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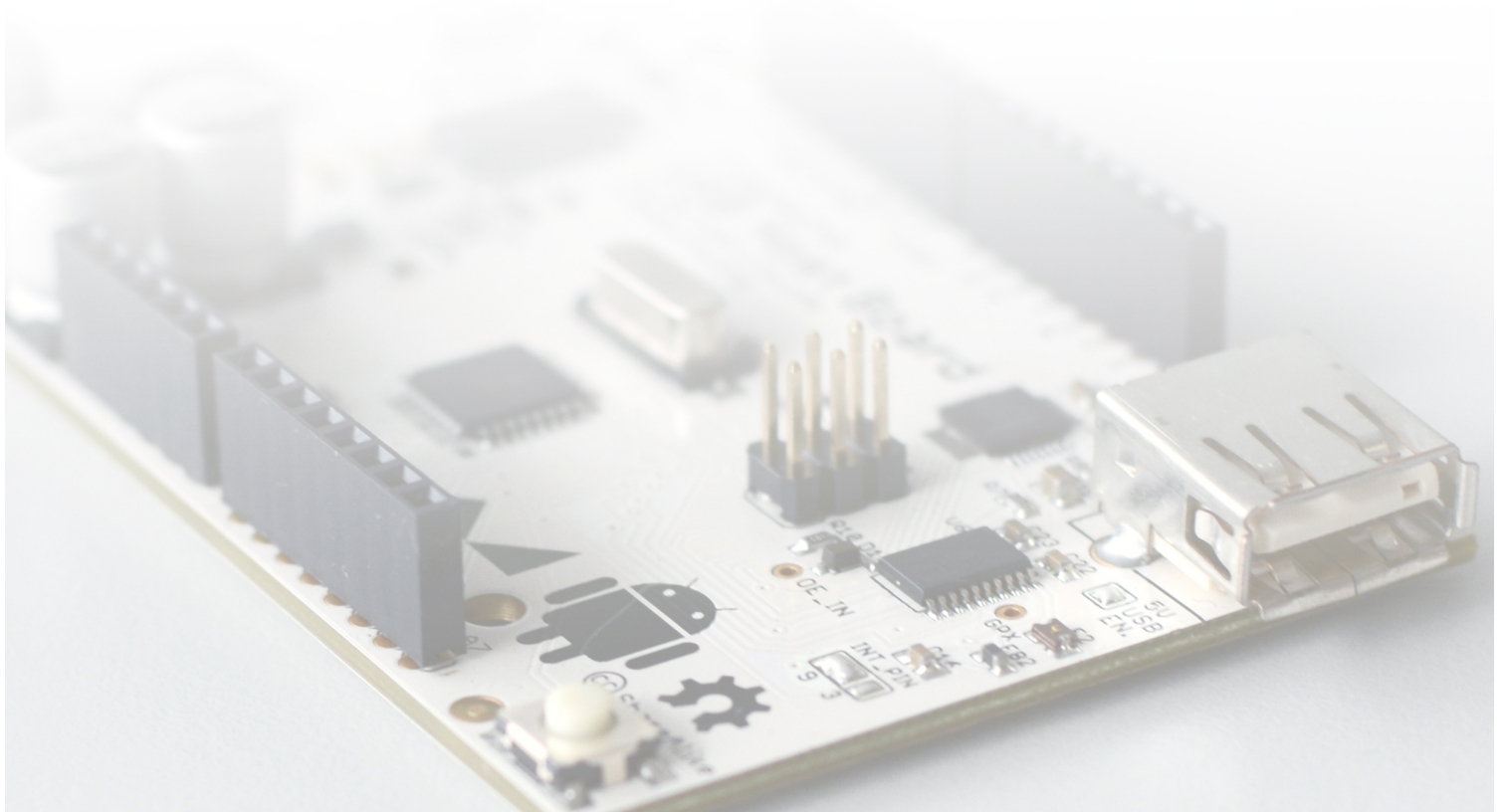
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Human Factors for Connected Cars

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Contents

Preface	4
Cooperative Driving <i>Matthias Cetto</i>	5
Traffic Flow Optimization via Connected Cars <i>Thomas Leutheusser</i>	14
Copyright Notes	23

Preface

The availability and power of embedded systems today benefits developments in the automotive domain. This and modern communication standards lead to a rising importance of work in the area of connected cars. Through the possibilities provided by Vehicle-to-Infrastructure (V2I) and Vehicle-to-Vehicle (V2V) communications, new types of applications are emerging. These applications can focus on benefits such as improved road safety but also on entertainment or information value for drivers and passengers. If we look beyond a communication between cars involving only automatically reacting systems, questions arise from an HCI perspective. What are human factors implications when designing interfaces for connected car scenarios? This technical report reaches to give an insight into potential answers using the areas of traffic flow optimization and cooperative driving as examples.

