Transportation Research Part C 93 (2018) 102–114

Contents lists available at ScienceDirect

Transportation Research Part C

journal homepage: www.elsevier.com/locate/trc

A Time-use Model for the Automated Vehicle-era

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ARTICLE INFO

Keywords:
Automated vehicles
Time-use model
On-board activities
Travel behaviour
Travel demand
Multitasking

ABSTRACT

Automated Vehicles (AVs) offer their users a possibility to perform new non-driving activities while being on the way. The effects of this opportunity on travel choices and travel demand have mostly been conceptualised and modelled via a reduced penalty associated with (in-vehicle) travel time. This approach invariably leads to a prediction of more car-travel. However, we argue that reductions in the size of the travel time penalty are only a crude proxy for the variety of changes in time-use and travel patterns that are likely to occur at the advent of AVs. For example, performing activities in an AV can save time and in this way enable the execution of other activities within a day. Activities in an AV may also eliminate or generate a need for some other activities and travel. This may lead to an increase, or decrease in travel time, depending on the traveller's preferences, schedule, and local accessibility. Neglecting these dynamics is likely to bias forecasts of travel demand and travel behaviour in the AV-era. In this paper, we present an optimisation model which rigorously captures the time-use effects of travellers' ability to perform on-board activities. Using a series of worked out examples, we test the face validity of the model and demonstrate how it can be used to predict travel choices in the AV-era.

1. Introduction

Today, many public transport passengers conduct activities while travelling (Keseru and Macharis, 2017, Frei et al., 2015, Lyons et al., 2007, Ettema et al., 2012, Malokin et al., 2016). Many scholars, policy makers and automotive industry practitioners anticipate that future Automated Vehicles[1] (AVs) will allow their users to engage in an even wider range of on-board activities. The ability to perform new on-board activities in the AV is generally expected to increase productivity and well-being (Kyriakidis et al., 2015, Bansal et al., 2016). Nevertheless, the increased attractiveness of travelling is also feared to cause more car travel in the AV–era and in due time even relocation of home and work locations to places further apart (Milakis et al., 2017; Fagnant and Kockelman, 2015; Heinrichs, 2016; Sadat Lavasani Bozorg, 2016). In order to anticipate these changes in travel and location choices, the AV-effect is usually conceptualised using the idea of a reduced travel time penalty, or similarly, a lower value of travel time savings (Gucwa, 2014, Childress et al., 2015). However, this approach has important limitations, which we illustrate with an imaginary narrative of a future traveller.

Before purchasing her AV, Anne used to commute to work with a conventional car. In the mornings, she used to wake up at 7:00 to get ready (dress, eat breakfast), depart at 8:00, and reach work at 9:00. She often contemplated visiting a swimming pool in the

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[1] We refer throughout the article to so-called level 5 automated vehicles, according to SAE International (2016) standards.

https://doi.org/10.1016/j.trc.2018.05.022
Received 23 August 2017; Received in revised form 23 March 2018; Accepted 24 May 2018
0968-090X/

morning, but ultimately did not want to get up earlier to do so. In the evening of a typical working day, she used to leave her work at 18:00, headed home for a 30-min nap, and then drove to meet her friends for dinner at 20:00. She often felt like working longer, but did not want to miss out on her evening activities.

Recently, Anne's company has adopted a new policy allowing employees to perform their morning work tasks in their fully automated vehicles, and arrive at the office at 9:30. Now, Anne has switched to an AV. She leaves home at 8:30 and arrives at the office at 9:30. About 30 min of her journey she spends preparing and eating breakfast; the remaining 30 min she spends replying to work emails. She uses the gained one hour in the morning to visit a swimming pool, which she reaches with her AV. In the evening, Anne stays an extra hour and a half at work, and takes a nap in her AV, while it drives her straight to the meeting with friends (saving her a detour to home).

