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COMPAS runs for autonomous vehicles scenarios

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Abstract
OTM is a tour based traffic model for the Greater Copenhagen. A shift of modelling of person travel demand to an activity based approach has been tried since 2011 through a development of the COMPAS model. This paper is a first Danish evidence of differences between the results of the two models for the same (or similar) scenario runs.

For the case study of scenario runs for autonomous vehicles (AV), we conclude that the tour based and activity based approaches to modelling of person travel demand result indeed in quite different results. Three largest evidences for this statement are the following:

- The effect of changing the carpark into AV is considerably stronger in OTM than in COMPAS, i.e. the increase in car trips is larger in OTM than in COMPAS.
- Slow modes contribute most to the new car trips in OTM runs. However, in COMPAS it is the PT trips that shift largely to AVs.
- The very short trips, i.e. walk, do not change to car trips in the COMPAS AV scenario runs. Actually, the walk trips increase alongside the car trips due to the positive induced traffic. Opposite to that, in all OTM runs the walk trips drop, sometimes quite much.

Introduction
COMPAS is Denmark's first activity based (AB) traffic model of a discrete choice type. The model covers the Greater Copenhagen Area (GCA), just as well as the OTM model, which is the operational tour based traffic model.
The paper aims to compare the OTM and COPMAS runs for autonomous vehicles (AV). In that way the theoretical advantages of AB models over the tour based models will be visualised through the models' outputs. The results are limited to person travel demand because the route choice model in COMPAS is still under development. The two models were run for three AV scenarios: changes in VOT for car drivers, changes in road capacity, and changes in parking policy. Three largest differences between the models' results are:

- Once the carpark in the GCA has changed to AVs, the modal shift is much larger in the OTM model than in COMPAS.
- Modal shift of the slow modes (i.e. bicycle and walk) is substantial in the OTM runs. Instead, the public transport (PT) modes shift largely to AVs in the COMPAS runs.

- Walk mode increases in the COMPAS runs, i.e. shift from personal cars to AVs results in increase of car and walk trips on behalf of PT and bicycle trips. In the OTM runs, the walk mode shifts to AVs in the same way as other available modes.

About the COMPAS model

COMPAS – COpenhagen Model for Person Activity Scheduling, is being developed for the GCA under the ACTUM research project. The ACTUM project is funded by the Danish Strategic Research Council, in the period 2011-2017. COMPAS is the first operational discrete choice AB model within the Scandinavian countries. COPMAS is a household (HH) based model.

The HH 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.

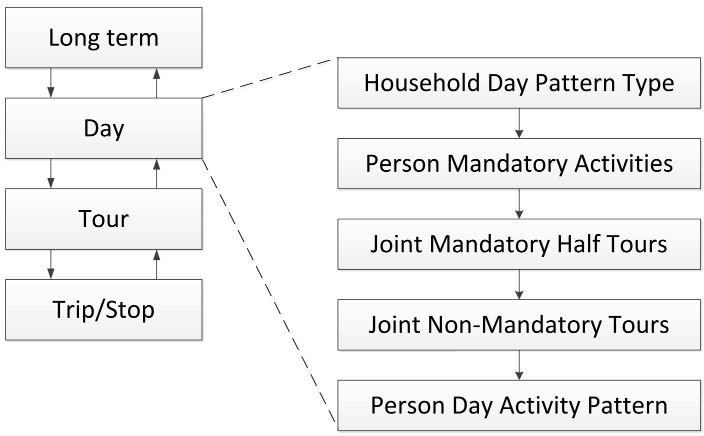

Figure 1: COMPAS model structure with details of the day level structure

The day level models consist of numerous models in five main groups that operate in conditional sequence, according to a priority hierarchy, as shown in Figure 1 on the right. The household day pattern type model determines the highest priority aspects of the day from the perspective of the household, namely a pattern type for each person, determined simultaneously for all members. For each person, the pattern type identifies whether they travel for work, school or business (mandatory type), travel only for other purposes (non-mandatory type), or stay home all day (at-home type).

Given the needs within the household for travel to work and school, the next set of models determines joint travel to and/or from those mandatory activities. Joint travel to work and school is only modelled for persons travelling to their usual work or school location. It can take the form of half tours, either to (Half Tour 1) or from (Half Tour 2) work and/or school. These half tours can be either paired or unpaired, where paired half tours are symmetrical, involving the same participants traveling together in both directions. They can also be either partially joint, in which one person drops off one or more others on their way to work or school, or fully joint, in which the destination for all participants is the same place. In fully joint half tours it is possible that one participant serves as a chauffeur and returns home after dropping off the other(s). The following examples illustrate the half tour definitions. In example 1, the household includes 2 workers (A, B) and two school children (C, D). In the morning, worker A drops both children C&D. In the afternoon, worker B picks-up child C, while child D returns home on her own. This household's day includes two unpaired partially joint half tours; Half Tour 1 with A, C and D, and Half Tour 2 with B and C. In example 2, the children (C & D) travel to and from the same school together, while the parents go to and from work separately. In this case the household's day involves two paired fully joint half tours conducted jointly by C and D.

