A RESEARCH AGENDA FOR VEHICLE INFORMATION SYSTEMS

Research in Progress

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Abstract

As modern cars have transformed to computers on wheels, digitalization is an important driver of service and business innovation within the automotive domain. As a new class of information systems (IS), vehicle information systems (Vehicle IS) are enabled through the data generated by a plethora of different sensors within modern vehicles, meshed up with data from a variety of different other sources. Expecting the awareness on and the needs for Vehicle IS to steadily increase in the future - as a result of the continuing provision of driver assistance systems towards fully automation - we investigate existing literature on Vehicle IS published by the academic IS community. To get an overview on topics discussed so far as well as publication activity in general, we use the AIS Electronic Library as an indicator. We then provide a definition of the term 'vehicle information system' and give an overview of relevant research directions with a set of example research questions, which we deem important for the academic IS community to advance the state-of-the-art in designing Vehicle IS.

Keywords: Vehicle Information Systems, Data-driven Services, Digital Innovation, Digitalization, Automotive.

1 Introduction and Motivation

According to numerous studies and reports published by business analysts from Gartner (Ramsey, 2017), IBM (IBM CAI, 2015), and McKinsey (Gao et al., 2016) digitalization is an important driver of service and business model innovation in the automotive domain. Modern passenger vehicles have slowly become 'computers on four wheels' equipped with a plethora of different types of sensors, generating and utilizing enormous amounts of data (Haeberle et al., 2015). While currently exclusively utilized for vehicle functionality and safety, the continuous collection of such vehicle data can facilitate the generation of novel IS for vehicle drivers and other stakeholders, even from beyond the automotive domain including e.g. insurers, meteorologists, or city planners. Due to another practitioners' report, future connected vehicles will heavily interact with ecosystems of automotive data (that may be generated by other road users' digital devices), with the digital infrastructure, and also with the data provided by other services (Strategy Engineers and fka, 2017).

Obviously, current up-to-date vehicles already capture manifold types and amounts of data about themselves and their environment and, and in this way, can even be coined *Quantified Vehicles*. This term is borrowed from the quantified-self movement sharing similar thoughts and then transferred to the vehicle domain (Stocker et al., 2017). Quantifying a vehicle represents one interesting field of digitalization in the vehicle domain, to which many tech-startups have already dedicated huge investments (Kaiser et al., 2017). Meshing-up the data a modern vehicle generates during its operation phase with environmental data, weather data, governmental data, or data from complementary businesses is a hot topic in the vehicle industry. It may pave the way for new IS and open the door to currently untapped potentials and opportunities, as a recent report from VDA (2016) outlines.

So, how can the IS community finally contribute to the digitalization of the automotive industry? Marabelli et al. (2017) state that the IS community has so far devoted relatively little attention to what they call *sensor-based technologies in the vehicle domain*. Our preliminary investigation of related work within the Association for Information Systems Electronic Library (AISeL) has confirmed this statement and the comparably limited interest of the academic IS community in vehicle-related IS. Applying the search string *"vehicle information systems"* on abstracts from the AISeL retrieved just 3 scientific papers. Widening-up the scope of search by using the search string *(("vehicle" OR "automotive") AND ("information systems"))* retrieves at least 67 publications, which still shows the limited awareness of the IS community in vehicle-related IS research directions. While we think the central topic *Vehicle Information System* has not yet fully arrived in the academic IS community, we nevertheless assume the IS community to contribute greatly to the digitalization of the automotive industry by providing appropriate models, methods and guidelines, and explaining or even predicting the behavior of the various road users involved.

Though our research-in-progress is not intended to be a systematic literature review, it nevertheless investigates at least existing research from and explores which topics have been addressed so far by the academic IS community on the state of the art of Vehicle IS. By using AISeL we ensure the integration of quality assured, peer-reviewed scientific knowledge but avoid sources tending to be biased, as for example industry-driven technology roadmaps. In a further step, we aim for a definition of the term *vehicle information system*. Then we propose a research agenda for directions, which we deem of importance to the IS community in an emerging field of Vehicle IS. These research directions have been identified as a result of in-depth interviews with six experts from different engineering domains (business informatics, business studies, data science, informatics, mechanical- and electrical engineering) employed at an Austrian research center, hosting several vehicle engineering disciplines, and three experts in management positions for product development from associated industrial partners, then synthesized and summarized by four authors and finally quality assured by the fifth author, a professor for IS.

