Information Systems in Automobiles – Past, Present, and Future Uses

Completed Research Paper

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ABSTRACT

A technology crucial for the transformation towards a sustainable energy paradigm, electric mobility recently has also drawn interest within the IS community. Electric vehicles are used for energy storage in residential energy management systems as well as in business models that aggregate the storage capacity of thousands of them to enter energy markets. In either case, information systems within the automobile can provide information on trips, driving patterns, and battery conditions. This paper provides an overview of such automobile information systems and current industry trends. We summarize their evolution during the past decades and argue that this evolution is still continuing with new innovations that offer interesting perspectives for IS research. We also illustrate how automobile information systems within electric vehicles can improve prediction accuracy concerning driving patterns and battery conditions. Thereby, they increase the efficiency of energy management systems as well as the profitability of electric vehicle business models.

Keywords

Automobile Information Systems, IS Innovation, Electric Mobility, IS Evolution.

INTRODUCTION

When Karl Benz completed and, subsequently, patented the "automobile fueled by gas" in 1886, he did so out of a desire to fulfill his lifelong passion of designing a horseless carriage (Flink, 1985). Since then, the automobile has evolved from an object solely for transportation into an object of information. Information systems pervade automobiles, fulfilling a wide range of different purposes. They provide information on the current location of the vehicle and the distance to its destination; they assist with parking and with driving; they enable communication with the world outside the car and provide entertainment for the occupants inside the car. And this might just be the beginning, as supplemental information systems have turned into unique selling points and differentiators between car models. As a result, car companies, researchers, and engineers are consistently invested into improving old systems and designing new systems that increasingly integrate cars into people's lives.

At the same time, electric mobility is becoming a crucial component of Energy Informatics research. Watson et al. (2010) coined Energy Informatics as a new subfield of Information Systems (IS) research. It investigates the contribution information systems can provide towards solving two of society's major challenges: climate change and the increasing scarcity of fossil fuels. An information system can serve as a centerpiece of a residential energy management system, which coordinates domestic energy regeneration from renewable sources, the energy storage capability of an electric vehicle (EV), and household demand (Brandt et al., 2013). In a similar manner, information systems can assist in the aggregation of thousands of EVs, using the aggregated storage capacity to compensate the intermittent generation from renewable sources on a large scale (Brandt et al., 2012; Wagner et al., 2013). In either case the information system requires detailed information on driving patterns and battery conditions to optimally control the system – information that is supplied by automobile information systems.

Hence, the purpose of this paper is twofold. First, we want to provide an overview of the evolution of automobile information systems, analyze their current state, and discuss trends that may become increasingly relevant for the IS community within the near future. Currently we can observe several such trends that will fundamentally change our traditional perception of automobiles. One example is the autonomous car, which is able to plan its path and execute it without human intervention (McGraw-Hill, 2003). It is becoming an increasingly important topic, with the IEEE predicting that 75% of all cars on the road by 2040 will be autonomous (IEEE, 2012). The societal change that usually accompanies such transitions is already visible, as well, with California being just the latest US state to legalize autonomous vehicles (California State Senate, 2012). The buzz surrounding Google's self-driving car is further proof that the development of automobiles is far from at a standstill

(Google Blog, 2010). Second, we particularly investigate how in-vehicle information systems augment the capability of electric vehicles as components in residential energy management systems. We illustrate such a management system and discuss which automobile information systems can increase its efficiency through which channels.

Hence, the research questions posed in this paper are as follows:

RQ1: How can automobile information systems be categorized and what factors determine their evolution?

RQ2: Which automobile information systems are relevant for integrating electric vehicle energy storage into energy management systems and how do they provide additional value?

The paper is structured as follows. In Section 2 we propose a systematic categorization of automobile information systems. Furthermore, we explore the history of some exemplary information systems in each category to understand what drives their evolution. In Section 3 we look ahead and identify trends that shape current automobile research and development. In Section 4 we focus on one specific trend, electric mobility, and consider how and what information systems are used to augment the potential of electric vehicles to function as energy storage devices. Section 5 concludes.