During the winter term in 2014/2015, the Embedded Interactive Systems Laboratory at the University of Passau encouraged students to conduct research on the general topic of “Human Factors for Connected Cars”. Each student analyzed a number of scientific publications and summarized the findings in a paper.

Thus, each chapter within this technical report depicts a survey of specific aspects of a topic in the area of automotive user interfaces and connected cars. The students’ backgrounds lie in Computer Science, Interactive Technologies, Mobile and Embedded Systems, and Internet Computing. This mixture of disciplines results in a highly post-disciplinary set of viewpoints. Therefore, this technical report is aimed at providing insights into various aspects of current topics in Human-Computer Interaction.

Passau, April 2015

The Editors

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Cooperative Driving

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ABSTRACT

Cooperative driving is a rising application area that aims for increased road safety, traffic efficiency and comfort. This paper provides an overview of the current state of the art in cooperative driving, including basics like different types of cooperation and technologies, as well as recommendations for designing interaction interfaces. Furthermore, a presentation of the benefits and challenges of cooperative driving demonstrates the practical use of such technologies. The main focus will be on the investigation of driver-passenger cooperation. Studies stated a positive effect on integrating front and even child passengers in the execution of assistive tasks while driving. Therefore, the main results of recent ethnographic studies are presented that reveal behavior patterns and factors for successful collaboration between drivers and passengers. These insights form the background for designing interaction interfaces that are suitable for efficient driver-passenger collaboration like touchscreens or natural language interfaces. Since current in-vehicle systems fail to provide drivers with the possibility to display their feelings and intentions to other drivers, expressive communication systems like holographic laser projections or LED lights should also be taken into consideration when designing interaction interfaces. Another important aspect is the mitigation of driver distraction for increased road safety.

Keywords

cooperative driving, connected vehicles, V2V, V2I, car-car, driver-driver, driver-passenger, collaboration, driver distraction

1. INTRODUCTION

In May 2011, the first *Grand Cooperative Driving Challenge* (GCDC) took place in Helmond, The Netherlands, in order to further accelerate developments in the area of cooperative driving. This competition was organized by the *Organisation for Applied Scientific Research* (TNO) and *The Dutch Automotive Innovation Programme* (HTAS). It enabled nine teams from all over the world to present and

compare their solutions on cooperative driving focusing on the topic of platooning. To achieve a small time headway between two consecutive driving vehicles and to still guarantee a high level of safety, each team extended the commonly used sensor- and vision-based *adaptive cruise control* (ACC) system. They did so by exchanging additional information via wireless communication. The evaluation of the last GCDC revealed the potential of collaborating systems for more traffic safety and efficiency [22, 8]. The decision to make the GCDC a regular event (next event in 2016)¹ concerning different aspects of cooperative driving indicates its significance in today's fields of research.

Intelligent transport systems (ITS) are a rising technology for setting up cooperative vehicular networks with a variety of applications that aim for increased road safety, traffic efficiency and comfort. These networks are based on wireless communication technologies that enable vehicles to share information either between each other or with infrastructures [3].

Separate from this approach, *cooperative driving* additionally takes into account the human ability of problem-solving and collaboration. Although most front passengers are already helping the driver to gather information and to make decisions [9], today's *in-vehicle information systems* (IVIS) are mainly designed to be controlled by the driver alone [21]. Since passengers only have restricted possibilities for supporting the driver like verbal communication or pointing at objects outside the car, upcoming in-car technologies, such as natural language interfaces or smartphone applications have the potential to make collaboration in the car more efficient. They can also decrease the cognitive load for the driver which is a main cause for potential driver distraction [21].

Driver distraction requires particular attention when designing interaction systems. Since driver distraction is one of the main causes for driver inattention and therefore hazardous driving and accidents, a lot of work has been spent on theory and mitigation of distraction. Young et al. [24] defined driver distraction as "the diversion of attention away from activities critical for safe driving toward a competing activity". Diversion of attention can occur willingly, e.g. when making mobile phone calls, or involuntarily, e.g. when certain objects in the road environment draw the driver's attention. Since the human brain is limited in its attention to multiple tasks at the same time, distracting factors inside and outside the car should be reduced for safe driving.

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¹The Grand Cooperative Driving Challenge. www.gcdc.net, 2014. [Online; accessed 16-December-2014].

Thus, the design process of interaction interfaces is always a balancing act between displaying relevant information for the participants and the amount of distraction caused by these systems.

