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The potential impacts of automated cars on urban transport: an exploratory analysis

Anthony D May [a] [1], Simon Shepherd [a], and Paul Pfaffenbichler [b] and Günter Emberger [c]

[a] Institute for Transport Studies, University of Leeds,
Leeds, LS2 9JT, United Kingdom
[b] Institute for Transport Studies, University of Natural Ressources and Life Sciences,
Vienna, 1190, Peter Jordan Strasse 82, Austria
[c] Research Center for Transport Planning and Traffic Engineering, University of Technology Vienna
Vienna, 1040, Gusshausstrasse 30/2, Austria

Abstract

Objective The concept of automated cars is rapidly becoming a reality, with a series of real world trial applications underway, and government predictions that automation will be introduced in the early 2020s. Yet there has still been very little analysis of the impacts of such developments on the performance of urban transport systems. These impacts are potentially complex. On the positive side, automation has the potential to increase road capacity, make driving available to more people, and reduce accidents and emissions. On the negative side, it could attract users away from public transport, walking and cycling, substantially increase traffic levels and stimulate urban sprawl. These impacts cannot currently be measured empirically and, by the time that they can, it will be too late to change the implementation model to rectify any resulting problems. Predictive assessments are therefore needed. The objective of this paper is to consider the possible impacts of automated vehicles, to predict their effects on the urban land use and transport system, and to discuss the policy implications. We focus specifically on automation of the car fleet, and do not consider the potential of automation of public transport or freight vehicles. This extended abstract presents our principal findings and is provided prior to publication of the full paper in 2019.

Methods In the full paper we consider the current literature on the range of attributes of automated vehicles which might affect transport and land use patterns, and suggest potential outcomes for each over the period to 2050. These attributes include the proportion of automated vehicles in the car fleet, whether automated vehicles are privately purchased or publicly shared, the impacts of automation on network capacity, the reduced need to pay for and walk from parking places, the potential reduction in the value of in-vehicle time and the ability of those who cannot currently drive to use cars. We represent these attributes in an expanded causal link diagram of the urban land use and transport system, import those causal links into the MARS systems dynamics model, and test the impacts in a set of ten scenarios using an updated MARS model of Leeds.

Results Based on our input assumptions, we find that kilometres travelled by car in 2050 could be over 50% higher than in the business as usual scenario. Public transport use could fall by 18%, threatening accessibility for those dependent on it, while walking and cycling could fall by 13%, reducing their health benefits. Overall person-km would rise, suggesting a tendency to urban sprawl, which is confirmed in subsequent tests. A requirement that all automated cars are made available as shared vehicles could reduce these adverse impacts somewhat, but the effects appear to be sensitive to the charge per km which is imposed.

Discussion These results demonstrate the importance of understanding the scale of systems response to each of the attributes which we have considered. In terms of policy, it will clearly be important to manage the way in which automated cars are introduced into urban areas, if they are not to lead to a worsening of the urban environment, accessibility and health. A requirement to make all such vehicles part of shared fleets offers one way forward, but more work is needed to understand the way in which use of such fleets should be charged.

Keywords: autonomous vehicles; urban transport; modal choice; land use

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[1] Corresponding author. Tel.: +44 (0)1904 621796.
E-mail address: A.D.May@its.leeds.ac.uk

1. Introduction

The concept of vehicle automation has been promoted for several decades, but has now approached reality. It is generally accepted that there are potentially six levels of automation: 0 No Automation, 1 Driver Assistance, 2 Partial Automation, 3 Conditional Automation, 4 High Automation and 5 Full Automation (SAE International, 2016). Vehicles of levels 1-3 are already available in the market, and offer drivers greater safety and comfort and a simpler driving task. Vehicles of types 4 and 5 are in production, and governments anticipate that they will be in operation on public roads early in the next decade. For example, Daimler recently announced the development of prototypes for levels 4 and 5 by 2020, BMW has announced it would offer automated vehicles at level 4 and 5 from 2021 and Tesla has declared that it can offer level 4 and 5 today, if they are legally permitted. The UK government has a commitment to have level 4 and 5 vehicles operational on public roads by 2021 (HMG, 2017). In 2016 the Austrian government published an action plan for automated driving (BMVIT 2016). The main objective of the action plan was to create the legal framework to facilitate Austrian test beds for automated driving.