CATEGORIZING AUTOMOBILE INFORMATION SYSTEMS

In-vehicle information systems provide a wide range of different services, which can be observed through the diversity in IS publications that address some facet of them. For instance, Olsson (2004) analyzes how context-aware entertainment applications increase interactions between passengers and driver. Andreasson (2009) presents a case study on systems for intelligent speed adaption that provide feedback to the driver when speeding. Hylving and Selander (2012) analyze the user interface design process at a large car manufacturer.

Evidently, the applications for automobile information systems are very diverse and there is no universal blueprint. Hence, for further analysis it is useful to divide them into categories according to shared features. Kantowitz and Moyer (1999) divided in-vehicle information systems into three categories: Safety and collision avoidance, Advanced Traveler Information Systems (ATIS), and Convenience and Entertainment. The fact that this decade-old categorization already seems somewhat cumbersome is a further indicator for the speed with which the evolution of in-vehicle information systems progresses. ATIS, for example, covers a wide range of information systems, from speedometers to GPS. While speedometers have remained more or less unchanged during the past decades, the performance and applications of GPS have constantly increased. Similarly, while the information the speedometer provides pertains to the car, navigation systems are more focused on the trip and the path the car takes. Hence, it seems counterintuitive to combine them into one category.

We propose a categorization approach that is more object-focused, i.e. we categorize according to the object of interest the system provides information about. Following this approach, we derive four different categories as illustrated in Figure 1.

Convenience, Communication, and Entertainment includes information systems where **people** are at the center, enabling communication between them and providing entertainment for them. Systems that focus on information on the **vehicle** belong to the category **Vehicle Monitoring**. The category **Geo IS and Navigation** contains systems that provide information on the **trip** or **path**. Finally, we concur with Kantowitz and Moyer (1999) in proposing a separate category **Safety and Collision Avoidance**, which collects information systems that focus on the **vehicle surroundings**.

In the remainder of this section, we look at each category separately, particularly at how the respective information systems evolved and what drives this evolution.

Convenience, Communication, and Entertainment (CCE)

Convenience and entertainment information systems started to develop relatively early in automobile history. The appearance of these systems indicated the transition of the automobile from a vehicle purely for transportation to a lifestyle product. These are systems that make travelling more convenient and enjoyable, but also provide passengers with news of the world.

The first commercial in-car radio appeared in the 1930s. It was produced by the Galvin brothers and was the first commercially successful car radio, as well as the first product bearing the name “Motorola” (King and Lyytinen, 2004). Berkowitz (2010) describes the following evolution of car radios, starting with the first FM radio, produced by Blaupunkt in 1952. One year later, Becker launched the iconic car radio “Mexico” with both FM and AM receivers and the first fully automatic station-search button. The progress of the car radio advanced with Chrysler and their music on demand radio system. This included a radio with a small turntable which started to be implemented in cars in 1955. In the 1960s the car radio advanced further with the transistor radio by Becker. In the 1970s the cassettes appeared and with them the first in-car cassette players. The music on demand concept continued to develop and in 1985 Becker introduced the first in-car CD player. This stable evolution of the car radio maintained its pace in the 1990s and 2000s with the LED display, the Radio data

Figure 1. Categorization of automobile information systems

system (RDS), Bluetooth and even DVDs as a part of the radio. Nowadays, the car radio has turned into an in-car entertainment system that offers many different features starting from the conventional FM/AM radio to Bluetooth and iPhone connection, DVD, and many others.

Telecommunication devices in vehicles went through a slightly different development process. The car phone was originally developed by the Bell System in the 1940s and was more popular than the regular mobile phone up to the 1980s (Bates and Gregory, 2007). With the rise of the mobile phone the demand for car phones decreased quickly and automobile communication systems started to work around the mobile phone, e.g. by supplying hands-free equipment and connections via USB or Bluetooth.

Most evident in this development is that its driving factor is not vehicle-related, since CCE information systems do not directly affect driving. On the contrary, the development of CCE systems is driven by innovations in the communication and entertainment industries. When CDs and mobile phones started to dominate their respective markets, automobile manufacturers need to adapt to survive and to design new selling propositions.