The following sections further investigate the idea of cooperative driving by summarizing results and trends of recent research and studies. The next two sections give a short introduction of the basic aspects of cooperative driving and different types of cooperation that can be used to share information among the collaborating parties. Section 4 summarizes the design recommendations of different studies and other research, which will be classified into interfaces for efficient driver-passenger collaboration and expressive driver-driver communication. The goal of this part is to suggest some design concepts of how future in-car technologies may look like. An overview on cooperative car-car driving applications and their benefits on road safety, traffic efficiency and comfort is given in section 5. Although cooperative driving is a promising system for the future, it has to deal with privacy issues, driver distraction and public acceptance in order to become an established system. These topics will be discussed in section 6. Finally, a conclusion of this work summarizes the main findings of cooperative driving.

2. BASICS OF COOPERATIVE DRIVING

Cooperative driving is an area of research that aims for increased traffic throughput, limited CO₂ emissions, improved traffic safety and increased driving comfort based on collaboration for sharing information. It mainly profits from recent work in vehicle communication technology using wireless communication. A distinction can be made between vehicles that interact with each other, *vehicle-to-vehicle* (V2V), and vehicles with roadside infrastructures, *vehicle-to-infrastructure* (V2I). These communication technologies can supply other cars and roadside units with information about the state of vehicles, as well as their intentions and road conditions [22]. In addition, driver-passenger collaboration can be used for sharing information inside vehicles.

3. TYPES OF COOPERATION

The subsequent sections describe different types of collaboration. These differ in the information that is shared among the communicating parties, as well as in the used technologies. *Car-car* systems use wireless communication networks to communicate, while *driver-passenger* pairs share their information inside the vehicles using verbal communication, gestures [16] or in-car interfaces. For *driver-driver* communication, different technologies for expressing drivers' feelings and displaying messages can be implemented, e.g. by displaying information on the exterior [6]. Since a considerable amount of research has been done in driver-passenger collaboration, we will focus our research primarily on the respective field.

3.1 Driver-Driver

Although driver-driver systems have to share their information between different drivers and therefore between their vehicles in accordance with car-car systems, we want to define car-car systems as those that automatically communicate with other vehicles, while communications in driver-driver systems are intentionally triggered by the drivers. A main purpose of driver-driver collaboration is to enable

drivers to express their intentions, thoughts, conditions and emotions to other drivers. The used technologies can range from displays over LED lights to holographic laser projections, which are presented in section 4.2 [12].

3.2 Car-Car

Car-car systems are mainly applied in ITS applications where vehicles automatically share information with infrastructures or other vehicles using V2I and V2V communication. Infrastructure-based technologies contain several base stations that are able to relay communication signals over a long range. Examples can be *cellular networks* that are designed for voice data exchange or *Worldwide Interoperability for Microwave Access* (WiMAX) that can provide wireless data (e.g. high-speed Internet) for mobile users [3].

These two examples may also be used for V2V systems that are based on indirect communication between vehicles. Those *indirect* V2V communication systems are mediated by a third party, while *direct* V2V communication systems do not consider such an involvement. Technologies for direct V2V communication can be based on IEEE 802.11 technologies like *dedicated short-range communication* (DSRC) and its next generation of *wireless access in the vehicular environment* (WAVE) for high-speed data transmission, as well as the *communication air interface for long- and medium-range* (CALM) communication standard [3]. Considering the benefits and the huge number of vehicles that have to be covered by such systems, it is obvious that vehicular communications are likely to become the most relevant realization of *mobile ad hoc networks* (MANETs). Such *vehicular ad hoc networks* (VANETs) consist of communicating nodes that can either be vehicles or base stations. The realization of such a network is very challenging due to the quasi-permanent mobility, high speeds, very short connection times between neighbors and its scale (hundreds of millions of nodes). However, unlike usual ad hoc networks, VANETs can take advantage of the computational and power resources of vehicles [19]. The range of such applications is presented in section 5.

3.3 Driver-Passenger

Driver-passenger collaboration is a well-researched topic in cooperative driving. A lot of ethnographic studies are available which analyze social and behavioral in-car activities of driver-passenger pairs while driving. To fully benefit from the collaborative human problem-solving abilities, we firstly want to emphasize the general factors that are relevant for successful human communication in view of in-car collaborasengers as signification.