The stimulus for these developments has been largely technology-led, with governments using their regulatory and financial support to achieve industrial competitive advantage. Benefits to the public are typically presented as increasing safety and driving comfort, enabling those who cannot currently drive to use private vehicles, and improvements in the capacity of the road network (BMVIT, 2016). However, full automation could potentially lead to a much wider range of impacts, whose benefits to society are at best uncertain (Hensher, 2018), Wadud et al, 2016). If the driving task is removed, time spent driving can be used for other purposes, leading to a reduction in the implicit value of travelling time. This in turn could make private car use more attractive than public transport, walking and cycling, resulting in substantial changes in modal shares, and potentially encouraging urban sprawl. If, as envisaged, empty vehicles can return autonomously to low cost suburban parking areas, this could accentuate the pressures for urban sprawl while making city centre space available for more intensive development (Zakharenko, 2016); moreover it would add substantially to traffic flow, thus reducing the benefits of capacity enhancement.

The scale of these impacts will depend also on whether automated vehicles are sold to individuals, as conventional manufacturers would prefer, or offered as shared vehicles as promoted by ICT companies and public transport bodies (ITF, 2015, UITP, 2017, Hensher, 2018). Shared vehicles are typically used more efficiently, since the adoption of a charge at the point of use makes their marginal use less attractive than that for private cars.

Despite these potentially significantly damaging societal impacts of automation, there has been little analysis of the potential impacts of automation on urban land use and transport, or of the strategies which cities should adopt to mitigate any adverse impacts. In some ways this is not surprising; prior to their full scale introduction it is not possible to obtain empirical evidence on behavioural responses to them. Instead, predictive models are needed, but conventional models typically do not represent automated vehicles as a mode or reflect the land use consequences.

In this research we aim to remedy this by using a systems dynamics model speculatively to assess the possible impacts over time of the introduction of automated cars under different governance regimes. The systems dynamics model which we use, MARS, has been validated for the city of Leeds, UK, and enables us to input possible behavioural responses to changes in market shares, shared or individual ownership, capacity, parking options, and in-vehicle travel time values, and hence to predict the range of possible impacts on modal shares, land use and congestion. We focus solely on full (levels 4 and 5) automation of private cars, and do not consider the potential impacts of parallel automation of public transport or freight.

In the full paper we review the literature on possible market penetration of automated vehicles, the ownership and sharing options, possible user and systems responses, and previous attempts at analysis. In subsequent sections we describe our analytical approach, outline the range of assumptions that we have tested and present the results of our speculative tests for Leeds. Finally we draw conclusions and discuss the policy and governance implications.

2. The analytical approach - approach to modelling

Given the earlier study of longer term impacts, we elected to use the MARS model to conduct the quantitative tests reported in this paper. MARS is a dynamic, integrated Land Use and Transport Interaction (LUTI) model. It includes a transport model which simulates the travel behaviour of the population related to their housing and workplace location, a housing development model, a household location choice model, a workplace development model, a workplace location choice model, and a fuel consumption and emission model. All these models are interconnected with each other via accessibility, spatial distribution of origins and destinations and land availability and price. The number of trips in MARS is determined assuming a constant travel time budget whereby the total time spent commuting is subtracted from the total time budget for the population and assigned to other trips. This effect may be significant once we include lower values of time associated with automated vehicles. MARS is implemented in Vensim® DSS with Microsoft Excel® as data user interface. More detailed documentation of the model MARS can be found in (Pfaffenbichler, et al., 2008), (Pfaffenbichler, et al., 2010) and (Pfaffenbichler, 2011).

The experience with modelling automated vehicle technologies in the CityMobil project made MARS an excellent starting point. Nevertheless, new developments in technology and new forms of mobility required significant revisions to the structure of the model. The first step in this process was the development of detailed causal loop diagrams identifying the connections between automated vehicles and the attractiveness and use of different means of transport. Figure 1 shows the resulting causal loop diagram for the effects of introducing automated private cars.

