Sohjoa Baltic

The Roadmap to Automated Electric Shuttles in Public Transport

Technology and Safety Requirements

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Foreword

The upcoming years are crucial to the development of automated driving in Europe. The technology has great potential to serve the public interest by improving the environmental sustainability of traffic and making transit safer and more enjoyable for everyone. At the same time, there is a risk that everyone will use his or her own private automated car, increasing the number of motorised vehicles on the road. Automated vehicles as part of public transport is a goal worth aiming for. Therefore, the Sohjoa Baltic project researched, promoted, and piloted the use of driverless, electric minibuses in public transport to secure the benefits of automated driving for society as a whole.

However, at the beginning we must answer the central question whether this innovation can be implemented within the existing legal framework. If this is not the case, the legal obstacles must be identified.

The technical and safety requirements document is intended to be used as a guideline underlining strengths and limitations of automation and electrification in mini-buses for last-mile urban transportation. Safety and technical requirements cannot be considered to be fully exhaustive as further research and studies need to be conducted, but rather as a starting point for future development of electrification and automation in urban areas.

This volume is intended to provide relevant legal information for persons or organisations interested in integrating automated driving into the public road system. It identifies the main implementation bottlenecks and gives practical insight into the requirements that must be fulfilled before an automated vehicle can be operated on public roads. Examples from practice illustrate the explanations.

About Sohjoa Baltic

The Sohjoa Baltic project developed the knowledge and competencies required to organise environmentally friendly and smart automated public transport by researching, promoting and piloting automated driverless electric minibuses as part of the public transport chain, especially for the first/last mile connectivity. It also provides guidelines on the legal and organisational frameworks needed to operate a service of this kind in an efficient way. The Sohjoa Baltic consortium has partners from Finland, Estonia, Sweden, Latvia, Germany, Poland, Norway and Denmark with expertise in transportation planning as well as legal expertise combined with a strong technical understanding.

Sohjoa Baltic brought autonomous small buses to drive demo routes in five Baltic Sea Region cities. The autonomous bus scans its surroundings and knows when to slow down or stop completely, if there are obstacles in the way. During the pilots there was always an operator on board.

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Executive Summary

This document is part of a series of volumes in the "Sohjoa Baltic - The Roadmap for Automated Shuttles in Public Transport", and it is targeted to professionals and administrations planning automated shuttles pilot projects and integration with the public transportation system.

The main topic covered in this volume concerns "Technology and safety requirements", the main content will describe the most recent state of the art in technology for automation and electrification in mini-buses for urban last-mile transportation, providing an overview of the challenges that arise when implementing automated buses as part of public transport.

The volume starts with the introduction to vehicle technology with specific reference to electrification and main electrical components required for battery charging, covering energy storage methods, energy density problems and charging infrastructure. This section exposes strengths and drawbacks of electrification, such as low pollution but also low energy density and infrastructure modification.

Then the automation problem is tackled from the perspective of vehicle control and environment perception. Here, the most recent technologies for vehicle localization, sensor equipment and artificial intelligence algorithms are described. Clearly, this volume does not pretend to be a full coverage of such an extensive topic but only to give a simple, and user friendly, overview of automation and electrification for last-mile transportation. Research in this field would be beneficial as localization accuracy must be increased, perception capabilities should also be increased including obstacle recognition and semantic segmentation.

The volume continues providing some experience about technical requirements that were asked to the tenders during the procurement process. Technical requirements are divided by vehicle requirements, operational requirements and routes requirements. From our experience it appears that our vehicle requirements and operational requirements had to be downsized to fit the current technological level. However, these pilot projects also push manufacturers to develop further in order to meet the demand from the contracting institutions.

Safety has been the most important issue during this project and so far the consortium did not experience any major risk for passengers or operators as safety components were pushed at the highest possible level. Our requirements and experience are summarized in the volume and it can be a starting point for others willing to continue with automated pilot projects. The main further development here would be how to release requirements (for example increasing maximum speed) while preserving safety for operators and passengers. The low speed was, indeed, one of the main issues to overcome for the integration in the public service.

I. Introduction

“What is the current situation of automated vehicles?”

“What does their future look like?”

“How can we use them safely?”

With the constant invasion of marketing messages about autonomous vehicles coming public expectancy about the technology is increasing sharply. Developers and technicians working in the field are though skeptical that such technology will be commonly available in the near future. The reason is twofold, hardware/software development not fully functional in any driving condition, and lack or a stable regulatory framework. In spite of these challenges, autonomous vehicles are seen as the future of transportation systems, and big strides have been taken in recent years thanks to the integration between vehicle mechanics and computer science. The latter has seen a turning point with the integration of machine learning and artificial intelligence that is currently driving most automated vehicles using data-driven controllers.