Our paper is structured as follows: In Section 1, we provide an introduction and motivation. We continue in Section 2 with a definition of the term *vehicle information systems* and further report on the results of our preliminary literature investigation on Vehicle IS in the AIS Electronic Library. In Section 3, we provide a research agenda for Vehicle IS as an emerging class of information systems. This research agenda includes relevant research directions and example research questions to explore without putting them in a temporal order yet as it would be the case for a scientifically sound technology roadmap (Garcia and Bray 1997, Phaal et al. 2003). The paper closes with a summary, a limitation of research, and an outlook of future work in Section 4.

2 Vehicle Information Systems (Vehicle IS)

2.1 Towards a definition of vehicle information systems (Vehicle IS)

It is the mission of the IS academic community to *'advance the knowledge and excellence in the study and profession of information systems'* (Association of Information Systems, 2017). The IS discipline has a more than 40-year history evolving through four eras with considerable diversity amongst its members in terms of research interests and believes what belongs and what does not belong into the field, spanning a wide variety of themes like decision support systems, organizational impact of IS, IS adoption, IS evaluation, or knowledge management to name a few (Hirschheim and Klein, 2012). According to Nunamaker and Briggs (2011), one major purpose of the IS discipline is to *'to understand*

and improve the ways people create value with information', while studying the *'understandings people require so they can create new value, and of the analysis, design, development, deployment, operation, and management of systems to inform these understandings'*.

While there has been a lot of attention within the IS community to investigate how IS – as an academic discipline – has evolved over time, there still seems to be no ultimate definition of what the tangible part of an information system (i.e. the system – not the discipline) factually is. Surprisingly, even many renowned scientific papers on IS dealing with the tangible part – the information system – neither review prior definitions of this term nor provide an own definition. For instance, both highly cited papers from Delone and McLean (1992 and 2003) on measuring the success of an information system within an organization introduce an IS success model without providing a sound definition on what the information system actually is. What seems to be a common practice in IS makes it more than challenging for us to provide a sound scientific definition of a *vehicle information system*.

However, some rather practical definitions in the literature have proven to be helpful: For example, from a Management Information Systems (MIS) perspective, Laudon and Laudon (2013) define an information system *'technically as a set of interrelated components that collect (or retrieve), process, store, and distribute information to support decision making and control in an organization'*. Another example is from Neumann et al. (2014) who define a business information system as a *'socio-technical system containing human beings and machines, which use and produce information to support and enable the processes and operations of an enterprise'*. Taking into account the cited work, we understand information systems as *socio-technical systems, supporting users to execute tasks by providing task-relevant information*. Information provision typically is supported by hardware and software capable to process digitized input efficiently (which increasingly is available due to digitalization) that in turn creates opportunities for increased automation or new business models.

Before going towards a definition of a 'vehicle information system', we deem it important to distinguish Vehicle IS from a series of *vehicle automation systems* (Stanton and Young, 2010), including in particular automotive safety systems (e.g. anti-lock braking system – ABS, or electronic stability control – ESP) and advanced driver assistance systems – ADAS (e.g. adaptive cruise control – ACC, or lane assist), which directly influence the driving process increasing safety and/or comfort. Vehicle automation systems even influence vehicle dynamics while keeping the driver fully out of the loop. In contrast the factual interaction of the driver with the information processed by an information system is one fundamental property of Vehicle IS. Hence, we understand Vehicle IS as a class of *software applications processing vehicle data and/or other relevant data from different sources to finally provide valuable and action-relevant information to the vehicle driver and/or to other stakeholders*.

2.2 Scope and examples of Vehicle IS

In order to describe the transformation and enrichment of (vehicle) data to enable Vehicle IS a data value chain can be applied. The Vehicle Data Value Chain adapted from Curry et al. (2016) shown in the figure below outlines the data process from vehicle data generation to usage in Vehicle IS.