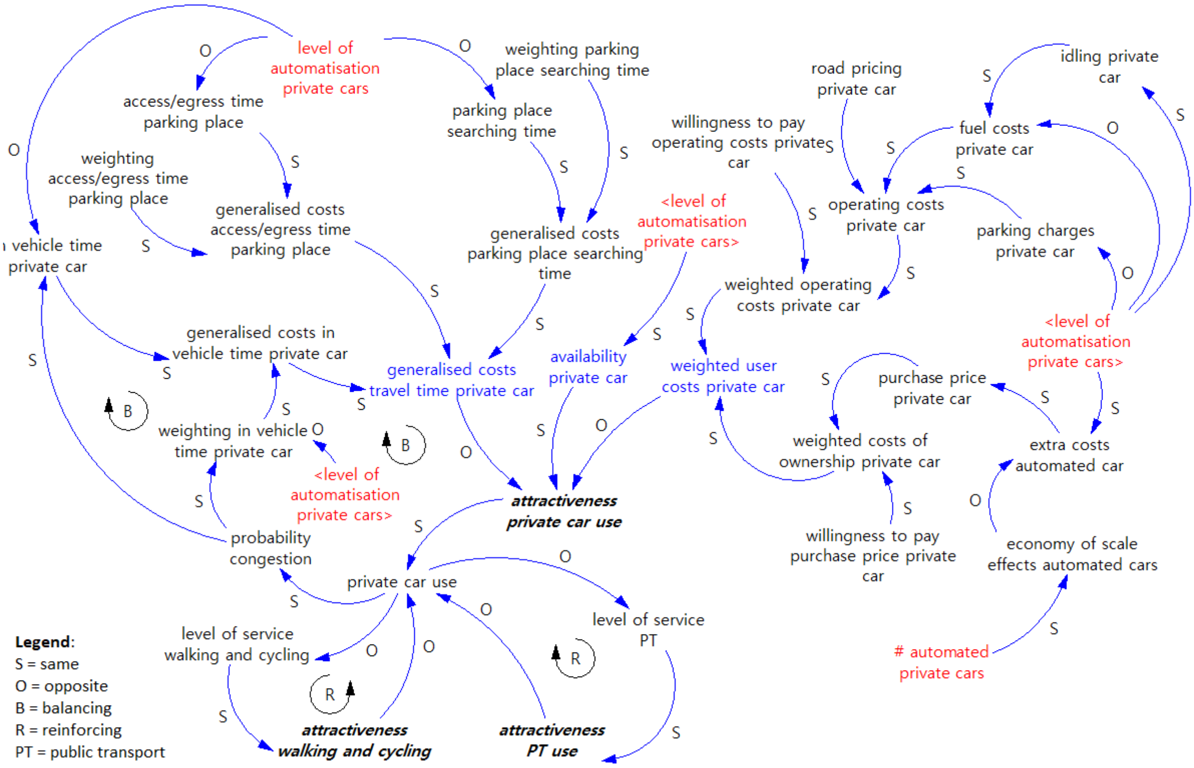

Fig. 1 Causal-loop diagram describing the effects of automated private cars

While we modified MARS to include all of these possible causal effects, the literature review demonstrates that they are not yet certain to arise, and that even if they do, their scale needs to be determined. We used our scenario testing to consider what appeared to us to be the most likely and significant impacts.

3. The scenarios tested

As noted in the introduction, the lack of empirical evidence means that we are unable to provide precise estimates of the scale of the causal processes affecting the response of urban transport and land use systems to the introduction of automated vehicles. Instead we used a literature review to categorise the variables which we consider in our MARS tests. Our analysis provides five variants for our test scenarios: ownership, capacity, parking search, value of time and widened access. For simplicity we have separated our tests into ones with private and with shared ownership, and tested each of the other factors on its own, and all applied together. This gives us a total of 10 scenarios for Leeds, as summarised in table 1.

Table 1. Dimensions of the scenarios tested.

Scenario	Market share Levels 4 & 5 cars	Ownership	Capacity	Parking search	In-veh VoT	Access for all	Scenario
0	Zero	Private	N	N	N	N	0
1	100% by 2040		Y	N	N	N	1
2			N	Y	N	N	2
3			N	N	Y	N	3
4			N	N	N	Y	4
5			Y	Y	Y	Y	5
6		Shared at € 0.55/km	Y	N	N	Y	6
7			N	Y	N	Y	7
8			N	N	Y	Y	8
9			Y	Y	Y	Y	9

4. Results - Key indicators for Leeds in 2050

Table 2 shows the key indicators of travel for 2050 and table 3 shows the mode share and point changes for 2050 for all ten scenarios.