Clark and Brennan [1] considered *common ground* as the key for successful human communication and collaboration. Common ground characterizes a vast amount of information that has to be shared between coordinating people, such as mutual knowledge, mutual beliefs and mutual assumptions. In order to collaborate successfully, both parties have to coordinate the content and the process of their communication, as well as to update their common ground steadily. The goal, people try to reach in conversations is called the *grounding criterion* which describes the state in which the contributor and his partner mutually believe that the respective other has understood what the contributor meant. *Grounding*, which denotes the collective process for the participants to reach this mutual belief, should change with

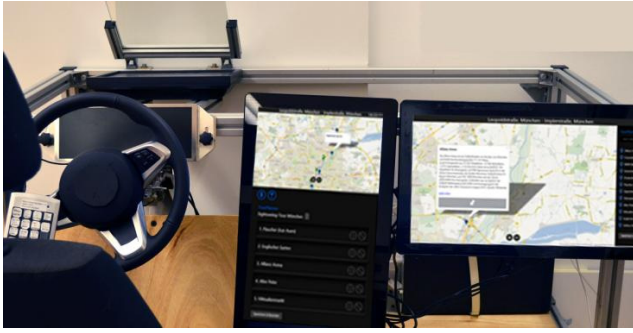


Figure 1: Hardware setup, running the ‘TourPlanner’ app. Left: shared information display. Right: front-seat passenger information display.

purpose and medium. People in conversations generally try to establish collective purposes. Therefore, grounding and techniques should also change as the purpose of the conversation changes. In a navigation task, the general collective purpose of the communication between driver and passenger may be reaching the destination or specific waypoints. If such purposes change, one can consider to offer different techniques like different input possibilities (gestures, speech) for in-car interfaces tailored for the specific purpose. This idea also applies when the communication medium changes. An example could be switching from verbal communication to collaboration on shared displays.

This brief excursion into the topic of common ground has already revealed interesting insights into factors for efficient and successful human communication that might be applicable to driver-passenger collaboration. To further investigate this topic, we will look at more detailed ethnographic studies which directly deal with driver-passenger pairs for capturing their current patterns of behavior and feelings while driving. Since adult front-seat passengers are the main clientele in the research of driver-passenger collaboration, the following subsection will concentrate on the respective group even if some findings may also apply to other passengers inside the car. Nevertheless, two brief subsections are devoted to back and child passengers.

3.3.1 Driver-Front Passenger

Before considering passengers as significant assistants for the drivers, we have to make sure that drivers are willing to transfer responsibility to their passengers. Rümelin et al. [21] conducted a study on this topic focusing on feelings of perceived control and involvement for each driver and passenger. Eight groups of regular driving and assisting people (4 women, 12 men, mean age 28 years) took part in this study in groups of two. The study consisted of two driving scenarios in a lab-setting. The hardware setup contained seats for the driver and the passenger, a steering wheel for the driver (with a numpad), as well as a display simulating the *head-up-display* (HUD). Two multi touch capable displays were used for the shared information display and the front-seat passenger information display (Figure 1). In the first task, executors who had the role of a driver or a passenger performed a task for displaying respective *points of interest* (POI) on a map using two apps called “BankFinder” and “BarFinder”. The second task was a more complex, shared task between driver and passenger using the sightseeing app

“TourPlanner” to set up a route along various POIs. While the driver only had an overview on the shared information display, the passenger’s view included more details and more possible interactions. To simulate the cognitive load of driving, the driver had to do an additional distraction task in which he had to respond to highlighted arrows as fast as possible via the numpad on his steering wheel.

The results of this study confirm the positive effect of integrating the front-seat passenger into the execution of tasks related to current driving. In particular, letting the passenger execute tasks can significantly enhance the feeling of control for both parties, whereas the execution of both primary and secondary task by the driver led to confusion and errors that did not exist with an interacting passenger. In the shared task, both parties had a high feeling of control. Shared discussions made the driver feel that he has a direct influence, even if the browsing of POIs was mainly performed by the passenger.

Regarding involvement, the respective executor in the first task experienced a slightly higher involvement than the other one, whereas participants rated their feeling of involvement equally high in the shared task. Even if the measured and subjective reaction time of the driver’s distraction task (which indicates the amount of driver distraction) was slightly higher in the shared task than letting only the passenger perform, driver distraction was significantly lower than letting only the driver perform.

In the next part, two studies are presented that focus on social factors which can be observed in collaborative human interaction inside the car.

Forlizzi et al. [7] conducted a qualitative study of 20 participants (10 women, 10 men, age from 18-53), including three different social groups of parents and their teenage children, couples and unacquainted individuals. The study took part in two US cities where each pair of driver and passenger had to navigate through one of two possible routes. They could only use the set of directions which the passenger prepared alone before the drive by choosing various tools like a computer with Internet access, a map, a pen and paper. The analysis of the data (gathered from the videotaped driving activity and interviews) revealed insights concerning the way teams collaborate, how social relationships affect interaction and how patterns of prompts, maneuvers and confirmation utterances affect the navigation task.