Vehicle Monitoring (VM)

This category comprises all the information systems used to keep track of different functions of the vehicle and to measure certain indicators during the driving process. They aim to provide the driver with accurate information about the status of the car as a whole, or individual components. Traditionally, vehicle monitoring systems have included displays which are within direct sight of the driver and usually located behind the wheel. Without having to take the eyes off the road for a longer period of time, the driver is able to read the displays to obtain necessary information about the vehicle. Important indicators are speed, fuel, revolutions per minute or the light status.

Due to the simplicity of the first automobiles (compared to modern examples), vehicle monitoring was either not possible or not necessary. With technical speed limits below 6 mph in town in the late 19th century, no sophisticated devices were needed to control compliance. However, the lack of monitoring devices sometimes led to bizarre situations. The first fine for speeding in history was probably issued in 1896, when a driver exceeded the speed limit of 2 mph by around 6 mph and was caught by a police officer who gave chase on his bicycle (National Motor Museum, 2012). Speed indicators were no standard feature in automobiles until the 1920s. As cars started to reach higher velocities and speed limits gained further importance, a more accurate way of measurement and visualizing was needed.

Similarly, the concern about running out of fuel caused by an increased travelling range since the beginning of the automotive age led to the invention of the fuel gauge in 1917. Warning signals for indicating low fuel levels were added in the latter half of the 20th century. Although most information systems were digitized from the 1980s on, displays of important indicators, such as speed or revolutions per minute, remained mainly analog. However, some car manufacturers experimented to integrate those figures into a multifunction display. The interior of the newest version of the Nissan GT-R is partly designed after a popular computer racing game and relays various additional data to the driver, including G-force and lap times (Auto Blog, 2007).

The development of VM systems appears to be driven by increasing demand for control and information by the vehicle driver, but also by regulations and laws which require drivers to be aware of their speed.

Geo IS and Navigation (GISN)

As traffic increased, being informed about the road conditions and traffic situation became a necessity. The German ARD-network started to use the "Autofahrer-Rundfunk-Information" (ARI, Automotive-Driver's-Broadcasting-Information) to broadcast traffic reports in 1974 (IRT, 2012). This was the first time that you were able to get traffic information while driving a car. Unfortunately, its popularity was mainly restricted to Germany and the implementation driven by Blaupunkt in the US failed.

The Radio Data System (RDS) entered the market in 1984 after almost 10 years of research and development done by the European Broadcasting Union (EBU) (Kopitz and Marks, 1998). As the more versatile RDS was invented, ARI became obsolete and finally stopped broadcasting in 2005.

Shortly after the implementation of the RDS, the era of the automotive navigation systems began. Even though the first GPS navigation systems (TRANSIT) had already been used by the navy since the 60s (Lachow, 1995), it took some time until they were also used in civilian vehicles. Who invented the first automobile navigation system is not clear. Etak was the first to provide a system which made use of digital map information stored on standard cassette tapes (Bullock and Krakiwsky, 1994). But it is questionable whether that has already been a "real" navigation system. Alpine as well as Honda both claim to have invented the first "real" navigation system; Alpine in 1981 and Honda in 1983 (Stansell, 1983). The first GPS-based automotive navigation system entered the market in 1990. Again, it is not sure which company was the first to produce it. Both Mitsubishi Electrics and Pioneer claim to be the first one (Bullock and Krakiwsky, 1994).

GISN systems have been enabled by advances in radio and satellite technologies. However, the driving force of the evolution in this area is a desire for trip optimization. This is emphasized by the fact that they originate in the military as means for acquiring tactical and strategic superiority.

Safety and Collision Avoidance (SCA)

The number of accidents occurring on roads is still increasing on a daily basis. According to the WHO (2004), there are more than 1.3 million accidents every year worldwide. This stands despite a long and still continuing development of safety and collision avoidance systems in cars.