To model joint half tours, a generation model determines for the household whether a joint half tour occurs and what type it is. This is followed by a participation model that determines, simultaneously for all eligible household members, which ones participate. This pair of models is repeated until the generation model determines that no more joint half tours occur.

Once the joint travel for mandatory activities has been determined, the next set of models determines the number of joint tours for non-mandatory purposes conducted by members of the household, and the purpose of each one. This is modelled via a tour generation model followed by a participation model, repeating until the generation model determines that there are no more joint tours to be conducted. The last of the day level models is the person day activity pattern. Constrained by all the prior model outcomes, this pair of models determines, for each person, the number of tours in the day, the purpose of each tour, and the purposes for which intermediate stops are to be made, if any. First, the pattern model determines the presence of tour and stop purposes. Second, the generation model determines the number of tours for each purpose that the pattern model determined to be present. The number of intermediate stops for each purpose is left to be determined subsequently as the tours determined here are being simulated.

COMPAS simulates the details of each household's tours in the following priority order:

1. household's partially joint half tours
2. household's fully joint half tours
3. aspects of each person's mandatory tours that have not been determined by joint half tour simulation
4. household's joint non-mandatory tours
5. each person's remaining non-mandatory tours

As each tour and trip is simulated, the outcomes are recorded for each participant, including the updating of their available time windows, so that subsequent models are properly constrained. For partially joint half tours, the pickup and/or drop-off sequence is determined, the tour mode is modelled, and the timing of all work and school arrivals and departures is modelled. For fully joint half tours, the tour mode and timing are modelled, and intermediate stops are generated—and the location, mode and timing of each stop are modelled—iteratively for both half tours. For person mandatory tours, the destination is modelled if it is a business tour, work-based sub-tours are generated, the tour mode and timing are modelled, and intermediate stops are generated and modelled as described above. For the household's joint non-mandatory tours and each person's remaining non-mandatory tours, the destination is modelled, and intermediate stops are generated and modelled, as described above.

AV runs with OTM

OTM has been the operational traffic model for the GCA since 1996 (Jovicic, 2003 and Vuk, 2006). The model has been updated number of times, the latest improvement being the sub-model for choice of time of day (version 6.1).

Danish Road Directorate has completed a number of OTM runs where the whole carpark in the GCA (split in 900 zones) has shifted to autonomous vehicles in 2025. Apart of the Base2025 run, the following three AV scenario runs were completed:

AV1: Road capacity enlarged by 30%

AV2: Driving costs lowered by 20%

AV3: Parking costs reduced by 50% while parking searching time was sat to zero

AV4: AV1+AV2+AV3

Table 1 shows the person trips for a workday in 2025 across model runs and available modes. Tables 2 and 3 show the absolute end percentage values for differences between scenarios and the base run.

Table 1: Person trips for a workday in 2025, in ’000

	Base2025	AV1	AV2	AV3	AV4
Car driver	2,795	2,807	2,929	2,912	3,079
Car passenger	1,326	1,346	1,261	1,343	1,293
Bicycle	1,358	1,348	1,332	1,314	1,274
Walk	1,139	1,132	1,117	1,104	1,073
PT	1,199	1,190	1,183	1,173	1,144
Total	7,817	7,823	7,823	7,846	7,863

Table 2: Changes in person trips for a workday in 2025, in ’000

	AV1	AV2	AV3	AV4
Car driver	12	134	117	284
Car passenger	20	-65	17	-33
Bicycle	-10	-26	-44	-84
Walk	-7	-22	-35	-66
PT	-9	-16	-26	-55
Total	6	6	29	46

Table 3: Percentage changes in person trips for a workday in 2025

	AV1	AV2	AV3	AV4
Car driver	0.4	4.8	4.2	10.2
Car passenger	1.5	-4.9	1.3	-2.5
Bicycle	-0.7	-1.9	-3.3	-6.2
Walk	-0.6	-1.9	-3.1	-5.8
PT	-0.7	-1.4	-2.2	-4.6
Total	0.1	0.1	0.4	0.6

The overall conclusions for all scenario runs relative to the base scenario are that Car Driver trips increase, Bicycle/Walk/PT decreases, and the induced traffic small and positive for all scenarios. The Car Passenger mode experiences shifts in both directions along the completed scenarios.

