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Assessing mobility impacts of automated driving in L3Pilot

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Abstract

L3Pilot project under H2020 programme is the first large-scale piloting of SAE Level 3 automated driving in Europe, with the aim to study key questions related to the deployment of automated driving functions (ADFs). This paper describes how the methodology has been developed to assess the mobility impacts of the availability and use of passenger cars with ADFs within the L3Pilot project, laying a basis for future work in the area. The paper begins with an overview of current assessment approaches and the potential implications of SAE Level 3 cars on mobility, as a function of known dimensions of mobility and mobility impact mechanisms. The paper concludes with a description of the approach and method developed for mobility impact assessment in L3Pilot, which is built on FESTA guidelines and work done in previous projects.

Keywords:

On-road test, automated driving, mobility impact assessment

Introduction

Significant advances in automated driving technologies are bringing automated driving closer to market introduction. Today we are at a stage that motivates the large-scale piloting of automated driving, to assess a number of impacts related to their real-world implementation. Although it is certain that the automation of road transport will change the way we travel, future mobility scenarios are uncertain. Gaining more knowledge and understanding of this topic is essential when striving towards more intelligent and sustainable transport systems. The L3Pilot project (2017–2021; l3pilot.eu), under the European Commission H2020 programme, tests the viability of automated driving as a safe and efficient means of transportation and addresses key questions ahead of the widespread introduction of automated cars. L3Pilot unites 34 partners across 11 countries and includes Original Equipment Manufacturers (OEMs), suppliers, research institutes, small and medium-sized enterprises, insurers, one authority and one user group.

The automated driving functions (ADFs) piloted and studied in L3Pilot include SAE Level 3 (conditional driving automation) functions, with an additional assessment on some Level 2 and Level 4 functions [1]. These functions can perform defined driving tasks in motorway, traffic jam, urban and parking scenarios in mixed-traffic, outlining operational design domains (ODDs). There is a slight variation in the features of piloted functions provided by the OEMs, and some functions are closer to market introduction than others. Therefore, generalized descriptions of market-ready functions will be used when scaling-up the mobility impacts. The time horizon of the deployment of functions and the penetration rates for evaluation purposes will be defined during the project. Overall, the L3Pilot project targets four major evaluation areas: user and acceptance, technical and traffic, socio-economic, and impacts including safety, efficiency, environment and mobility. The focus of this paper is to present the approach taken within the L3Pilot project to assess the mobility impacts of automated driving.

There is currently a dearth of research addressing scenarios involving mixed-traffic with conventional vehicles and automated vehicles (SAE Levels 0–3). The mobility of people is a key issue in future transport, and knowledge of the potential impacts of automated driving is essential for different stakeholders including authorities and industry. While the ability of people to move from one location to another conveniently is essential for our society, mobility is also a key factor in responding to environmental challenges. Automation renders future mobility scenarios uncertain, and research is therefore needed to predict the implications of automated driving on travel behaviour. As L3Pilot is the first large-scale piloting of SAE Level 3 ADFs, the project enables the definition and discussion of mobility scenarios based on views of test users having actual experience on the systems combined with complementary mobility impact assessment methods. This approach will enable new insights into the effect of automation on mobility.

Aim of this paper

Mobility impact assessment in L3Pilot aims to evaluate the potential mobility impacts of automation. The assessment approach is building upon multidisciplinary research, including available frameworks, theories and methods and applying them to driving automation and experiences of real test users in the project. The first objective of this paper is to present current assessment approaches and to give an overview of what driving automation means for mobility impacts assessment. The second objective is to describe the approach and method developed for mobility impact assessment in L3Pilot.

Approaches to researching mobility

Mobility concept

Mobility is a concept that reaches beyond visible travel to consider things like travel potential, experience and constraints. Although various definitions exist for mobility in different contexts, human mobility is usually defined in transport research as the ability to move, the ease of movement, or the potential for movement [2, 3]. According to some definitions, it includes peoples' preferences and experiences of travel and their decisions over time, mode and route [4]. Thus, the quality of travel is considered an important aspect of mobility. An individual's mobility is dictated by the "mobility tools" they have available to them, such as the networks and means of travel they know about, has access to and is willing to use [5]. Realised travel thus happens within mobility. In L3Pilot, mobility is defined as the potential for [spatial] movement of people (see Figure 1). According to this definition, it consists of means of travel and networks one has access to, knows about and is willing to use. Along with transport and infrastructure, it encompasses peoples' and intentions, opinions and choices in their daily travel.