The automatic braking assistant was developed in order to cope with rear end collisions, the most common type of accidents. Its history dates back to 1996 when Mercedes introduced the Braking Assistant Standard (BAS), a system that is interpreting the braking behavior of a driver and initiates braking when there is an up-and-coming emergency situation (Groover et al., 2008). Other car producers, such as BMW and Volvo, followed soon afterwards. Nowadays, the automatic braking assistant has been developed much further than the original BAS. Volvo, for example, developed an innovative braking assistant system that helps drivers avoid or reduce speed when a rear end collision is impending. The system uses the forward-sensing wide-angle camera fitted in the front of the interior rear-view mirror to continuously monitor the road using long-range radar. When obstacles are detected (even moving objects) the system will show a flashing red warning light in the head-up display on the windscreen, also a sound will be activated at the same time. If the driver does not respond by applying the brakes to slow down, the braking system will automatically reduce speed (Volvo, 2010).

Currently the use of the automatic braking systems is expanding from a safety feature to a system that supports the charging process of an electric car. The regenerative braking as a source of energy has become so popular that it even got introduced into the Formula 1 (kinetic energy recovery system, KERS). While KERS is used for charging the car battery to increase the driving distance in conventional cars, Formula 1 vehicles get additional horsepower to accelerate even faster (The Economist, 2009).

Despite this potentially hazardous development, SCA systems are constructed for safety reasons – be it the people and objects inside or outside the car. It took quite some time before they started to develop, as car drivers feared that the "driving

Category	Focus	Driving Force
Convenience, Communication, and Entertainment	People	Innovations in communication and entertainment industries
Vehicle Monitoring	Vehicle	Demand for control; regulations
Geo IS and Navigation	Trip	Trip optimization
Safety and Collision Avoidance	Vehicle surroundings	Desire for safety while preserving driving experience

Table 1. Overview of the focus of each category and the force that drives its innovation

experience" would be lacking. Hence, SCA innovations are driven by a desire to make cars safer while preserving the unique experience of driving.

Table 1 summarizes the results from this section, relating the different IS categories to their focused object and driving force.

TRENDS IN AUTOMOBILE INFORMATION SYSTEMS DEVELOPMENT

The development of automobile information systems is still continuing. Advances in artificial intelligence and vehicle-to-vehicle communication are starting to transform the car into an intelligent, self-driving vehicle that takes care of efficiency, pollution, and safety while still serving its original purpose – transporting passengers from one point to another. In this section we will shine a light on three important developments and how they can reduce the environmental impact of driving through information technology.

Vehicle-to-Vehicle Communication

Vehicle-to-vehicle communication (V2V), which is currently being tested by various car manufacturers, may become one of the greatest revolutions in automotive history. It includes communication systems for vehicles that can create a network where individual cars are communicating with each other in order to provide the driver with information, such as collision warnings and traffic reports (Röckl et al., 2008). With a typical communication range around 300m the drivers can receive necessary information well in advance (Edwards et al., 2011). This not only plays an important role for the avoidance of rear-end collisions, but also in situations when the driver does not have a clear overview over the traffic situation, e.g. at highly frequented intersections. While the driver's attention is by nature restricted, V2V systems can sense threats and hazards with a 360 degree awareness of the position of other vehicles and the danger they present. They are also regarded as an important step towards reducing the danger from ghost drivers. The success of V2V systems critically depends on a fast penetration of the market. It is estimated that even in the optimal case only 10% of vehicles will be equipped with V2V after 1.5 years. Hence, for customers to by V2V systems, there have to be tangible benefits with even lower levels of penetration (C2C-CC, 2007). Additionally, concerns about security of such systems against hacking and the variety of communication standards need to be addressed (Dhar et al., 2011).

Figure 2 illustrates that V2V systems merge communication systems with SCA systems to increase the safety of people inside and outside the car.