Nowadays, data is considered a valuable asset, generating massive investments though not yet enough to feed the data hunger. Indeed, the real question is: how much data should autonomous vehicles collect to generate a reasonable driving model? Currently, Google (with its subsidiary Waymo) has a fleet composed of roughly 55 vehicles tested for over 1 million kilometers per year, corresponding roughly to 30,000 hours of driving, which is more or less what one taxi driver does in his/her entire work life. Such data covers most of the common scenarios, different illumination conditions, and weather, but still not enough to be considered safe.

The reason why autonomous driving is not considered safe yet is to be found by analyzing the driving statistics, that, for most of the situations, involve previously seen and predictable scenarios. However, unpredictable events, though part of the real driving scenarios, hence probable, cannot be considered as outliers, as they can generate catastrophic events. This concept is known in economics as “the black swan”, but often neglected in AI systems, though fundamental to reach a high level of safety. The black swan is an example of an event that can occur with low proba-bility, thus part of the distribution, and with major effects on the system. Swans are white, should a black one still be considered as a swan? For an intelligent system to recognize unpredictable events effectively, it is necessary to acquire as much information as possible regarding the occurrence of such events that for autonomous driving correspond to safety loss. To answer the initial question, we do need more data describing unpredictable events and variability, but many hours of driving are required to find a black swan. The more research, the more knowledge, the more safety, the sooner autonomous driving will be a reality.

II. Technological background

Autonomy and electrification constitute enabling technologies for the next generation of the transportation system. In this section, these two concepts will be reviewed according to the recent state of the art

1. Electrification of Transportation

Industry and research are working together toward the electrification and automation of urban vehicles thanks to its potential to reduce pollution. Unfortunately, full electrification is not to be considered fully economically convenient yet, due to the high costs of batteries and the low energy density of electrochemical storage compared to fossil fuel, but fortunately, automation and intelligent technologies are contributing to approach this ambitious target by increasing the global efficiency of vehicles. Indeed, energy efficiency is currently one of the most important topics in the road vehicles industry.

The full-electrification of the public transportation system requires both vehicles and infrastructure to adapt to the new concept. The infrastructure should be updated with new charging stations around the urban areas, whereas vehicles should be equipped with high-density batteries. An important aspect of the recharging infrastructure concerns the choice between a unique station (centralized architecture), or the installation of many small charging points in each parking lot (distributed architecture). In most of the studies, the predominant direction is toward a decentralized architecture [1,2]. In [1], the authors compare centralized and decentralized architectures in simulation, concluding that a decentralized method would be more effective, also in terms of costs. However, they neglect a few important parameters such as the possible overloading in the electric grid due to too many vehicles recharging at the same time in the same area. Such a connection can be either wired or carried out in a wireless manner using magnetic inductors. The solution features the magnetic inductors at the bottom of the minibus and on the ground surface of the parking lot. As indicated in Figure 1, both systems could coexist in the minibus, where an automatic switch can select the power source based on the specific situation and location.

The basic components for the electrification are: Electrical motors, battery packs, AC/DC and DC/AC converters for recharge and power, cooling systems, cables and safety components [3]. Figure 1 provides a schematic example. From a vehicle point of view, electrification would bring countless advantages in terms of pollution reduction, heat generation, noise in urban areas and safety. However, the main lack in the use of batteries versus fossil fuels for transportation purposes is the lower energy density in electrochemical storage, defined as the amount of energy per mass. More specifically, the energy density in diesel is roughly 13,440 Wh/kg, whereas a lithium-ion battery has an energy density around 220 Wh/kg [3].

