational AB model of a discrete choice type. As an innovation we introduce the concept of Primary Family Priority Time (PFPT), which represents a high priority household decision to spend time together for in-home activities. Structural tests and estimation results identify two important findings. First, PFPT has a place high in the model hierarchy of day activity schedule submodels, and second, strong interactions exist between PFPT and the other day level activity components of the model system.

Forecasts, for the year 2030, are generated for two case studies: a) a road pricing and congestion scenario by COMPAS and a comparison version of the model system that excludes PFPT, and b) an Autonomous Vehicle (AV) scenario. With respect to the first scenario, the COMPAS model system with PFPT is measurably less sensitive to a road pricing and congestion scenario than the comparison model system without PFPT. This is most evident in lower mode shift from car to other modes and smaller shift of car commutes away from the afternoon peak period. With respect to the Autonomous Vehicle scenario, we get for the morning peak traffic and home-work trips only, an increase of car trips by 8.2%.

1. INTRODUCTION

Although many activity and travel decisions relate to individual persons, anyone living in a household is affected by the presence of other household members, and the effects are likely to extend to activity and travel choices. Modelling of such activity and travel choices is at the heart of activity based (AB) models. However, AB models used for traffic forecasting have not thus far dealt with the impact that families have on individual activity and travel by choosing to spend time together at home, i.e. blocking out periods of time where out-of-home activities and travel cannot take place for members of the household.

In reality there can be important interactions between in-home activity and travel activity choices. Spending time together as a family is of high importance in Denmark. For instance, two parents, both working, usually have only a couple of hours at their disposal to spend with their children, especially if they are small. In that time period, child care is a high priority, as is planning of household activities for the next day.

The research reported in this paper addresses a notion that, for some households, spending time together at home as a family is of high importance, so high that even work schedules may be adjusted to accommodate it, where this is possible. This high priority in-home family time is called Primary Family Priority Time (PFPT). It is called “Primary” in contrast to “Secondary” Family Priority Time, which refers to family priority time that involves joint travel and activity away from home.

This paper presents the model for Primary Family Priority Time as well as its application in the COPMAS model. Further on, we test the COMPAS model for two policies; a Road Pricing policy and an Autonomous Vehicles policy.

2. BACKGROUND

2.1. Behavioural theory behind the concept of PFPT

Researchers from Aalborg University under the ACTUM project present the results of in-depth household interviews that establish the importance of PFPT in Danish society (Aalborg University, 2012):

> *"... it is a wish or urge of the household and its members to spend time together. This is often referred to as quality time."* (p92)
> *"Especially households with younger children seem to have a high valuation of family time."* (p80)
> *"... most of the households seek to synchronise their personal schedules around dinner. However, this can both be seen in a functional perspective (one has to eat dinner) and in an emotional perspective (it is nice to spend time together with the family)."* (p92)
> *"The above-mentioned tactics are found in the empirical data and is something the households employ on a daily basis. A primary priority across the households in the sample is the synchronization of the household members for family quality time."* (p93)

Summarizing the Aalborg research, the interviewed household members seek to arrange work and personal activities in order to fulfil high priority commitments to in-home quality family time, called PFPT in the current paper.

There have been frequent efforts in the social sciences, similar to the Aalborg work, to understand and describe causal links between work, children and leisure within Danish families. Bonke (2009) shows that Danish parents spend about 50% more time with their children than those in England, while parents in Canada and the USA fall in between them. Bonke (2002) concludes that for workdays, family quality time happens most often in the evening – about 50% of the investigated families had two pre-agreed evenings when the whole family was together. In 2005 the Danish Government established the Commission of Work-Life Balance. The Commission published a report, “Chance for balance” (2007), which provides 31 recommendations to the government in order to ease and improve everyday life, especially for young families. Recommendation number 28 urges taking the complexity of everyday life into consideration when planning and promoting future traffic policies—such as Wi-Fi access in busses and trains—and transport infrastructure—such as metro and light rail systems in cities.