Intelligent Navigation System

Currently, many companies are doing research on improving the in-car GPS system and transforming it into a device that will offer more than just positioning capabilities. BMW for example is developing a GPS system called Intelligent Learning Navigation (ILENA). ILENA is a navigation system that can predict where the driver will be heading and what route will be chosen even when a driver has not entered a destination (BMW Blog, 2009). Early warnings of congestion, rapid selection of the most likely destination, as opposed to the most recent one or one from the address book, and cross-checking of predictions against the personal calendar function in the driver's smartphone are just the first of many potential functions of this Intelligent Navigation System (BMW Group, 2009). An important feature of ILENA is the increase of fuel efficiency, as the intelligent navigation system is integrated with the vehicle's own internal systems. While currently regenerative braking only works when the engine is on overrun, for example driving on a descending hill, ILENA can predict upcoming hills and the energy regeneration process can start earlier. Also, since the system can alert the driver to an upcoming decrease in speed limit before the actual appearance of the sign, the driver can gradually start reducing velocity which will lead to an increase in fuel efficiency. BMW predicts that with these features vehicles will be able to achieve fuel savings from 5 to 10 percent (BMW Group, 2009).

Intelligent Navigation Systems improve traditional GISN systems and connect them to mobile CCE devices like smartphones as depicted in Figure 2. The objective is to optimize trip routing and fuel consumption.

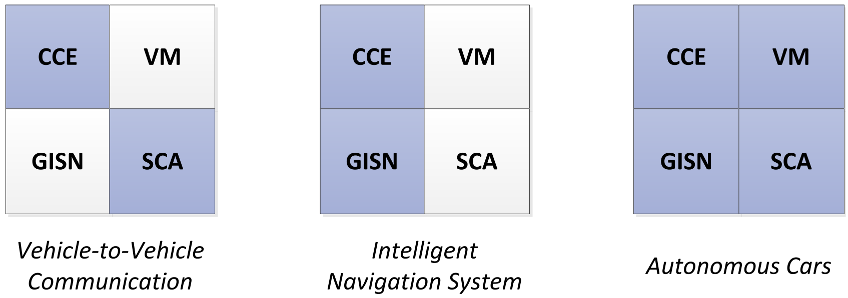

Figure 2.Trends in automobile information systems and the categories they affect

Autonomous Cars

The self-driving car has gained substantial public attention with a recent project conducted by Google, which has made significant progress towards the long-term vision of autonomous vehicles (Teichman and Thrun, 2011). However, it is not the only recent development in this research area, as autonomous driving features are already showing up in some regular mass-produced cars. This includes some models of the Toyota Prius, which have a driving-assist function that keeps the car centered on its lane and another function that can park the car completely by itself (Guizzo and Deyle, 2012).

Autonomous cars raise multiple questions, a central one being the optimal implementation into the current traffic system. One possibility is the gradual replacement of normal operations associated with driving a vehicle with already existing technologies like driving assistance and advanced safety features. Another option is the designation of lanes specifically to autonomously driven cars (Silberg et al., 2012). In any event, a question that raises itself is about liability in case of accidents.

As illustrated in Figure 2, autonomous cars evolve and connect information systems from all categories. CCE systems provide an interface for a car that automatically optimizes routing in a safe manner while observing the status of the vehicle. Autonomous cars would fundamentally change the automobile experience from driving to being driven.

Automobile Information Systems and Green Mobility

V2V, intelligent navigation, as well as autonomous cars all can provide a tangible contribution towards decreasing the environmental impact of the transportation sector. A substantial part of this environmental footprint is caused by congestion – traffic jams. V2V communication lessens the threat of traffic accidents, which are a main cause of congestion. V2V as well as intelligent navigation can be employed to redirect traffic once congestion occurs, thereby decreasing the negative impact.