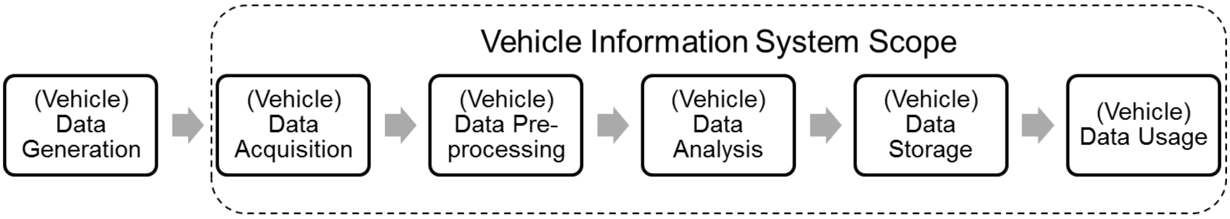

Figure 1. Stages of a Vehicle Data Value Chain.

A Vehicle IS is an IS providing information to users (e.g. the vehicle owner, the vehicle driver, or co-drivers who are granted the rights to access this information) during different phases of vehicle operation, most notable before a trip, during a trip, and/or after a trip has been completed. Depending on the particular vehicle operation phase, Vehicle IS can be used from inside a car (often referred to as *in-vehicle information systems*, e.g. by Ryder et al. (2016), Peng et al. (2014) and in a patent of Banski and Faenger (2017)) as well as from outside the car. Vehicle IS may directly use the dashboard of the vehicle, but may also extend the system border of the vehicle and establish a second dashboard (Stevens et al., 2017). The following visualization provides two examples of Vehicle IS for each operation phase.

Examples for Vehicle Information Systems		
Optimization hints No acceleration approaching a red light	Live visualization Average speed of 74km/h, 4230 rpm	Driver behavior statistics Number of safety relevant brake events
Routing suggestions Based on known driving style & traffic	Driver tutoring Approaching a crossing, release gas pedal now	Road statistics Number of hard brakes per road/city/area

Figure 2. Examples for Vehicle IS to be used before, during, and after a trip.

3 A Research Agenda for Vehicle IS

Our preliminary literature investigation of the AIS Electronic Library has retrieved few relevant publications from the academic IS community related to Vehicle IS: Ryder et al. (2016) present an in-vehicle information system prototype for drivers providing warnings of upcoming accident hotspots based on data collected from service users. Nastjuk et al. (2016) investigate the impact of in-vehicle IS on perceived range stress (fear of a discharged battery). Brandt (2013) reviews the past, present and future of IS in automobiles, especially paying attention to IS linked to electric vehicles. Taking a wider viewpoint, Brandt provides a categorization for Vehicle IS in convenience, communication, and entertainment (CCE), vehicle monitoring, geo IS and navigation, and finally safety and collision avoidance. Kolbe et al. (2015) investigated the influence of technological and sociodemographic factors on perceived stress, resulting from human interaction with Vehicle IS. Wacker et al. (2014) investigated what information green IS should provide to the individual users of electric vehicles.

Our preliminary analysis has shown that research is scattered and diverse. In accordance to Rehm et al. (2017), we therefore argue that structuring research directions in three different domains, the technical domain (e.g. the technology enabling the Vehicle IS), the governance domain (e.g. a Vehicle IS has to be designed in accordance to legal and ethical standards), and the human domain (e.g. a Vehicle IS has to provide value to the human driver in order to be used) is a feasible approach when aiming towards a research agenda.

So, in which areas within these three domains can the academic IS community finally contribute to the design of Vehicle IS? To answer this question, we apply an approach similar to Yoo et al. (2010) and comparable to Abbasi et al. (2016) briefly describing relevant research directions and providing a set of example research questions after an introduction of the concept in scope. Those are presented in Table 1 at the end of this section. Our identified research directions for Vehicle IS are classified in the proposed domain scheme from Rehm et al. (2017) as it can be seen in Figure 3. From this diagram it is apparent, that we are dealing with highly interdisciplinary research directions as all of them are part of at least two domains.