Figure 1. Mobility concept in L3Pilot evaluation.

Factors affecting mobility

Mobility is multidisciplinary in nature and studied from a wide range of perspectives in different fields of research. Mobility is affected by many factors, some of the most relevant ones to be considered are outlined and discussed below.

- *Land use, infrastructure and transport planning*. Regional development and planning impact locations of places that are relevant for everyday life. Land use thus affects the needs for everyday travel. The existing transport systems define to what extent different places are accessible and by what means. This directly affects the alternatives people have for travelling. In addition, an environment can affect travel decisions by encouraging people to engage in certain travel behaviour [6].
- *Social, cultural and psychological factors*. Socio-economic factors affect mobility by shaping the needs and possibilities for travel [7]. Furthermore, socio-economic and demographic factors are tied to multiple complex social and cultural mechanisms that affect travel behaviour, besides the natural preferences of people. Travel behaviour studies rooted in psychology and the social sciences have researched the indivisible relationship of abstract constructs, such as attitudes, values and desires, to one’s travel choices [8]. People also build their perception of situations, possibilities and constraints in different ways, which makes mobility a subjective matter.
- *Situation-specific factors*. Needs for mobility vary between individuals, and are often a matter of prioritisation. Mobility needs are also situation-specific [9], and different means of mobility can be preferred for different types of trips. For example, having a car boot can be important when having plenty of groceries along, while the available time budget can be more restricted for commuting vs leisure trips. It is also possible that different travel alternatives are available for different trips. However, travel behaviour varies across trips [10].
- *Habits*. Habits have a remarkable impact on travel behaviour, like behaviour in general. Triandis [11] argued that habits and intentions are reciprocal, suggesting that the stronger the determinant habit is, the weaker the determinant intention, and vice versa. In other words, the stronger the habit one has over something, the less probable are changes in that behaviour. This applies also to travel behaviour [12]. Humans are not rational beings, and besides habits, emotional impulses create another challenge for predicting travel behaviour.

Therefore, when assessing the impact of automation on mobility, it is important to consider the potential impact of these factors. As to land use and transport planning, automated driving (AD) would mean there is an additional transport modality option. AD may lead to changes in infrastructure, for example, favoured or segregated automated vehicles (AVs) on highways, which can encourage to certain travel behaviour. Social, cultural and psychological factors can have an impact on acceptance of automated systems, which can be reflected in their use. People may also perceive the benefits and threads of AD differently, which can have a significant impact on their feelings of safety and comfort. Some enjoy driving and being in control more than others and may not find AD that attractive. If automation of the vehicles raises their prices, it would constrain users with limited means. On the other hand, AD could enable mobility for users currently unable to drive themselves. When considering situation-specific factors, it is possible that AD is perceived more useful for some kinds of trips than others. Thus, it is good to consider whether the impacts of AD on travel are different depending on trips. With regard to habits, given that changing behaviour causes psychological stress and driving habit is strong for many, getting used to various automated systems could even decrease quality of travel if the gains are not big enough.

Assessing mobility

Impacts of driving automation on travel behaviour have been investigated by various simulation and modelling studies in recent years [13]. The methodologies include for example activity- and agent-based models and often consider travel behaviour through trip generation rate, mode choice and mobilisation of new user groups. While models are typically based on real network and travel data, the changes in travel behaviour due to automation are based on assumptions and are limited to "what if" scenarios. Any modelling components require in-depth analysis to produce meaningful results. Therefore, data from the field and real users can be helpful in developing more accurate assumptions for simulation and modelling.

Field studies differ from simulation and modelling studies, although modelling and simulation can also be utilised for scaling up of the field study results. Field tests are an evaluation method, for driver support systems and automated functions, aimed at evaluating the real-world effects that such systems have on different impact areas, including travel behaviour and mobility. The FESTA handbook [14] is maintained and updated to give guidance to facilitate the successful delivery of field operational tests (FOTs). Although it is acknowledged that L3Pilot differs from FOTs as the tested functions are prototypes [15], the overall methodology for evaluation in L3Pilot [16] is set based on FESTA guidelines. Regarding mobility impacts, three points of view are identified in FESTA: amount of travel, travel patterns and quality of travel.