Autonomous driving is certainly the most far-reaching approach. In addition to the effects related to congestion, it increases the energy efficiency of driving in general. For instance, human drivers often brake too late accelerate too much given the traffic situation. An automobile information system used for autonomous driving on the other hand can be calibrated to minimize wasted energy during a trip

RESIDENTIAL ENERGY MANAGEMENT AND AUTOMOBILE INFORMATION SYSTEMS

Another revolution in automobility is the rise of electric vehicles (EVs) and the shift from gasoline to electrical energy as fuel. In our previous work (Brandt et al., 2013) we have analyzed how such an EV can be integrated into a residential energy management system for a single household with a photovoltaic (PV) panel. The fundamental problem of such a household is that power supplied by the PV panel is at times larger than the power consumption of the household and smaller at other times. The household now faces the problem that compensation per kilowatt-hour (kWh) energy fed into the grid is much less than the price per kWh sourced from the grid. An EV can serve as a way to store excess energy and supply lacking energy while it is connected to the household. As the EV is also used for mobility, the energy management system has to use information on the driving behavior of the owner to minimize overall energy cost.

Optimization Model

Figure 3 illustrates a basic model of the circuits within the household and the attached components. This includes the PV panel, the EV (if it is plugged in at home), the remaining devices in the household, and a connection to the power grid, which balances any excessive or lacking power. If we assume power dissipation from resistance of the wiring and power losses from inversion when transferring to the EV to be zero (as it does not change the implications of this analysis), power P

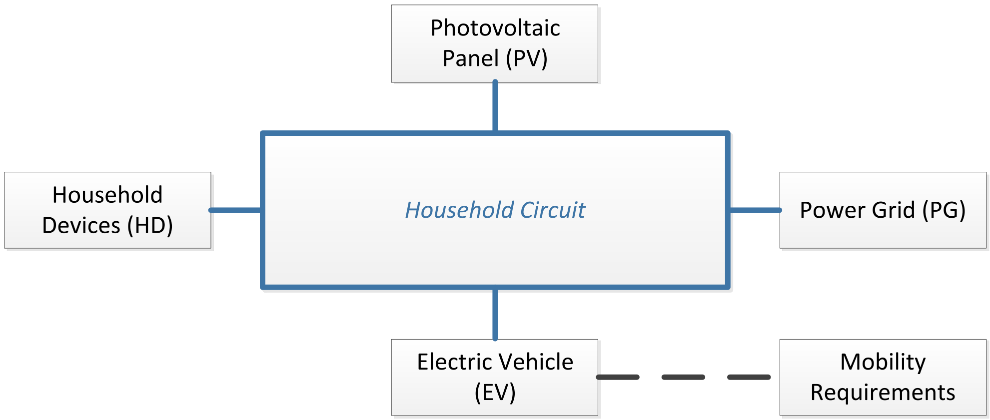

Figure 3. Model of the household circuit when EV connected

consumed and supplied by the components must be equal, resulting in Equation 1. The indices denote the respective components and β equals 1 if the vehicle is connected and zero otherwise.

$$\beta P_{EV} + P_{HD} + P_{PV} + P_{PG} = 0 \quad (1)$$

As electricity consumption is measured and billed in units of energy, we discretize time and transform this relationship into Equation 2.

$$\beta dE_{EV} + dE_{HD} + dE_{PV} + dE_{PG} = 0 \qquad \forall\, dt \quad (2)$$

The energy management system needs to optimize power consumption over a future interval, say the next 24 hours. To make this optimization manageable, the differentials cannot be arbitrarily small. Hence, the total optimization horizon is divided into $\mathrm{T} = \{1 \ldots T\}$ segments. Equation 2 is again transformed into the final condition for the optimization problem, with $\Delta E(t)$ denoting the supplied or consumed energy during segment *t*.

$$\beta(t)\Delta E_{EV}(t) + \Delta E_{HD}(t) + \Delta E_{PV}(t) + \Delta E_{PG}(t) = 0 \qquad \forall\, t \in \mathrm{T} \quad (3)$$

The objective function itself is quite straightforward, since the energy management system simply tries to minimize overall energy costs (Equation 4).

$$\min_{\Delta \mathrm{E_{EV}}(1) \ldots \Delta \mathrm{E_{EV}}(T)} \sum_{\mathrm{T}} p_R \Delta E_{PG}^{+}(t) + p_C \Delta \mathrm{E}_{\mathrm{PG}}^{-}(t) + p_G \Delta E_{HM}(t) \quad (4)$$

The energy management system can decide whether to charge or discharge the vehicle with the objective of minimizing overall costs. These consist of the retail price of energy p_R times any energy sourced from the grid ΔE_{PG}^{+} (positive values of ΔE_{PG}), the compensation p_C times any energy fed into the grid ΔE_{PG}^{-} (negative values), and any expenses for gasoline if the EV has a hybrid motor and it needs to be used to recharge the batteries (denoted by $p_G\ \Delta E_{HM}(t)$).