Table 2. Key indicators of travel for 2050 per scenario

	Car-km	Car speed Peak	Pkm-slow	Pkm-pt	Pkm-car	Pkm-total
Scenario 0	100.0	100	100.0	100.0	100.0	100.0
Scenario 1	113.4	140	107.3	112.6	116.1	114.8
Scenario 2	102.2	85	89.6	85.3	101.8	97.0
Scenario 3	113.2	95	106.3	105.5	115.3	112.4
Scenario 4	106.7	86	87.4	83.0	106.0	99.2
Scenario 5	156.2	107	87.2	81.5	163.4	138.6
Scenario 6	116.2	131	97.9	107.9	119.9	115.8
Scenario 7	103.1	73	74.9	73.7	102.0	93.4
Scenario 8	113.7	84	96.1	98.7	116.2	110.7
Scenario 9	141.4	113	90.3	95.8	148.4	132.0

Table 3. Mode share (trips) and point shifts for 2050

	car	PT	Slow	%change car	%change PT	%change slow
Scenario 0	53.0%	26.3%	20.7%			
Scenario 1	53.9%	26.2%	19.9%	1.0%	-0.2%	-0.8%
Scenario 2	58.9%	22.5%	18.5%	6.0%	-3.8%	-2.2%
Scenario 3	54.7%	25.2%	20.1%	1.7%	-1.1%	-0.6%
Scenario 4	58.3%	22.8%	18.9%	5.3%	-3.5%	-1.8%
Scenario 5	70.1%	16.0%	13.9%	17.1%	-10.3%	-6.8%
Scenario 6	58.7%	23.5%	17.7%	5.8%	-2.8%	-3.0%
Scenario 7	64.6%	19.4%	16.1%	11.6%	-7.0%	-4.7%
Scenario 8	59.4%	22.5%	18.1%	6.4%	-3.8%	-2.6%
Scenario 9	68.0%	17.8%	14.2%	15.0%	-8.5%	-6.5%

S1 solely increases capacity. This increases the person-km by all modes. The additional capacity results in less time in peak (commuting) as indicated also by the significant increase in average speed in the peak and so, due to the constant time budget, we see more travel off-peak, so all modes have an increase in kms travelled. There is a slight shift in shares to car. S2 reduces park search time and removes access/egress times for parking. This results in a large mode shift to cars. Overall more time is spent in the peak due to greater congestion (with a 15% reduction in speed in the peak) meaning less travel overall and so we see a significant reduction in travel by non-car modes in the off-peak. S3, with the value of in-vehicle time lowered, results in a shift to car use with a lower average speed. This results in increased time being spent in the peak but due to the lower unit value of time this still translates into a lower value of time spent in the peak and so we see more travel in the off-peak. Thus we see increases in person-km for all modes. S4 increases the availability of the car which results in a significant mode shift despite being subject to current car costs. This results in a significant reduction in average speed, and there are no time budget savings so we see a slight reduction in overall person-km. S5 combines all the changes from S1-4. This brings greater synergies than perhaps expected. We see more than a 56% increase in car-kms, though with a greater average speed, and a 38% increase in overall person-kms, while travel by slow modes and public transport fall by 13% and 18% respectively. This synergy is explained by the fact that the impacts in S1-3 are not extended by greater car availability. The combined effect of all benefits with the extended car availability results in significant increases in car use.

All the scenarios S6-S9 assume access to a car club which means there will be greater availability of AVs than in S5 or S4; however this greater availability is tempered by the charge per km reflecting the full costs of car use. S6 solely increases capacity. In comparison with S1 there is a greater increase in car use with a slightly lower increase in speed, and a small increase in person-kms reflecting reduced use of other modes. S7 with reduced parking search time and with access/egress times for parking removed results in a larger shift to car use than in S2 (with an even greater reduction in speed), hence without the increased capacity travel time in the peak increases which means there is less travel overall. S8 with a lower value of time again results in a greater shift to car use than in S3 despite the charge per km. However, changes in car-km, speeds and person-km are little changed from S3. S9 combines the changes from S6-8. Again there is evidence of synergy, but compared to S5 we see fewer car-kms despite greater availability as a result of the charge per km. These results are obviously dependent on the charge per km we have assumed and some sensitivity tests around this value would be in order.