The mobility model described in FESTA was developed in the TeleFOT project (Figure 2, [17]), which tested driver support functions, and was used later in the DRIVE C2X project [18], in the assessment of cooperative systems' impacts. In the TeleFOT project, data on each mobility aspect identified in the model was gathered by using travel diaries and was analysed using statistical methods. In DRIVE C2X project, impacts on mobility were mainly assessed by questionnaire results and input from the focus groups. In addition, some logged data analyses on driver behaviour were utilised. TEAM project [19] assessed impacts of cooperative applications that were under development through this framework as well.

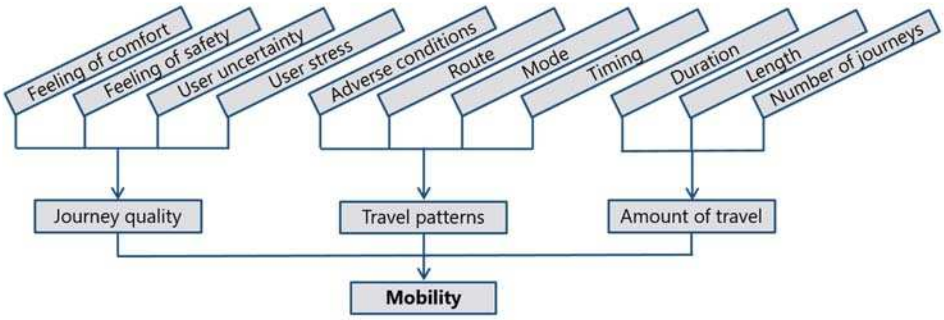

Figure 2. Mobility model for impact assessment [17]. Edited.

Since measuring potential for movement, as mobility is defined also in the projects mentioned above, is challenging, the focus in the impact assessment has been on realised travel, which is used as an imperfect measure of mobility. Based on TeleFOT mobility model, a conceptual mobility framework was developed to illustrate the mobility-shaping factors identified in multidisciplinary literature [20]. Both of these frameworks can be used in different stages of the evaluation process, starting from evaluation approach and design as well as setting up of research questions. As for handling more complex aspects to be considered in mobility impact assessment, such as handling with direct and indirect impacts and impact mechanisms, the Trilateral Impact Assessment Framework for Automation in Road Transport [21] offers recommendations and support. It has also listed relevant key performance indicators (KPIs) for travel behaviour and mobility to be used in impact assessment.

What does automation mean for mobility and its assessment?

Automating the driving task changes mobility in many ways. Among other things, introducing automated driving features can influence travel behaviour of people who might otherwise not be able to drive themselves, thus offering new potential for travelling. Travel behaviour, as well as possibilities of people to move between locations in their daily life, are key issues when aiming towards more efficient and sustainable transport in the future. Therefore, there are a number of aspects pertinent to consider relating to the potential impact of automated driving on mobility. For example, the extent to which automated driving will impact travel exposure, with respect to the amount of travel (e.g. number of trips, length, duration), travel patterns (e.g. timing and conditions, mode choice, route choice) and trip quality (user stress, user uncertainty, feeling of safety, feeling of comfort). In addition, it is important to assess the impact of automated driving on the types of trips being taken, for example, commuting vs. leisure trips, long vs. short trips, or urban vs. rural trips. Besides different types of trips, it is necessary to ascertain the impact that automated driving will have on the mobility of different user groups.

Empirical modelling work has recently begun to address some of these questions. For example, some studies indicate AVs could lead to a reduction in public transport and slow modes share [22]. Others have shown that this migration from other transport modes would result in a concomitant increase in vehicle kilometres travelled (VKT; approx. 15-59%), and assuming an increase road capacity would only marginally increase VKT estimations [23]. In terms of the impact of AVs on the mobility of teenagers, adults without driving license (concerns only SAE Level 5) and mobility-impaired people [24], showed a decrease in public transport share from 8.6% to 7.7% and an increase in car share from 45.1% to 48.8% (penetration rate = 37.6%) for Germany. These estimates assumed a reduction in the value of time by 25%, and different penetration rates for private AVs (based on a diffusion model) and private AV availability.