3. SURVEY DATA AND DEFINITION OF PFPT

For more than twenty years Denmark has been collecting travel data across the whole country using a one-day person based survey with very limited information about other household members, the so-called TU-survey (DTU Transport, 2012). For the ACTUM project, additional households were added to the survey. A few new questions were added and all household members were included, so that household decisions and interactions among persons in the household could be modelled. One household adult answered questions related to the household (e.g. car ownership, household income), while every person completed an activity/travel diary for the same weekday. Diaries for children under age nine were completed by a parent. For the purpose of modelling PFPT, questions were asked about in-home activity participation. In particular, for each in-home episode, each respondent reported the amount of time they spent in each of several activity purposes and—importantly for modelling PFPT— for each purpose who joined them in the activity.

The households included in the survey were sampled across the Greater Copenhagen area, with a strong focus on the central municipalities of Copenhagen and Frederiksberg, an area in which one would expect some divergence from national averages for key socio-economic and demographic variables. The sample was taken from the internet panel of a survey company, and the sampling procedure was based on family structure, age and geography. In total, 903 households were interviewed. Of those, 801 provided complete enough information to be used, too few for implementing a system for real-world forecasts, but enough to test the PFPT concept and implement a complete working model system. Tables 1 and 2 show the distributions of sample households and persons by type.

Table 1: The household sample description

	Frequency	Percent
One adult no children	157	19.6
One adult with children	114	14.2
Two+ adults no children	145	18.1
Two+ adults with children	385	48.1
Total	801	100

Table 2: The person sample description

	Frequency	Percent
Full time worker	922	41.7
Part time worker	61	2.8
Retired	149	6.7
Nonworking adult	99	4.5
University student	115	5.2
Child age 16+	119	5.4
Child age 5 through 15	534	24.2
Child age under 5	210	9.5
Total	2,209	100

Because of concerns about increased respondent burden, efforts were made to reduce the number of questions, which, unfortunately, caused the loss of some information about in-home joint activity participation. In particular, households that stayed at home together all day have no reported shared in-home activities, there is no record of shared morning activity if everybody in the household left for work or school before 9am, and there is no record of late evening shared activity if everybody arrived home after 8pm. The result is that the survey data is biased downward in joint in-home activity participation.

Furthermore, since respondents were not asked directly whether they engage in high priority family in-home shared activities on a regular basis—for this the current research relies on the qualitative research from Aalborg University—and the survey covered only one day, it may not be possible to fully understand the nature of the observed behaviour. For example, in some cases an observed joint in-home activity might have occurred even without a family commitment to quality time together, and in other cases a family committed to regularly spending high priority quality time together might not have exercised that commitment on their survey day; such behaviour would not be captured in the data. In the light of intuition about Danish society and the results of the Aalborg study, the concept was tested in the models presented here, and they give plausible results.

PFPT participation was defined as a binary variable and deemed to have occurred if the household satisfied the following conditions:

- At least one person age 13 or older journeyed away from home during the day, returned home by 8pm, and reported shared at-home activities after returning home.
- The respondent explicitly reported participation in shared at-home activity for purposes other than work, school or commerce.
- The shared activity involved all members of the household and lasted at least 20 minutes.

In total, 644 households in the sample include two or more persons. With the above definition, 206 of those 644 households, i.e. 32%, participated in PFPT on their survey day.

This restrictive definition enables PFPT to be modelled simply and provides a high standard for statistically validating that it occurs. It leaves room for enhancement in future research using larger data sets with improved collection of information about in-home activities. For example, PFPT might be defined as a multinomial outcome, allowing for less than full household participation in some cases. Or, PFPT might be defined as a latent variable—representing the need to spend time at home with family members—whose indicators are participation in and duration of various in-home activities. This would then entail the estimation of a hybrid model structure, jointly modelling the formation and impact of PFPT, an important but also potentially data hungry development we leave for future research.

4. MODEL STRUCTURE AND MODEL ESTIMATION

4.1. Model overview

The household travel demand portion of the COMPAS model system consists of an integrated set of discrete choice models implemented on the DaySim software platform (Bradley, et al, 2010). As depicted on the left in Figure 1, the COMPAS household models consist of long-term choice models (i.e. usual work location, car ownership and public transport pass ownership), models at the day level that identify the tours and stop purposes, and tour and trip models that model the details of each tour, generating and modelling each trip.