The complete optimization problem is summarized in Table 2. Equation 5 expresses that the energy stored in the vehicle battery at the beginning of *t*, $E_{EV}\ (t)$, plus any changes is bounded (generally by zero and the maximum capacity of the battery).

Improving Results through Automobile Information Systems

The central issue with this optimization problem is that all values of interest are predicted. Automobile information systems may be able to alleviate this problem. While they cannot assist in predicting the photovoltaic input $\Delta E_{PV}\ (t)$ or the household consumption $\Delta E_{HD}\ (t)$, they can provide valuable information to forecast the variables related to the vehicle: $\beta(t)$ and $E_{EV}\ (t)$.

$$\min_{\Delta \mathrm{E_{EV}}(1)\ldots\Delta \mathrm{E_{EV}}(T)} \sum_{\mathrm{T}} p_R \Delta E_{PG}^{+}(t) + p_C \Delta \mathrm{E}_{\mathrm{PG}}^{-}(t) + p_G \Delta E_{HM}(t)$$

s.t.

$$\beta(t)\Delta E_{EV}(t) + \Delta E_{HD}(t) + \Delta E_{PV}(t) + \Delta E_{PG}(t) = 0 \qquad \forall\, t \in \mathrm{T}$$

$$E_{EV}^{MIN} \leq E_{EV}(t) + \beta(t)\Delta E_{EV}(t) + \Delta E_{HM}(t) \leq E_{EV}^{MAX} \qquad \forall\, t \in \mathrm{T} \qquad (5)$$

$$p_R, p_C, p_G, \Delta E_{PV}(t)(t) \geq 0, \quad \Delta E_{HD} \leq 0 \qquad \forall\, t \in \mathrm{T}$$

Table 2. Complete optimization problem

Figure 4 illustrates this further. $\beta(t)$ states whether the car is at home (and, implicitly, plugged) or on the not. In addition to historical data on the driving behaviour of the owner, GISN systems can provide information on the current location and destination of the vehicle. Together with the VM system, they can also provide estimates on $E_{EV}\ (t)$, the state of charge of the battery when it gets home. In both cases the communication infrastructure accessed by CCE systems is needed to transmit the information to the household. However, CCE systems themselves can provide additional information by offering the driver an interface where planned trips during the day can be entered.

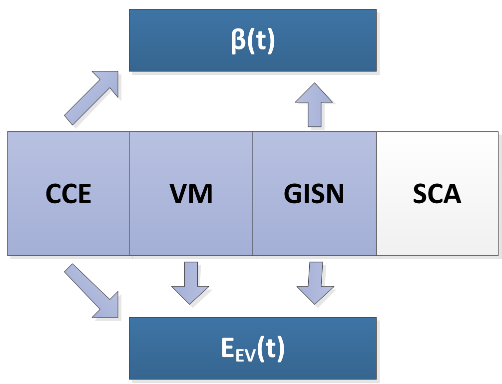

Figure 4. Overview on which categories of automobile information systems affect which variable that must be predicted for optimization

CONCLUSION

In this paper we illuminate the evolution of information systems in cars and the categories of automobile information systems that we face today. While this review is not meant to be exhaustive, our goal is to shine a light on recent innovations in this field, such as vehicle-to-vehicle communication and autonomous cars, as well as their relevance to sustainability research through decreasing the environmental footprint of the transportation sector.

Furthermore, we link automobile information systems to our previous research on electric mobility and residential energy management systems and illustrate how automobile information systems can increase prediction accuracy, thereby providing financial benefits to the residents and increasing the appeal of green technologies.

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