Traditional travel research methods on analysing trips are not sufficient to capture the changes in mobility that automation might introduce. Models and predictions of future travel that are based on data about past trips fit well to circumstances where the mobility ecosystem follows a predictable or stable pattern of development. However, if the future is uncertain or major changes like automation occur, models based on the current situation and behaviour will not be very usable. Identification of the ways in which automation affects travel is crucial in this situation. The Trilateral Impact Assessment Framework for Automation in Road Transport has identified multiple mechanisms in which AD changes mobility. For example, it highlights the changes in use and value of travel time in an AV that affect travel quality but influence amount of travel and mode choice as well. In addition, the CARTRE project Deliverable on socio-economic impacts of AD [25] has listed factors that may have an effect on mobility performance indicators. For example, continuing the example of travel time use, it states that possibility to focus on other activities during AD can impact timing of trips, as the additional travel time caused by congestion at peak hours can be used to e.g. working. The ways in which automation is assumed to affect travel are to be taken into account in mobility impact assessment in L3Pilot.

L3Pilot methodology for assessing mobility impacts of ADFs

Overall approach

Methods for mobility impact assessment in L3Pilot aim to assess the potential impacts of four types of automated driving functions on mobility. The overall approach for mobility impact assessment within L3Pilot has three major phases: 1) Definition of the baseline, 2) Definition of the scope for impact, and 3) Assessment of the potential mobility impacts of the ADFs (Figure 3). Ultimately, the evaluation process aims to answer questions regarding how ADFs might impact the amount of travel, travel patterns and trip quality (see [26] for an overview of the development of the project research questions and logging requirements).

Since it is not possible to empirically measure the changes in travel behaviour based on data collected in L3Pilot tests – as the testing takes place in defined scenarios and not in participants' daily life – it is necessary to use complementary data and methods, for example, interviews and focus group discussions, to learn about the potential mobility impacts of ADFs. The L3Pilot methodology will combine actual quantitative and qualitative data on current travel in different European countries with the analysis of the perceptions and views of people that have actually experienced driving with automation in L3Pilot tests. This provides a good opportunity to use multidisciplinary mobility approach and frameworks to define the potential mobility impacts of ADFs, and further, to answer questions about potential impacts on actual travel exposure.

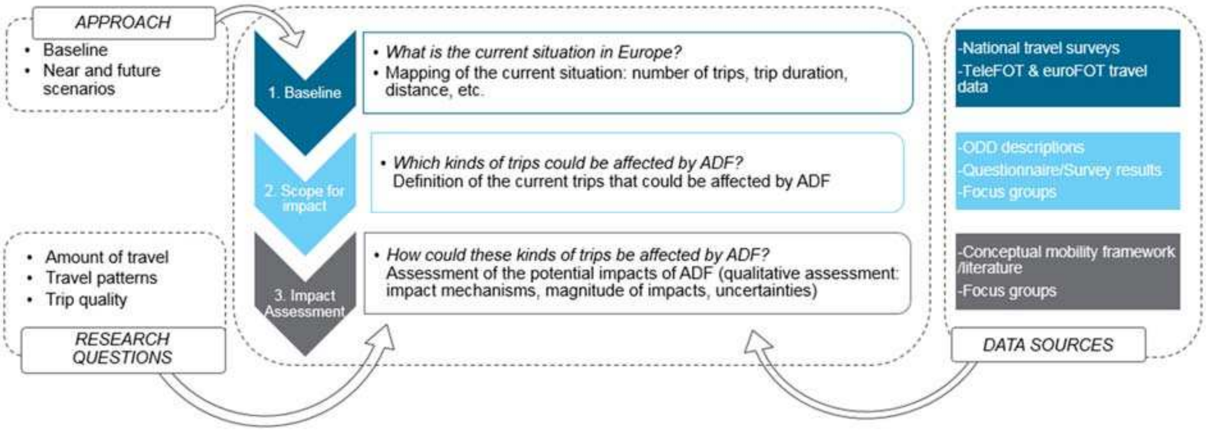

Figure 3. Overview of the L3Pilot methodology for mobility impact assessment.

The ADFs tested in L3Pilot include SAE level 3 functions for passenger cars. Specifically, these are motorway chauffeur (up to 130 km/h), traffic jam chauffeur for motorways (up to 60 km/h), urban chauffeur and parking chauffeur. In the tests, ADFs are exposed to a range of users in mixed-traffic environments, along different road networks on open roads.

Defining the baseline

The baseline used for analysis will be data collected on the current travel exposure in Europe. During this phase, a broad range of sources will be explored, such as data sets derived from national travel surveys or travel data from previous projects, for instance, TeleFOT or euroFOT. The existing travel data includes information about the amount of travel and travel patterns. The trips made by people can be clustered by any number of factors, for example, by the place of residence or household structure socio-economic factors. This way, baseline data can be set for different groups of people according to the requirements for assessment. Some datasets, such as certain travel surveys, include also trip quality aspect. Baseline data on the subjective experiences of current travel patterns can also be set by using data from the L3Pilot test site questionnaires, global annual survey, focus groups and interviews.