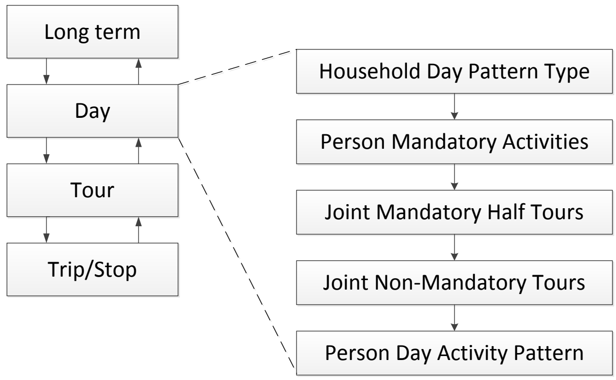

Figure 1: COMPAS model structure with details of the day level structure

According to the figure, the day level models consist of numerous models, placed in five main groups that operate in conditional sequence according to a priority hierarchy. Most of these models focus on modelling intra-household interactions explicitly. They constrain and condition the tour models, and are also impacted by accessibility arising from them. Also, in the course of the simulation, when a model at the day or tour & trip level determines that an activity or travel spans a particular period of time, that period becomes unavailable for other activities and travel. This method has already been implemented within DaySim for the Puget Sound Regional Council, the Metropolitan Planning Organization serving the Seattle region, and is currently being implemented also by the Delaware Valley Regional Planning Commission serving the Philadelphia region. Details of the entire COMPAS AB model system are presented in the appendix to provide context for the research presented in this paper.

The innovative part of the current research is that PFPT participation is modelled and inserted into the hierarchy as a household choice at the level of the household day pattern type, conditioning the other dimensions of choice within the day. PFPT is modelled jointly with the household's choice of whether to conduct one or more joint tours for non-mandatory purposes. A joint tour is one in which two or more members of the household conduct a complete tour together, sharing purposes, destinations, and all travel. It can involve situations where one person escorts another to an activity, stays while that person carries out the activity, and then returns home together with them. Also, given that PFPT participation occurs, a PFPT schedule model determines the start time and duration of the PFPT activity. This time is then blocked out, making it unavailable for on-tour activities and travel. In this way, PFPT conditions the other models of the day in two ways: PFPT participation is used as an explanatory variable in the other choices, and the PFPT schedule serves as a hard time constraint. Details of the PFPT participation model within the COMPAS model system are presented in the rest of Section 4.

4.2. Estimation results for a joint model of PFPT and presence of joint non-mandatory tours

Table 3 presents estimation results of the best model (many model definitions were tried). The model consists of 26 coefficients: fourteen for the presence of PFPT, eleven for the presence of one or more joint non-mandatory tours, and one constant for the joint presence of both components.

PFPT is less likely in larger households, which is not surprising given the PFPT definition requiring participation of all members and the greater complexity of coordinating more schedules. It is also more likely in households with children but also when at least one adult (in the households with two adults) has higher education. As the number of cars increases the likelihood of PFPT drops. It may be that car ownership and PFPT are jointly determined, i.e. households with independent members may be more likely to own cars and less likely to engage in PFPT. Car ownership is rather low in Denmark compared to other European countries due to high taxation, so this finding might have an important impact in the future. Household income does not show a strong connection to PFPT. The model includes two logsums that make the PFPT model sensitive to changes in travel conditions. The work tour mode choice logsum indicates that PFPT is more likely if workplaces are more accessible. The at-home mode-destination logsum represents accessibility for non-mandatory activities. It uses a size function that includes effects of various magnitudes for all categories of employment, school enrolment and households, with food and retail employment being the strongest attractors. The small negative coefficient indicates that PFPT is slightly less likely in neighbourhoods where there is good non-auto access to out-of-home non-mandatory activities.

Joint non-mandatory tours are more likely to be present in larger households as the possibilities increase with the household size. Households with children are less likely to make this type of tour; these households are likely to have size three or greater, so this result partially offsets the effect of the larger household. A household of only two people, both adults, is more likely to make joint non-mandatory tours. The same goes for households where at least one adult has a high education and for single parent households. The effect of car availability on joint tours is very similar to its effect on PFPT participation. While it is not statistically strong in either case and needs to be tested with larger samples, it indicates that in this population, the presence of a car correlates with households doing fewer of both these things together as a family, not only less PFPT, but also—somewhat counterintuitively—fewer joint non-mandatory tours (SFPT). The income effects are very similar to the ones already presented on the PFPT part of the model.