The study revealed group differences in collaboration. Less experienced teams or teams with interpersonal familiarity were more explicit in their task roles as driver or passenger. They shared less common ground and talked more about the route itself than teams that were more experienced. In addition, different social roles and relationships also affected the way the driver-passenger pair behaved. While the task roles took precedence over the social roles in teams with less shared knowledge, teams with more shared knowledge adapted their social role instead of their assigned task roles. Parents, for example, took the opportunity to teach teenagers and provided them with information. They mostly talked about utterances and experiences related to the drive. Couples collaborated loosely by switching between their task and social roles. Unacquainted teams mostly talked about the maneuvers on the drive. Since informal discussions about landmarks formed the most common discussion topic, one can conclude that situating the route in experience of driver and navigators is important to help developing their route

and survey knowledge. Another important aspect is the right timing of prompts and exchanges, e.g. about the next step of the route in a navigation task. Designing appropriate in-car feedback systems can be difficult, as even passengers had problems with the right timing.

The study of Gridling et al. [9] investigated social and collaborative in-car activities not only in navigational tasks. Therefore, nine groups consisting of a driver and a front passenger (mean age 27.9 years) from car-sharing platforms were escorted and observed by a researcher on the back seat while they were driving.

The qualitative analysis showed that most of the front-seat passengers help the driver to gather information and to make right decisions. During navigation tasks, in which the drivers needed more help, passengers even used two systems in parallel like the navigation system and their cell phones. According to the previous study, group differences were considered as impact factors for human assistance and collaboration. The closer the relationship between the driver and the passenger was, the more assistance was shown in terms of kind and frequency. Passengers were also aware of the driver's mental state and provided more assistance when the driver was exhausted or tired. The feeling of trust and perceived safety had been the highest priority for other passengers and increased the collaboration. Thereby, distrust (e.g. a tailgating vehicle) and perceived safety (e.g. limited perceived safety at snowstorms) between the driver couple caused more active interaction and cooperation.

3.3.2 Driver-Back Passenger

While front passengers are a well studied topic for providing driving assistance, there hardly exists any corresponding research on passengers on rear-seats. This may have several practical reasons. First of all, the spatial arrangement of rear-seats which are directly placed behind the front-seats (and force back passengers to look at the backs of the heads of those in front) disables a natural conversation environment. Furthermore, front passengers are not able to see the passengers in the back at all, without turning their head or using mirrors. Since back passengers commonly lean forward to launch or participate in conversations, one can conclude that using verbal communication between drivers and back passengers is not suitable for efficient collaboration. Another reason for this is the ambient road noise during travel which makes a conversation almost impossible on motorways. Since car travels, especially among families, are used as a social space to exchange informal information that is not related to the driving task, it might be difficult to win back-seat passengers for assisting the driver [15]. Nevertheless, some non-verbal collaboration ideas on integrating back passengers have emerged and will be presented in section 4.

3.3.3 Driver-Child Passenger

Car trips with children are one of the most frequent forms of transportation [2]. Cyncil et al. [2] studied the role of child passengers in assisting parent-drivers during family journeys. The main reason for this is the fact that in particular young children have been overlooked in the design of in-car technology. Therefore, one of the most important issues for parents and their children is to fight boredom by using entertainment systems. Those systems can range from traditional toys to modern technology like portable video, audio and gaming devices [23]. The study of [2] collected

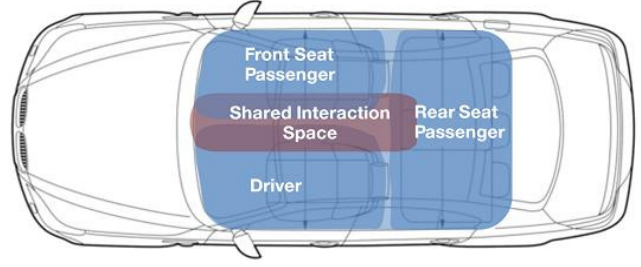


Figure 2: Design space areas (for driver, front-seat passenger, rear-seat passengers) and shared interaction space.

about 60 hours of video clips from six families who were asked to film their typical journeys over one week. The goal was to analyze the assistive capabilities provided by children as front-seat passengers and their collaborative use of technology while assisting adults.

The study confirmed the assisting ability of child passengers in front-seats. Those children were able to actively and successfully interact with their parents. However, the quality of coping with the task depended on their level of competency in dealing with the complexity of the situation like the ability to read or write down notes. In addition, the children were not completely independent in their assistive tasks. While some children were expected to do tasks independently, others were guided and monitored by their parents. It could be observed that children did not simply follow the driver's requests. They were able to take on tasks semi-autonomously, provide appropriate verbal feedbacks of their actions and form their responses in a comprehensive way (e.g. summarizing) to the driver. In addition, children reminded the driver about events and were able to deal with mobile phones.