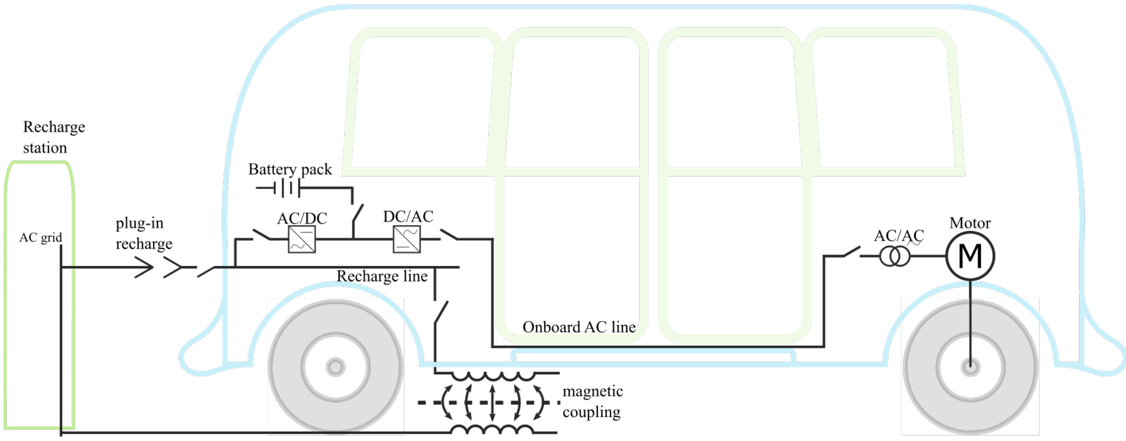

Figure 1: Electric components for a typical electric minibus

This means that over 60-times the weight in batteries should be needed to obtain the same amount of energy of fossil fuel. Fortunately, electric motors have a higher efficiency (over 90%), in contrast to combustion engines which have an efficiency less than 30% in optimal conditions and which goes below 20% in normal usage. From a reasonable estimation the additional weight can be between 10 and 20 times. This calculation does not pretend to be a precise estimation of the weight on board which may depend on vehicle specifications, but it gives the idea that batteries constitute an additional weight. As the efficiency of the electric motor is quite high, the efforts are currently concentrated on increasing the energy density and the efficiency of the recharging process. Following this line of research, the scientific world is investigating materials with high electrochemical energy density, going from old lead acid batteries [4] to Li-ion batteries [5], and even lithium-air batteries [6], which are expected to operate in the next decades with energy density comparable to fossil fuels.

One of the challenges in the field of Li-ion batteries is a phenomenon so-called “dendrite formation” [5], i.e., small spikes in the lithium anode, which cause short circuits between anode and cathode [7]. Although far from the market, a possible solution is to protect the anode using a graphene layer reducing the problem of dendrites and promising high energy density around 1000 Wh/kg [8]. Furthermore, a recent research on the same technology promises to triplicate the energy density of graphene-based batteries using an additional silicon layer [9]. According to the U.S. Geological survey there is enough lithium, in the United States only, to equip over 30 billion vehicles worldwide with lithium-ion batteries [10]. The current costs of lithium carbonate, required for batteries, is around 10 $/kg with increasing trend due to the increasing market demand. The other materials composing a lithium-ion battery such as cobalt oxide, manganese oxide, copper, and aluminium, are also inexpensive and common in nature.

2. Autonomy in Urban Transportation

In order to achieve the ambitious goal of safe fully autonomous driving within urban areas, vehicles have been equipped with a large number of sensors, essentially converting a normal car into a type of robot, adding new functionalities for control such as perception and Artificial Intelligence (AI) [11]. These basic concepts referring to the state of the art technology of autonomous driving are still controversial and discussed in the recent literature. For instance, which specific models of sensors and perception systems to use, or whether to use a precise model-based or an artificial intelligence approach to solve the problem of autonomous driving from end-to-end [12]. The latter approach copes with the problem as a whole using artificial intelligence.

Volumes of the Roadmap to Automated Electric Shuttles in Public Transport

1. The Legal Framework

   What is the current legal status of automated driving in different European countries of the Baltic Sea Region? Sohjoa Baltic presents the relevant legal information for implementation and provides policy recommendations for the future.

2. Technology and Safety Requirements

   What are the current relevant technological and safety challenges to be taken into consideration in the implementation of automated shuttle buses? Sohjoa Baltic provides information from Germany, Denmark, Poland, Finland, Sweden, Estonia, and Latvia.

3. Starting Your Own Pilot

   How to deploy an automated vehicle pilot in a city? Sohjoa Baltic provides a practical toolkit with recommendations based on the practical experiences from automated shuttle bus pilots in Norway, Poland, Finland, Estonia, Latvia and Denmark.

4. Procurement Challenges

   What are the barriers and enablers of autonomous vehicle procurement in public transportation? The experiences of Sohjoa Baltic's automated shuttle bus pilots in Estonia, Denmark, Finland, Latvia, Norway and Poland describe the complexity.

5. User Experience and Impact on Public Transport

   How and why should cities prepare to implement automated public transport? What is the role of automated shuttle buses? Sohjoa Baltic provides views based on experiences from pilots in Norway, Poland, Finland and Estonia.