Defining the scope for impact

The scope impact phase addresses the potential users' currents trips and travel options that could be affected by using one or more of the four ADFs. This phase is based on two main sources of information. First of them is the ODD defined for each ADF, specifying the conditions under which the ADFs are assumed to work. These conditions include, for example, infrastructure needs or road types, weather conditions and speed limits. In other words, it is to be defined for which trips automation would be available. The second source of information is drivers' willingness to use the systems and their perception of the ADFs' usefulness for different trips. This information comes from user and acceptance evaluation performed during the project.

Four scenarios are defined to consider the scope for impact for each of the four ADFs covered by the test piloting of automated driving, including motorway, traffic jam, urban and parking. The use cases derived from these scenarios are described as follows. The use case scenario for motorway covers all motorways in free flow with speed range of 0-130 km/h, whereas the use case for traffic jam the speed range of 0-60 km/h. For the urban case scenario, different intersections and street types as well as interactions with vulnerable road users will be considered for a speed range of 0-50 km/h. Last, parking will be evaluated for parking lots or designated or private garage. Besides the scenarios, the user groups with interest for the L3Pilot approach are going to be defined to meet the evaluation needs and to provide insights for the mobility research questions, which were mentioned earlier in the methodology section. Examples of the aspects that can be analysed include user's age, household structure, household income, vehicle purchasing decisions (intention for next car acquisition, frequency of changing cars, and intention for car investment), technology attractiveness, driving history and use of different travel modes.

Assessing the potential impacts

The last phase of L3Pilot approach, the assessment of the potential mobility impacts will focus on the use of qualitative assessment methods, in addition to quantitative analyses on potential magnitudes of the mobility impacts. As this project relies on pilot testing of prototype vehicles and the test users are experiencing the ADFs under test situations – not in their everyday lives – using real measurement data of the trips in assessment is not possible. We, however, have valuable access to the perceptions and views of users that have experienced the systems. Interviews (questionnaires) and focus group discussions are used to gain information about the ways the users see automation as a part of their mobility. The real experience with ADFs also gives, for example, stated preferences regarding individual travel behaviour higher reliability.

Multidisciplinary literature on mobility and mobility frameworks (TeleFOT mobility model [17] and conceptual mobility framework [20]) have been used to define the research questions, questions to be included in user interviews, and the overall mobility assessment approach. In the assessment of the potential mobility impacts of automation, the literature and frameworks will be utilised to report the interview and focus group results. After definition of the baseline and the scope for impact, this phase of approach is aimed at assessing the potential impacts within the defined scope. The assessment will aim to answer at least the following questions:

- What are the probable impact mechanisms in which the studied ADFs would affect mobility?
- In which direction (increase, decrease) is the change in mobility likely to occur for each mobility key performance indicator (e.g. regarding amount of travel, travel patterns and travel quality)?
- What would the magnitude of the expected impacts on mobility be?
- What are the mobility impacts of the ADFs on different user groups?
- What are the mobility impacts of the ADFs for different types of trips?

The results of this mobility impact assessment will be published in L3Pilot Deliverable D7.4 'Impact evaluation results' in the autumn 2021.

Summary and next steps

The L3Pilot project under H2020 programme in Europe will test and study the viability of automated driving as a safe and efficient means of transportation, as well as explore and promote new service concepts to provide inclusive mobility for different user groups across 11 European countries. First, this paper gave an overview of mobility impact assessment methods and how automation could change them. Second, it described the overall approach for assessing the mobility impacts of availability and use of passenger cars with ADFs and evaluating mobility of identified user groups across four specific driving scenarios: motorway, traffic jam, urban and parking. This mobility impact assessment approach developed for L3Pilot will be helpful for other studies on the impacts of automated driving, conducted all over the world.

As the work on planning for the mobility impact assessment is still underway when writing this paper, the final details of the method can be found from L3Pilot Deliverables D3.3 'Evaluation methods' (published in autumn 2019) and D3.4 'Evaluation plan' (published in spring 2020). Mobility impact assessment results will be published in L3Pilot Deliverable D7.4 'Impact evaluation results' in the autumn 2021.

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