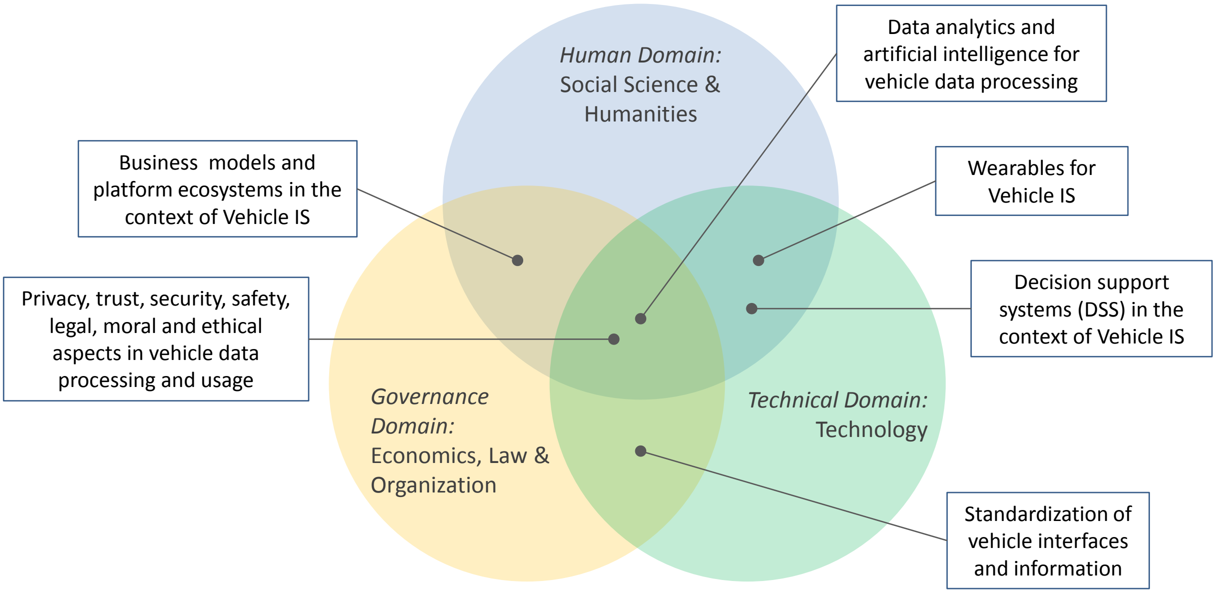

Figure 3. Characterizing research directions for Vehicle IS.

3.1 Data analytics and artificial intelligence for vehicle data processing

Data is one key source for Vehicle IS – and data analytics is the key to leverage its value. The data generated by modern vehicles is of enormous size and often describes very volatile processes (AutoMat, 2017). It can thus not easily be interpreted by humans in raw form. Instead, it is necessary to either transform the data, i.e. to compute meaningful and interpretable properties of the data (e.g. fuel consumption) or to assess the driving metric of interest by statistically describing it with a (machine learning) model. The metric "aggressiveness of driving" may serve as an example for the latter case: It cannot easily be computed directly, but only by complex interactions of many other, simpler parameters (Toledo et al., 2008). In contrast, many of the parameters in-vehicle IS present to the driver are exactly computable by some formula derived from physical or chemical system properties and in most cases easily interpretable. Machine learning models, on the other hand, seem to be rarely used.

Algorithms to build ("train") such machine learning models are typically not directly leveraging the raw data, but use so called *features*, i.e. calculated properties of data which are related to the parameter of interest. For many applications, especially in the context of vehicles, it is not straightforward to choose the right set of features: If you want to model a property of the driver, you need to ensure that the chosen features do indeed capture those properties and non-properties of the vehicle or of environmental conditions as road type or traffic volume. While other disciplines, like image recognition have developed de-facto standard sets of robust features for different tasks (Lowe, 1999; Rosten and Drummond, 2006; Alcantarilla et al., 2012), comparative feature sets for Vehicle IS are still missing.