The positive constant for the joint presence of PFPT and joint non-mandatory tours captures the tendency for these two outcomes to occur together.

Table 3: Estimation results of the joint model for PFPT and presence of joint non-mandatory tours

Summary statistics		
Number of observations	644	
Degrees of freedom	26	
Log-likelihood of naïve model with only a full set of three	-658.4	
Log-likelihood (final)	-464.2	
Rho squared (with respect to naïve model)	0.295	
Segmentation variables – PFPT	**Estimate**	**t-value**
Constant	-1.37	-3.4
HH size 3	-1.19	-3.4
HH size 4+	-1.52	-3.8
Pre-school children	1.15	3.6
One adult + school children	1.11	2.8
Two adults, both working	1.84	4.3
Two adults, 1+ with high education	3.47	10.4
Two adults, one car	-0.44	-1.6
Two adults, 2+ cars	-1.00	-2.2
HH income 300K-600K DKK (€40K-80K)	0.59	1.5
HH income 600K-900K DKK (€80K-120K)	0.29	0.7
HH income over 900K DKK (€120K)	-0.11	-0.2
Work tour mode choice logsum for up to 2 workers	0.13	1.6
At-home non-auto mode-destination logsum	-0.03	-2.4
Segmentation variables – joint non-mandatory tours		
Constant	-2.77	-5.5
HH size 3	1.18	2.0
HH size 4+	1.41	2.4
Children	-0.95	-1.9
HH size 2, both adults	0.57	1.1
Two adults, 1+ with high education	0.80	2.0
One adult + school children	0.85	2.5
HH with a car	-0.41	-1.6
HH income 300K-600K DKK (€40K-80K)	0.39	1.0
HH income 600K-900K DKK (€80K-120K)	0.52	1.3
HH income over 900K DKK (€120K)	-0.20	-0.5
Interactions		
PFPT + Joint non-mandatory tour alternative constant	0.66	2.0

4.3. Effects of PFPT on other model components

Incorporating PFPT in the COMPAS model system includes conditioning the models lower in the model hierarchy on the outcome of the PFPT model. Altogether there are 16 day level submodels. Conditioning these models involves restricting availability of alternatives. For example, given the definition of PFPT, then if PFPT is present the Household Day Pattern Type alternatives without at least one person over age 13 traveling away from home are not available and are excluded from the choice set.

Conditioning these models also involves using PFPT presence as an explanatory variable in the conditional submodels. Table 4 shows the estimation results for two selected day pattern sub-models, the Household Day Pattern Type model and the Joint Half Tour Generation Model. For persons other than full time and part time workers, the presence of PFPT is accompanied by a significantly increased likelihood of a person day pattern that involves at least one mandatory or non-mandatory tour.

Table 4: Coefficients of the PFPT participation variable in day pattern models

Household Day Pattern Type model	**Estimate**	**t-value**
Mandatory; Full time worker	0.30	0.9
Mandatory; Part time worker	-0.07	-0.1
Mandatory; Gymnasium or university student	1.58	2.0
Mandatory; School child	1.36	2.2
Non-Mandatory; Full time worker	0.37	0.9
Non-mandatory; Part time worker	-0.27	-0.2
Non-Mandatory; Retired	2.54	2.7
Non-Mandatory; Non-working adult	2.59	2.3
Non-Mandatory; Gymnasium or university student	2.27	2.6
Non-Mandatory; School child	1.28	1.9
Non-Mandatory Pre-school child	0.79	1.2
Joint Half Tour Generation model		
Partially Joint Paired Half Tours (paired, to and from work/school)	1.59	3.0
Partially Joint Half Tour 1 (unpaired, to work/school)	1.80	2.9
Partially Joint Half Tour 2 (unpaired, from work/school)	0.54	1.3

Incidence of joint half tours (travel to and/or from work and/or school together) is positively influenced by the presence of PFPT. (To better understand the cases covered by these three coefficients see the appendix for detailed definitions and examples of the various types of half tours.) This result—along with the previously reported likelihood of co-incident PFPT and joint non-mandatory tour presence—is intuitively appealing; households that are more likely to do things together at home are also more likely to travel and do non-home activities together, in this case travel to and from work and school.