4. DESIGN OF INTERACTION INTERFACES

After the theoretical view on different modes of collaboration and social aspects in driver-passenger assistance, we will inspect different design approaches for in-vehicle interfaces that were recommended by studies mentioned in the previous section and in additional research. These design recommendations will be grouped by its purpose for efficient driver-passenger collaboration and expressive driver-driver communication.

4.1 Efficient Driver-Passenger Collaboration

To enable efficient driver-passenger collaboration inside vehicles, Rümelin et al. [21] adapted the design concept of dedicated workspaces from Meschtscherjakov et al.[18] and extended this approach with an additional shared interaction space (Figure 2). The idea behind this design is to provide each driver and front-seat passenger with own interaction spaces. The driver's dedicated space could be an instrument cluster on the steering wheel or a HUD displaying car-related information. A possible input module could be positioned on the steering wheel. On the other side, the front passenger's dedicated space has the advantage that the passenger can use both hands and his full attention for the interaction. In addition, a shared space between the driver and front passenger allows them to perform collaborative

tasks. A suitable interface would be the center console, since it is easy reachable for both parties. This concept responds to the tendency of people to perform individual tasks in personal spaces and collaborative tasks in shared spaces [21].

The overall functionality of collaborative activities can be further increased by providing more information for the passenger than for the driver. Since drivers want to know what their passengers are doing, they should always be informed about the current status. Therefore, a constantly accessible overview on the assisting task should be given [21]. Besides spatial arrangements, the use of new in-car technologies has much potential to make collaboration more efficient.

Touchscreens are common tools and suitable for passengers who can use both hands to interact. Therefore, some concept cars even consider installations of touchscreens for rear-seat passengers [21]. For the driver, smartphone applications like Apple's "Siri"² and Google's "Voice Actions"³ are able to offer interaction with mobile devices that no longer require hands-on operations [2].

Rümelin et al. [20] investigated free-hand pointing for identification and interaction with distant objects. This technology aims to provide a system that enables users of vehicles to point at items outside and select them. Selecting objects may be used for further interaction like marking POIs with tags, calling associated numbers or using the location in social media. Besides, pointing is commonly used as means for identification in human communication, gestural interfaces have the potential to increase safety by decreasing the visual demand. Therefore, the researchers carried out a pre-study to investigate the reliability of pointing detection and a real-life driving study to explore the effects of pointing on the participants' driving behavior and its acceptance. In the pre-study, 18 participants (mean age 27 years) had to point at highlighted buildings in three city scenes which were projected to the wall in front of them and at numbered areas on the cockpit surface. The pointing direction was captured using a *Microsoft Kinect* for depth and image recognition. Since the Kinect was not suitable for usage inside a real-car setting due to disturbing objects between the driver and the camera, good recognition rates (average: 95.8%) could be achieved in an additional lab setup.

In the second real life driving study, the deficient Kinect was replaced by an investigator in the rear part of the car who used his view from the back of the car and a video stream of the driver's gaze (using an eye-tracking system) to identify the selected objects by the driver. It was ensured that the investigator's recognition rate was similar to the achieved one in the first lab study. 15 employees (13 men, 2 women, mean age 27 years) of *BMW Group Research and Technology* who were not involved in gesture research were recruited to drive a specific route, including three different scenarios. In these scenarios, each participant had to find predefined POIs (restaurants, flats) or different buildings for a sightseeing tour using both pointing technology (for selection and saving objects) and a menu on the central display (for additional information and saving objects).

After the scenarios, the drivers were asked about their subjective impression of distraction. This revealed that the perceived distraction of gestural interaction was less distrac-

²Siri. www.apple.com/de/ios/siri, 2014. [Online; accessed 16-December-2014].

³Voice. www.google.com/voice, 2014. [Online; accessed 16-December-2014].

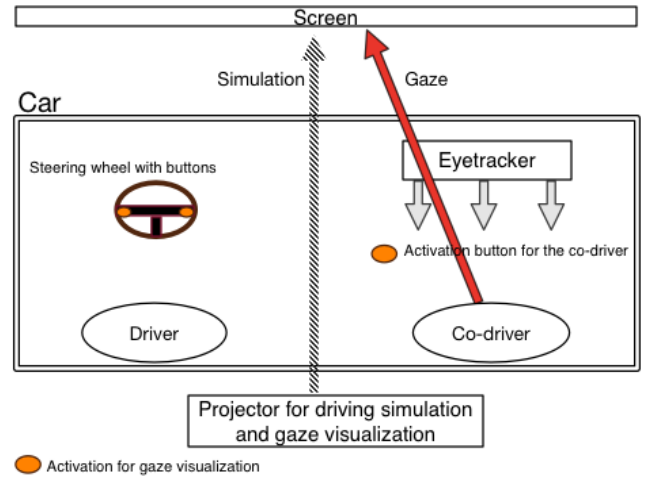


Figure 3: Technical setup for gaze visualization.

tive than controller interaction. The main positive arguments were the direct connection to the selection process, the same modality between selecting and changing and the easy learnability. Even if this work mainly considered drivers using these systems, pointing may also be used by passengers for efficient collaboration.