When machine learning models for Vehicle IS become more common, additional challenges will arise, especially ones related to safety and reliability. To ensure proper, correct and save behavior of the models, the development of suitable testing procedures will become inevitable. It is however uncertain if such procedures can be based on classical machine learning quality metrics which give information on one model at a time only. Suitable testing will need to take the possible interactions between multiple models into account, and, to make things even harder, a ground truth to compare the results against is often not available or hard to obtain.

3.2 Wearables for Vehicle IS

Besides data directly linked to vehicles, also appliances usually rather related to "quantified self" (QS) can act as data source and operating infrastructure for a Vehicle IS. Wearables, including smartwatches, fitness trackers, head-mounted displays, smart clothing or jewelry, or even implantables, deliver a huge variety of data with different quality levels. Although De Moya and Pallud (2017) denote QS as an immature domain of research, their literature review revealed that profound research was conducted in technological, health-related and, social domain. Applications based on wearables range from finger/hand gesture recognition using smartwatches (Xu et al., 2015) to emotion recognition systems via electrocardiography (Zhao et al., 2016) through to drowsiness detection of drivers (Warwick et al., 2015). Sun et al. (2017) explore challenges and future directions in the view of combined smart wearables and intelligent vehicles. The authors classify further research potential into *Communications and Services* like interference mitigation, *Security and Privacy*, *System-Level Considerations* in terms of, e.g. communication protocols or networks, and *Other Issues* covering for example dynamic channel modelling or power supply issues.

3.3 Privacy, trust, security, safety, legal, moral and ethical aspects in vehicle data processing and usage

Whenever data from human behavior is captured and leveraged in IS, ethical aspects have to be discussed, as the data might be exploited for other purposes, too. For example, thousands of smartphone applications are available for “free”, if users agree terms and conditions, which include access to personal information like search terms, or even the ability to record sound from the microphone. As a result, users of free applications often pay indirectly through data they provide to the application, which then can be sold on the digital data market. At the moment, a majority of users does not care about privacy. However, this situation might change if their initial trust is destroyed.

Especially with behavior-revealing information including speeding, accelerations in kick-down-mode, or hard breakings, it is important that users can trust the IS to only use the data to improve their end user experience, e.g. to defuse dangerous crossroads instead of exploiting it for other purposes like automating the detection of speeders for the police.

Consequently, regarding vehicle data and Vehicle IS, privacy and trust are related to each other, while security has to ensure that data and information is kept within defined boundaries, e.g. that no intruder can get access to a vehicle. This is safety relevant as well, as there will be services which also write data to the vehicle interface, and thereby possibly – depending on the setup – can have a negative impact on vehicle behavior.

3.4 Standardization of vehicle interfaces and information

Vehicle usage data is produced if a vehicle is operated, therefore it could be concluded that this data belongs to the person operating (be it manually or autonomously) and/or owning it. Currently, most of the produced raw data is not accessible to the driver at all. In turn, we believe that vehicle usage data, collected from a mass of vehicles, can lead to the development of novel services for various stakeholders, if it were publicly accessible. Consequently, it has to be decided which stakeholders (e.g. vehicle manufacturers or public transport departments) are in charge of playing the governmental role in order to push standardization and execution.

According to Pillmann et al. (2017), standardization is required since in the current state parameters vary from engine type to engine type and from manufacturer to manufacturer. The amount of signals which are currently accessible and in fact available across all passenger vehicle types and manufacturers is quite small (e.g. the signals defined in OBD-II standard to be found in ISO 15031-5) and thus not much greater than what one can find out using sensory of a smartphone mounted in the vehicle.

Another critical point is the anticipated amount of data to be sent and the querying frequency used by the data logging device, as stressing the vehicles’ bus system for information exchange with this low-priority information retrieval might hinder more important actions.