5. POLICY FORECAST

5.1. Road Pricing

This section tests the importance of PFPT in the COMPAS model system by comparing its predictions under a policy scenario to those of a version implemented without PFPT. The comparison version is implemented by removing the PFPT model from the structure and re-estimating all other model components without PFPT constraints and PFPT explanatory variables.

The two model versions are tested for a scenario with congestion and pricing in which travel times are increased and peak period road pricing is introduced. The portion of car travel time exceeding free flow time is increased from the 2010 base year values to 2030. The road pricing policy includes morning and afternoon peak charges of 3.00 DKK/km (approximately €0.40/km) with no pricing in the middle of the day or evening. The simulation is implemented using the 801-household estimation sample. To reduce the noise associated with simulation, each household's day is simulated ten times with a different set of random seeds each time.

Table 5 shows trip-percentage changes by mode and the total change in generation of trips. The dominant finding here is that the decrease in person car trips (the sum of car drivers and car passengers) in the COMPAS PFPT version of the model is significantly smaller than in the non-PFPT model. In other words, the PFPT model version is less sensitive to the tested policy scenario than the non-PFPT model. In response to the shift in person car trips, the trips by other modes go up, again with a smaller increase for the COMPAS PFPT version, except for walk mode. Finally, the COMPAS PFPT version's reduction in total number of trips is slightly smaller than that of the comparison non-PFPT model.

Table 5: Percentage change in trips by mode for Road Pricing scenario run, 2030

	Comparison model	COMPAS with PFPT	% difference
Car drivers	-9.97%	-9.32%	-6.5%
Car passenger	-8.77%	-6.16%	-29.8%
Public transport	6.63%	6.27%	-5.4%
Bicycle	3.64%	2.49%	-31.4%
Walk	1.54%	1.63%	6.0%
Total	-1.03%	-1.01%	-2.3%

Figure 2 shows the changes in work trips by car by time-of-day. This result is subject to higher noise-to-signal ratio than Table 5 because it includes a smaller sample of trips (work car trips only) and it spreads them out over an entire day. The two models show similar results, with the peak period pricing and congestion causing the car trips in the peak periods to drop, with some observed shifting, on average, to the other periods. The reduced sensitivity of the PFPT model (black line in the figure) is apparent in the afternoon peak, where the work car trips drop by a far smaller rate relative to the model version without PFPT (grey line in the figure).