Another approach for the future design of collaborative in-car interfaces is to provide the driver with the additional information where the front passenger is looking at. Maurer et al. [17] reported the results of a first explorative study of their "Gaze Assist" system. This system captures the front passenger's gaze and visualizes it for the driver. Therefore, a car simulator was equipped with a projector above which visualized a car simulation on a screen in front of the simulator. Three cameras were used to track the eyes of the passenger. The X and Y coordinates of his gaze were processed by the simulator software and displayed as a circle on the screen. The system could be activated via buttons on the back of the steering wheel, as well as in the console in front of the co-driver (Figure 3). The study consisted of five, about ten-minute driving sessions with changing drivers (colleagues between 26 and 40 years). In the scenario, driver and co-driver had to navigate through an unknown city. For this task, the co-driver was equipped with information about the route, and verbally informed the driver about specific directions or landmarks. To support this task, both driver and co-driver could activate the "Gaze Assist" if they felt that the verbal communication was not sufficient.

The study and informal interviews underlined the potential of shared gaze in a collaborative navigation task. Participants mentioned that the resulting reduced amount of verbal communication reduced their feeling of being stressed. Moreover, locating spatial references seemed to be more ambiguous than using only verbal communication. Participants even proposed their own design recommendations for such systems. One desire was to put more information into the gaze visualization itself like color coding for different kinds of information, such as hazardous situations or general information. However, it has to be ensured that the additional information coding does not distract the driver significantly.

For the passengers, the activation of the gaze visualization depended on the area of application. In hazardous sit-

uations, the co-driver should be able to activate the system while during navigation, the driver should have the trigger. Future systems may be able to detect such situations and automatically activate the gaze visualization when help is needed. The use of eye tracking devices in cars and the windscreen as a HUD would realize gaze visualization in a real car scenario.

Due to the positive supportive behavior of child passengers in their study, Cycil et al. [2] proposed design approaches tailored for child passenger assistance. An important factor here is to distinguish between different kinds of passengers and their skills. As an example, providing images of buildings along a route in a navigation task for children would be more useful than geospatial routes. Therefore, systems could be able to sense who is speaking and provide customized responses and feedbacks in a suitable form. The complexity of such systems for the children may be compensated by the presence of adult drivers. Since they were able to instruct their child passengers, the idea of making the internal state of systems visible for the driver and easy describable for the passenger, would allow for richer driver-passenger negotiation. One way to support child passengers is to investigate developing media in the front passenger space. Instead of input devices like keyboards, children with missing skills like reading or writing may profit more from voice-based technologies or interfaces that allow to draw characters. Besides providing simplified versions of interaction technologies for children like using bigger screens and large fonts, their ability of reasoning or engaging in extended collaborative discussions should also be considered when designing such systems.

Concerning multi-person interaction with passengers on the rear seats, Cycil et al. [2] suggested to adapt natural user interfaces to support the communication, including speech and gestures. Such systems may be able to determine who is speaking inside the car and identify gestures to draw conclusions about the topic of discussions, relevant content and detect who is currently interacting with media content.

4.2 Expressive Driver-Driver Communication

After recommending designs for driver-passenger collaboration, we want to consider new systems that are suitable for interactions between drivers. Hwang et al. [12] took up this topic with a focus on expressive driver-vehicle interfaces. They stated that current vehicle interfaces primarily focus on the car-driver interaction and miss out the drivers' needs to express their thoughts, conditions and emotions to pedestrians and other drivers. Therefore, various interaction methods were presented for this purpose.

Since holographic laser projections are considered to monitor approaching objects on the road (e.g. on the windshield, rearview mirror and side mirrors), these systems can also be used to display visual messages from the driver to other drivers and pedestrians. Such messages can be projected as images on the road or onto the curved car surface. In the first case, projected areas around the car could be further used as an input screen, e.g. to alert a tailgating vehicle as it is crossing the borderline of the front car's projected image (Figure 4) [12].