Standardization on higher levels of aggregated information is another topic: Different manufactures are typically no longer an issue as the collected data is more or less source-agnostic. Nevertheless it is still challenging to create a suitable data model, as the complexity and variety of the computed information is huge. There are already ongoing research projects, which aim to create such models, specialized in representing transportation and traffic related data and its exchange. The DATEX II multi-part standard (http://www.datex2.eu) and the EU project AutoMat proposing a Common Vehicle Information Model (CVIM) (Pillmann et al., 2017) may serve as examples of such.

3.5 Business models and platform ecosystems in the context of Vehicle IS

According to Rehm et al. (2017), platform ecosystems conceptualize a platform as a "set of shared core technologies and technology standards underlying an organizational field that support value co-creation through specialization and complementary offerings" (Thomas et al. 2015). Consequently, platform owners provide the platform, manage, and control the ecosystem (e.g. Google with the Android platform), and according to Svahn et al. (2017) platform ecosystems based on vehicle data recently attracted vehicle manufacturers that seek to improve "end user experience and open up new revenue streams" with digital technologies.

Kuschel and Dahlbom (2007) stated that leveraging vehicle sensor data for services will not be profitable unless manufacturers make the sensor data open. Since then, vehicle sensor data still is not publicly available or accessible. However, some ICT start-ups from the US exploit the OBD interface or the smartphone sensory for their Vehicle IS, which in turn now forces manufacturers to react and develop ideas how they can enter this promising market themselves, as the EU project AutoMat (AutoMat, 2017) shows. In case of the ICT start-ups, many stakeholders from different domains, especially insurance, made investments in this topic to develop and explore new business models (Kaiser et al. 2017). Hence, Mikusz and Herter (2016) mention, there is a "research gap on value propositions in business models for the Connected Car".

3.6 Decision support systems (DSS) in the context of Vehicle IS

Over the last decades, a shift from pure human-made decisions to more and more computerized decision support systems could be observed. This is particularly true in the context of vehicles. Decision support or even automated decisions are provided for drivers with respect to (re)routing (Santos et al., 2011), braking in dangerous situations (Broggi et al., 2009), automated overtaking (Richter et al., 2016) or refueling (Suzuki et al., 2014). A recent article (Ryder et al., 2017) studies the impact of accident hotspot warnings on driver behavior. In this regard, increased driving data availability can even provide new options for stakeholders or infrastructure, like in the case of insurance risk selection processes (Baecke and Bocca 2017) or charging infrastructure planning (Dong et al., 2014).

In the more distant future, fully automated vehicles will automatically obtain and interpret data from sensors correctly (positioning system, acceleration sensor, cameras, radar, etc.), aggregate and process this data, and decide on context-related information. However, until a sufficient level of automation is achieved, human interaction is required. Thus humans will probably still play a major role in decision-making in foreseeable future.

In the view of a transition phase towards automated vehicles, major questions regarding vehicles' DSS appear, concerning drivers as well as stakeholders.

3.7 A summary of research directions and example questions

In the context of Vehicle IS, the academic IS community may pay attention to the outlined research directions. To support this, we provide a list of example research questions per research direction listed in the following table.