This example exposes two key aspects of travel behaviour in the AV-era, which are overlooked when applying the travel time penalty approach:

1. On-board activities can create time savings. If an activity is transferred from another time of the day to the AV, then time is saved, because the activity and travel are simultaneous. In the example, Anne gains time in the morning, as well as in the evening. If the analyst does not account for such possibilities (which is the case when AV-implications are conceptualised using the travel time penalty approach), then he/she implicitly assumes that all activities that are executed in the AV are *added* to the existing daily activity schedule of the traveller, rather than being *transferred*. Note that the share of work activities transferred to the business travel time is explicitly modelled in Hensher's equation (used to obtain the value of business travel time savings, Hensher, 1977), and empirical evidence for such transfer of work activities is available (e.g., Gustafson, 2012).
2. Changes in on-board time-use can lead to more travel, as is commonly argued. However, it can also lead to less travel, given a certain activity wish-list (or daily activity plan) of the traveller. The narrative illustrates both possibilities: more travel (in the morning) and less travel (in the evening). When only reductions in the travel time penalty are considered as in many previous studies, the possibility of a decrease in travel is implicitly ruled out. Note that conceptually this idea is not new: already 20 years ago, Kitamura et al. (1997) wrote that 'the key question to be addressed when dealing with induced or suppressed trips is how people use time'.

The above aspects summarise the main problem of solely using (reduced) travel time penalties to model the impact of on-board activities in the AV. This travel time penalty-approach disregards the duration of on-board activities and their interactions with other activities. Therefore, more subtle effects, such as the difference between adding and transferring activities, are likely to be missed. In other words, by solely using the travel time penalty as a proxy for the effect of productive time use in the AV, the researcher or policy analyst implicitly assumes that activity-travel patterns - beyond the added activities during travel and extended or generated trips – will remain unchanged in the AV-era. This assumption leads to an incomplete understanding of travel behaviour and potentially mistaken forecasts of travel demand in the AV-era, which carries important and obvious risks for transport policy making.

We aim to address this problem by modelling on-board activities in the AV explicitly, rather than implicitly assuming that their only effect is a reduced penalty associated with travel time. Specifically, we propose a formal model that accounts for changes in time-use, when some of a traveller's activities can be performed on board the AV. The model is based on, and extends, classical time-allocation frameworks (Becker, 1965; DeSerpa, 1971; Evans, 1972). Our model is also in line with previous studies that have made important steps towards using the time-allocation framework to model on-board activities and ICT use (Pawlak et al., 2015, 2017; Banerjee and Kanafani, 2008). Pawlak et al. (2015, 2017) build upon Winston's (1982) extension of the classical time-allocation framework and represent the effect of AVs with higher intensity of on-board activities. They study a multi-dimensional choice, including the choice of on-board activities, in a two activity, single-trip setting. This implies an interaction between on-board activities (and their productivity) and the scheduling of the directly neighbouring activities (pre- and post- travel). Banerjee and Kanafani (2008) adapt the time-allocation framework to study effects of working in the train (using wireless internet) on travel choices. They model a choice to transfer the work activity from a fixed office location to train.

Our work contributes to this literature in several important aspects. First, whereas previous work exogenously specified which activities are to be performed in stationary locations or on board, we allow for endogenous selection of activities and their locations. Second, by considering longer activity lists than in previous studies and by allowing activity transfers to the AV, our model captures a wider range of possible changes in daily travel and time-use, which can be expected in the AV-era.

The remaining sections are structured as follows. Section 2 builds the time-use model. Section 3 illustrates the model's working using minimalistic examples. Section 4 applies the model to an extended example. Section 5 reflects on the role and scope of our model and provides suggestions for calibrating, applying and extending our model. Section 6 concludes and discusses policy implications.

2. Time-use model considering on-board activities

We base our model on the core ideas behind the classical time-allocation frameworks derived by Becker (1965), DeSerpa (1971) and Evans (1972). These microeconomic frameworks postulate that people choose the activities that provide most utility for them, while staying within total available time and monetary budget constraints. In other words, they suggest that an optimisation task is solved to obtain the optimal daily activity plan.

However, the original formulations of the model, for understandable reasons, do not allow for overlapping activities, such as the