AV1 (Road capacity enlarged by 30%): It comes as a surprise that the overall impact of improving road capacity by 30% on car trips (i.e. trips by Car Driver mode) is almost none. It is also a bit difficult to understand why Car Passenger trips increase in this scenario relative to the base run. Finally, modal shift from slow modes is larger than from public transport modes – a tendency that, at least for long distance trips, should be opposite.

AV2 (Driving costs lowered by 20%): This scenario was originally thought as a decrease of car driver’s VOT by 40%. However, that turned not to be possible to operationalize in OTM. As an approximation, the driving costs were lowered by 20%. Shift to car trips in this scenario is large, i.e. +4.8%. In OTM driving costs are payed only by car drivers, which results here in a large drop of car passenger trips (i.e. half of all new car driver trips comes from car passenger mode). Again, just as in AV1, the shift from slow modes is larger than from PT.

AV3 (Parking costs reduced by 50% while parking searching time was sat to zero): Shift to car trips when parking policy has been changed is quite substantial, i.e. +4.2%. Again, just as in AV1 and AV2, the shift from slow modes is larger than from PT.
If all three improvements related to AVs are introduced in 2025 (i.e. AV4) then OTM predicts a large increase of car trips, i.e. 10.2%. More than half of those trips origin in slow modes.

AV runs with COMPAS

The following three AV runs were completed with the COMPAS model (base year 2010):

AV5: VOT for car drives reduced by 40%

AV6: Parking costs reduced by 50% while parking searching time was sat to zero, and Road capacity enlarged by 30%

AV7: AV5 + AV6

Tables 4 and 5 summarise the obtained results.

Table 4: Changes in person trips for a workday in 2010, in '000

	AV5	AV6	AV7
Car driver	73	19	90
Car passenger	-7	23	2
Bicycle	-32	-34	-37
Walk	40	40	37
PT	-30	-34	-48
Total	43	13	45

Table 5: Percentage changes in person trips for a workday in 2010

	AV5	AV6	AV7
Car driver	3.5	0.9	4.3
Car passenger	0	2.3	0
Bicycle	-2.7	-2.9	-3.1
Walk	3.9	3.9	3.7
PT	-3.4	-3.9	-5.4
Total	0.7	0.2	0.7

AV5 (VOT for car drives reduced by 40%): In contrary to OTM, it is possible to scenario adjust VOT in COMPAS control files within the DaySim software. Therefore, in this scenario run we lowered car driver's VOT by 40%, according to the international literature on AV model runs. Shift to car trips in this scenario is 3,5%, relative to the base run. PT deceases most, followed by bike. It is interesting to note that walk trips increase almost 4%. Investigating this more closely we found out that the great majority of the positive induced traffic trips are (short) walk trips.

AV6 (Parking costs reduced by 50% while parking searching time was sat to zero, and Road capacity enlarged by 30%): An increase in car trips is marginal in this scenario, i.e. about 1%. The patterns for bicycle, walk and PT modes repeats from scenario AV5. What is interesting here is that the car passenger mode goes up by 2.3%.

If both improvements related to AVs are introduced in 2010 (i.e. AV7) then COMPAS predicts an increase of car trips by 4.3%. Most of those trips shift from PT. Short trips by bike shift to AV by 3.1% relative to the base 2010 scenario. Like in AV5 scenario, the walk share increases due to a positive induced traffic.

<u>Additional results</u>

Table 6 shows %-changes in number of trips by SOV (Single Occupancy Vehicles) by distance intervals in the Base2010 and AV7 scenario runs. Due to the modal shift of walk, bicycle and PT trips to AVs, the portion of short trips, up to 2 km in length, increases quite dramatic. On the other side, the portion of car trips between 2 and 20 km drops.

Table 6: %-changes of SOV car trips by distance in Basis2010 and AV7 scenario runs

	0 to 1km	1 to 2km	2 to 5km	5 to 10km	10 to 20km	Over 20km
Base2010	8.5	8.6	23.9	19.3	23.3	16.3
AV7	9.3	10.0	23.5	18.8	22.0	16.4
%-changes from Base to AV7	+9.6	+16.6	-1.9	-2.8	-5.6	+0.3

We also observe that car occupancy drops from 1.46 persons/trip in the base run to 1.42 persons/trip in AV7 scenario. This is to say that a switch from personal car to AVs will increase the number of car trips with a single person.