Research direction	Example research questions per direction
Data analytics and artificial intelligence for vehicle data processing	- How can data analytics and artificial intelligence be leveraged for the design of Vehicle IS? - What added value can be generated for Vehicle IS users through applying machine learning and artificial intelligence on data their vehicle generates? - Which requirements will Vehicle IS pose on the quality of analysis algorithms? - What are the most relevant features in vehicle data that are useful for generating data-driven services? Which features describe the driver, which the environment? - What are relevant and available data sources for Vehicle IS? - How intrusive should information about possible dangers be presented to the driver in order to achieve optimal response? - How can the quality and reliability of complex models and information based on their interaction be assessed?
Wearables for Vehicle IS	- How can wearables contribute to optimized information provision? What type of information should be extracted from provided data? - Under which conditions can wearables provide additional insights in the context of a Vehicle IS? Which data and functionalities provide added value to an IS considering current status and future development of wearables? - Which requirements demand data of persons instead of data of vehicles? How can the supply of person-related data (e.g. level of stress) be organized while driving / co-driving? - How can wearables contribute to more safety, both for occupants and non-drivers, in the context of a Vehicle IS? - How can wearables be integrated into the quantified vehicle? How can the integration be ensured, in particular between the priorities of rapid software development and maximizing safety? - To which extent are security-related as well as data privacy issues concerned, if wearables are integrated in the quantified car? How can unintended transfer of personalized data be prevented? What is needed in order to guarantee information security?
Privacy, trust, security, safety, legal, moral and ethical aspects in vehicle data processing and usage	- What is the impact of privacy and trust to the design and appropriation of Vehicle IS? - How can Vehicle IS be designed in order to respect privacy and trust? - What kind of privacy and trust labelling is required to better judge the risk of using Vehicle IS? - How can IS design assure that the security of vehicles and as a consequence the safety of the vehicle driver is protected? - What are ethical issues linked to Vehicle IS and how can ethical concerns be considered in a best possible way? - How can the data owner of data generated by vehicle usage be defined? - How can Vehicle IS provide information on how and by whom data is used?
Standardization of vehicle interfaces and information	- What is the influence on standardization on the design of Vehicle IS? - How can the IS community support standardisation in the domain of Vehicle IS? - How can standardisation accelerate the emergence of Vehicle IS and new business models based on Vehicle IS? - What factors influence standardisation processes in the digital ecosystem of automotive industry? - What are roles of actors within the vehicle ecosystem with respect to standardisation processes? - How and by whom could a governmental authority be installed to orchestrate standardization respecting all stakeholders equally?
Business models and platform ecosystems in the context	- How and by whom should platform ecosystems and business models be managed and controlled in order to enable innovativeness and fairness? - What are the different roles of stakeholders within a digital ecosystem for the Vehicle industry? - What are individual value propositions in business models of Vehicle IS? - How can IS contribute to a better understanding of digital ecosystems in the vehicle domain?

of Vehicle IS	- How can ecosystems based on vehicle data be sustained? - What is the role of ICT start-ups in the design and sustainability of platform ecosystems in the context of Vehicle IS?
Decision support systems (DSS) in the context of Vehicle IS	- What are driving factors of public acceptance for semi or fully automated driving without the need for human supervision? - Under which conditions and to which extent is the transformation from human decision-making to automated decision-making accepted? - How can interaction between manually-controlled and (semi-)automated vehicles be organized? - What kind of information needs to be provided by a Vehicle IS for decision support regarding vehicles? What are sufficient data to provide information? How can the processing of information into decisions be designed? - How to cope with situations not represented in underlying decision support system's models? How can human decision-making be ensured if required? - In which way can DSS support non-drivers/stakeholders' decision-making?

Table 1. Example research directions and questions for Vehicle IS.

4 Conclusion and Future Work

To conclude, this research in progress paper presents a research agenda for Vehicle IS with relevant research directions, including a set of example research questions per direction which we deem important for the academic IS community to advance the state-of-the-art in designing Vehicle IS.

The investigation of literature indicates increased research activities in the field of Vehicle IS, but at the same time emphasizes the need for definition and standardization of concepts and terms. To the best of our knowledge, our approach is the first one aiming at bridging the gap by defining a vehicle-centred IS. Furthermore we indicate Vehicle IS as a new class of IS, which are currently probably considered too little by current research published in the AIS Electronic Library. Though the AISeL database has a broad coverage of IS literature relevant for the IS discipline, including no additional academic libraries in our investigated related work clearly represents a limitation of the current research-in-progress paper. Evidently, the limitation to exemplary research questions is inherent to the current approach.

Hence, for our future work we consider to conduct a systematic literature review in additional major scientific databases including e.g. ACM, ScienceDirect, Scopus, and Springer Link. Furthermore, we want to extend our research agenda (including the vehicle data generation stage) and develop a scientifically sound technology roadmap to even better support the IS community in finding appropriate and relevant research topics. In addition, we plan to conduct a qualitative, system-oriented study to add perspectives from science, business, government and society in order to provide a holistic view of Vehicle IS. This study ensures overcoming the limitation of exemplary research questions by offering a complete research agenda including a multi-dimensional set of relevant and precise research questions.

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