5. Conclusions

Fully automated cars are likely to appear on public roads within the next decade. They are being promoted as ways of improving network capacity and reliability, making car use available to a wider range of people and reducing accidents. However, several researchers have suggested that they could lead to a significant increase in car use, with a parallel reduction in walking, cycling and public transport, and that this could more than offset the benefits of capacity increases and lead to urban sprawl. Our own review of the literature and qualitative analysis using causal link diagrams suggest that the most significant triggers of such changes will be the market share of automated vehicles, whether they are available privately or as shared vehicles, the extent to which capacity is increased, the potential for reducing time spent in parking and access, the possible reduction in the value of in-vehicle time and the expansion in the numbers of people able to drive.

In this research we have used a systems dynamics model, MARS, for the city of Leeds UK, to test the impact of one set of assumptions for each of these triggers over the period from 2015 to 2050. The starting point for the analysis was to reprogram MARS to incorporate the main influences identified in the literature review and causal link diagram. We based our tests on the highest levels of market share in the literature, and used a stock flow model to predict the fleet share in each year, giving a fleet share in 2050 of approaching 90%.

The individual triggers all increase kilometres travelled by car compared with the business as usual scenario, with the largest effects arising from capacity improvement and reduced value of in-vehicle time. These two factors also increase total person-km travelled, while reduced parking costs and increased access to cars have the net effect of reducing person-km travelled slightly. As a result person-km by slow mode and public transport fall under these two triggers. Peak car speeds only rise in the case where capacity is increased; other factors lead to a reduction in speed compared with the business as usual scenario because of the offsetting effect of increased car use.

The combination of these triggers has a synergetic effect. In the case of privately owned automated cars, this principally involves the interaction with the expansion in the numbers able to use automated cars (S4). As a result in S5 kilometres travelled by car increase by 56% compared with the business as usual scenario; total person-km increase by 39%, person-km by public transport fall by 18% and person-km on slow modes by 13%. The net effect on peak car speed is to increase it by 7%.

However, in S9, which combines all the triggers with automated cars shared, synergy still occurs, even though all scenarios S6, 7 and 8 assume an expansion in the numbers able to use them. The effects found in S5 are tempered by the assumed charge for using these vehicles of €0.55/km, which broadly equates to today's car sharing charges. This results, in S9, in smaller changes from the business as usual scenario of a 41% increase in car-km, a 32% increase in person-km and reductions of 4% and 10% for public transport and slow modes. The net effect on peak car speed is to increase it by 13%. Preliminary sensitivity tests, not reported here, suggest that these results are very sensitive to the charge imposed; with no charge public transport use falls dramatically.

The increases in car-km suggest that, other things equal, the environment will be adversely affected. The decline in person-km by public transport suggests a loss in accessibility for those dependent on it; the decline for walking and cycling implies a loss in the health benefits which these modes afford; while the increase in person-km per capita suggests a tendency to urban sprawl. We were able to assess the impacts on population distribution with a modified version of the model, in which opportunities for development remained available through the period to 2050. This confirmed that with private ownership of automated vehicles there would be a tendency to urban sprawl. However, under shared ownership there was instead a tendency to densification as a result of the relatively high charge imposed per km travelled.

These results are dependent on our input assumptions, but they suggest that it will be important to gain a clearer understanding of the likely scale of each of the factors which we have considered: impacts on capacity, parking and access time, in-vehicle values of time and the extent to which current non-drivers will be permitted to use cars. They confirm that the introduction of automated cars is likely to have a deleterious effect on the environment, accessibility, health, urban sprawl and overall sustainability. They also indicate that these adverse impacts can be tempered by the imposition of a requirement that automated vehicles in cities be made available as shared vehicles rather than privately owned ones. However it appears that, to be effective in avoiding these negative impacts, the charge will have to be higher than that currently imposed by car sharing companies.

There are a number of factors which we have not been able to model and which might further aggravate these effects, including the propensity for automated vehicles to travel empty to base or to collect the next shared user, and the response of public transport operators to declining patronage. Conversely, we have made no assumptions on the opportunities for automation of public transport, which could offset some of these effects. We plan to assess these factors, and also to extend our analysis to a second city, in further research.

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