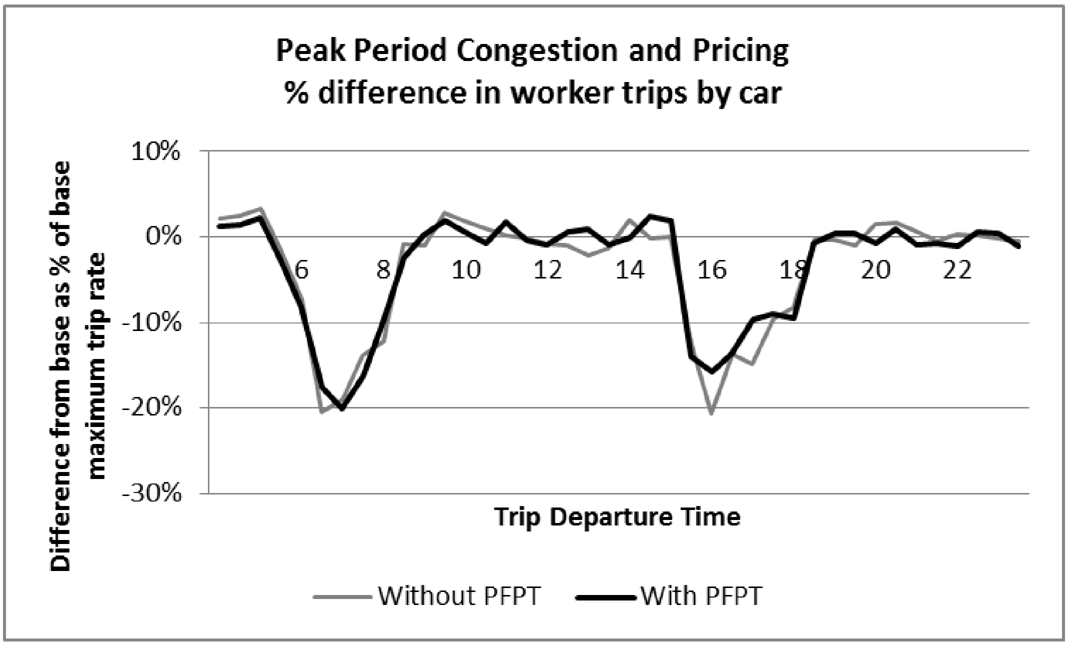

Figure 2: Scenario changes in time-of-day in the two model versions, 2030

The main reason that the model with PFPT is less sensitive than the comparison version without PFPT in its mode and time-of-day responses to the congestion and pricing policy lies in the fact that PFPT usually occurs during the evening peak period, which coincides with the dinner hour. PFPT households do not travel while they engage in PFPT, so those who engage in PFPT during the evening peak are substantially less affected by the policy than they otherwise would be. Overall, this causes the attractiveness of evening peak travel by car to be reduced less than in the comparison version without PFPT. As a result, there is less mode shifting away from car, and less shifting away from travel in the evening peak period.

From the traffic planning point of view the observed time-of-day result also makes sense. Afternoon and evening are usually periods of the day rich in trip chaining; the after-work commute gets connected to activities such as shopping, personal business and leisure activities. As these activities, including PFPT, are time-constrained, the resulting time-of-day shifts are smaller.

5.2. Autonomous Vehicles

In the Autonomous Vehicle policy we tested two runs; Increased road capacity and reduction in VOT for car users, both for the year 2030. The increased road capacity scenario equals decreasing the congestion travel time by half while the second scenario equals reduction of car driver VOT by 35%, i.e. an increased comfort for car drives drops their VOT to 65% of the original VOT.

The results of these two runs are presented in Table 6 for three options: All trip purposes and whole day, Work trips only and whole day, and Work trips in the Morning Peak only.

With respect to the results related to all trip purposes, the demand for car trips increases moderately between 3 and 5%. As it could be expected the largest shift happens from public transport; a decrease between 2% and 3%. When we look into the results related to the home-work trips only, then the car demand increases to between 4% and 6.5% relative to the base 2030 scenario. Finally, car demand increases between 6% and 8% in the two AV scenarios when focusing on the home-work trips in the morning peak only.

Table 6: Percentage change in trips by mode for scenario run with AVs, 2030

All trips, whole day	2030	AV1	AV2
Car	31%	+3.2%	+4.9%
PT	12%	-2.4%	-2.8%
Slow modes	57%	-0.8%	-1.3%
	(*100%*)		
Work trips, whole day	2030	AV1	AV2
Car	48%	+4.0%	+6.5%
PT	16%	-4.1%	-4.4%
Slow modes	36%	-1.9%	-2.9%
	(*100%*)		
Work trips, Morning Peak	2030	AV1	AV2
Car	50%	+5.8%	+8.2%

6. CONCLUSIONS

This paper demonstrates how family in-home quality time, denoted as Primary Family Priority Time (PFPT) in the current research, can be integrated into a fully operational discrete choice AB model system and how this particular model component impacts travel demand of the family members. PFPT is implemented in the model system for Copenhagen, the COMPAS model, which is the first operational AB model in Scandinavia.

Does Primary Family Priority Time play any significant role in policy forecasts? The comparative forecasts provide strong evidence that it does. The COMPAS model system with PFPT is measurably less sensitive to a road pricing and congestion scenario than the comparison model system without PFPT. This is most evident in lower mode shift from car to other modes and smaller shift of car commutes away from the afternoon peak period. Explanation for such results can be found in the fact that, although PFPT itself is only mildly affected by travel conditions, it strongly constrains all conditional choices, via time constraints implemented throughout the COMPAS model structure, reducing their sensitivity to travel conditions. The scenario results show therefore that incorporating in-home activities into the AB model for Copenhagen is important. Not only does including PFPT improve the quality of the lower level models, but also if the COMPAS model ignored in-home activities it would overestimate response to changes in travel conditions.

The results of the second scenario run, i.e. introduction of autonomous vehicles) show that better utilisation of the road capacity (i.e. decrease of congestion travel time) results in an increase in car travel demand by 3% - all travel purposes, whole day, and by 6% - work trips in the morning peak. If at the top of this we decrease the drivers VOT, due to the increased travel comfort, then car travel demand increases further by 2%.

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