Comparison of scenario runs between the two models

Table 7 summaries the differences between the OTM and COMPAS AV run where the driving costs were decreased in OTM while the VOT for car drives were decreased in COMPAS. As mentioned before, originally, it was intended to run a scenario where VOT for car drivers were decreased by 40%. That turned not to be possible in OTM, because of what an approximation was done by decreasing driving costs (pays by the driver) by 20%.

Table 7: OTM vs. COMPAS runs for AV scenario with changes in driving costs (OTM) and VOT (COMPAS)

	OTM	COMPAS
Car driver	134.000 (+4,8%)	73.000 (+3,5%)
Car passenger	-65.000 (-4,9%)	-7.000 (0%)
Bicycle	-26.000 (-1,9%)	-32.000 (-2,7%)
Walk	-22.000 (-1,9%)	40.000 (+3,9%)
Public transport	-16.000 (-1,4%)	-30.000 (-3,4%)
Total	6.000 (+0,1%)	43.000 (+0,7%)

Going from the top of the table:

- The scenario gives a much larger increase in car trips in OTM than in COMPAS.
- Car passengers contributes by 50% of all new car trips in OTM, while in COMPAS the change is 0%.
- It seems that the bicycle decrease is of a similar magnitude. However, when comparing the bike decrease to the increase in car trips then bicycle shift in COMPAS is much larger than in OTM.

- Changes in walk mode are somewhat most radical. While walk decreases in OTM it increases in COMPAS. Also, the %-change on COPMAS is twice of that in OTM. COMPAS walk increase happens because of the significant positive induced traffic.
- PT decreases twice as much in COPMAS than in OTM, i.e. the shift of long distance PT trips happens in COMPAS.
- Finally, the induced traffic is zero in OTM while about 1% in COMPAS.

Table 8 summarises the differences between the OTM and COMPAS AV run where all three AV scenarios are included. The general difference between the results is the following:
- All values related to OTM are equal to the sum of the individual scenarios (or, just about is)
- All values related to COMPAS are much smaller than the sum of the individual scenarios.

Table 8: OTM vs. COMPAS runs for AV scenario where all changes are included

	OTM	COMPAS
Car driver	284.000 (+10,2%)	90.000 (+4,3%)
Car passenger	-33.000 (-2,5%)	0 (0%)
Bicycle	-84.000 (-6,2%)	-37.000 (-3,1%)
Walk	-66.000 (-5,8%)	37.000 (+3,7%)
Public transport	-55.000 (-4,6%)	-48.000 (-5,4%)
Total	46.000 (+0,6%)	45.000 (+0,7%)

Going from the top of the table:
- The scenario gives a much larger increase in car trips in OTM than in COMPAS.
- Car passengers contributes by 12% of all new car trips in OTM, while in COMPAS the change is 0%. We believe that this happens because …..
- The slow modes in OTM contribute by as much as 53% to the car trips increase. Individually, they decrease by some 6% relative to the base scenario.
- In COMPAS, the bike trips decrease by 3%, which is 40% of the car trips increase. However, the walk (short) trips increase by 4% and that is due to the positive induced traffic.
- Public transport contributed by only 19% to the car trips increase in OTM, while in COMPAS that share is equal 50%.
- Finally, the induced traffic is zero in OTM while about 1% in COMPAS.

Conclusions

OTM is a tour based traffic model for the Greater Copenhagen Area (GCA). OTM has been in use, and therefore in a permanent update, since 1996. A shift of modelling of person travel demand to an activity based approach has been tried since 2011 through a development of the COMPAS model. This paper is a first Danish evidence of differences between the results of the two models for the same (or similar) scenario runs.

For the case study of scenario runs for autonomous vehicles (AV), we conclude that the tour based and activity based approaches to modelling of person travel demand result indeed in quite different results. Three clearest evidences for this statement are the following:

- Intensity: The effect of changing the carpark in the GCA into the AV (of different scenarios) is considerably stronger in OTM than in COMPAS, i.e. the increase in car trips is larger in OTM than in COMPAS.
- Modal split: Slow modes contribute most to the new car trips in OTM runs. However, in COMPAS it is the PT trips that shift largely to AVs.
- Walk mode: The very short trips, i.e. walk, do not change to car trips in the COMPAS AV scenario runs. Actually, the walk trips increase alongside the car trips due to the positive induced traffic. Opposite to that, in all OTM runs the walk trips drop, sometimes quite much.

Additionally, the COMPAS runs show that shift to AV will shorten the car trips and decrease the car occupancy.

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