Another possibility for transferring information from the inside of a vehicle to the outside can be customizable car surfaces. They are able to display a driver's message onto the curved car surface, a flexible OLED display and a LED

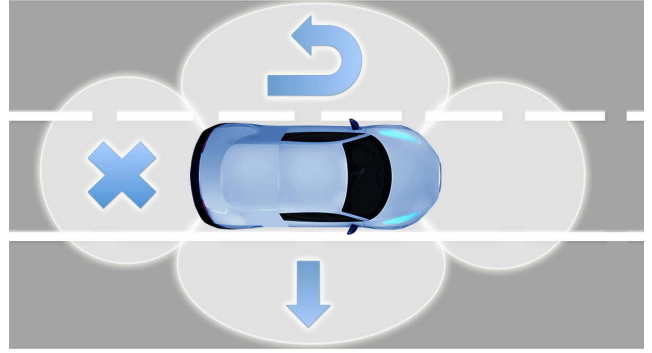


Figure 4: Holographic laser projection on the road.

glass-like display. Such surface designs allow users to design their cars using images, videos and to express their thoughts and intentions onto the car's surface in real-time [12].

The use of LED lights also enables drivers to express their feelings. *Drivemocion*⁴ is offering little car message devices that can be placed at the backside of a car to present messages to drivers behind. This event is triggered by a button on a connected controller. Instead of purchasing such LED devices, customizable LED taillights could also offer services to display instant messages or alerts to other drivers [12].

Flexible displays and screen displays are other systems that can be used to present information. With the extension of new human-vehicle interfaces that enable drivers to use their mobile phones, these displays can be controlled by touch or speech recognition apps providing real-time interaction with other drivers and pedestrians [12].

5. BENEFITS & APPLICATIONS

With the knowledge of the technical background of connected vehicles, we will now inspect the range of practical applications of collaborative systems. Since benefits and examples of collaborative driver-passenger and driver-driver systems have already been discussed in the previous sections, this section presents some applications in the area of ITS that are based on car-car collaboration using V2V and V2I technology. We will group those examples by their purpose in the three categories of road safety, traffic efficiency and comfort.

5.1 Road Safety

In the paper [13], the main goals of road safety applications are summarized as those that are primarily employed to decrease the probability of traffic accidents and the loss of life of vehicle occupants. Sharing information like vehicles' positions, intersection positions, speeds and distance headings between vehicles and roadside units can detect hazardous situations and avoid collisions.

Collision avoidance systems are used to warn drivers when a collision between vehicles is probable. Parts of these systems are designed to prevent collisions with other vehicles driving in the same and in opposite directions. This can also apply to collisions with crossing bikers and pedestrians, especially with disabled people [4]. *Rear end collision*

⁴Drivemocion. www.drivemocion.com, 2014. [Online; accessed 16-December-2014].

warning systems can warn drivers about the risk of a possible rear-end collision in front which can be caused by a breaking vehicle or at road curvatures [13]. This goal can be achieved by *safe distance* applications that adjust the vehicle's distance to the vehicles ahead and its speed according to the current traffic situation. Since such systems are mainly short range V2V systems, a low latency is important to guarantee minimal response times [3]. If the drivers line of sight is obstructed, *emergency electronic brake lights* can warn drivers when a vehicle that may not be seen has to break hard. Therefore, the breaking vehicle broadcasts self-generated emergency break events to the surrounding vehicles [13, 1]. Collisions with approaching vehicles can be avoided by *head on collision warning* systems that send early warning to vehicles that are traveling in opposite directions. An example of such messages is the so-called "Do Not Pass Warning". Its purpose is to warn drivers during a passing maneuver when a slower vehicle in front of their lane cannot be passed safely. This can occur when the passing zone is occupied by vehicles driving in the opposite direction [13, 1]. *Intersection collision avoidance* systems can be realized by using additional V2I communication. These systems can assist drivers in turning left or right at road intersections. When approaching these, vehicles or roadside units can detect the risk of imminent collisions and inform approaching vehicles in order to reduce the risk of lateral collisions [13, 3]. Regarding future collision avoidance systems, Healey et al. [11] devised an extension by transmitting additional driver state variables. Such states may describe the amount of distraction of a driver which can be detected by driver monitoring systems. Some examples are writing text messages on a mobile phone, listening or answering a phone call. Transmitting the driver's state to surrounding vehicles can make them more aware of his potential hazardous driving and may be used in the future to generate related responses like honking or sending warning messages.

Additional road safety can be achieved by *road sign notifications*. They aim to inform drivers about traffic signs further down the road. Such systems can provide drivers with information conveyed by traffic signs, so-called *in-vehicle signage* systems or *curve speed warnings* from roadside units that are located before curves [3].

Just as important as to prevent accidents, is to respond to incidents that have already happened. Therefore, *incident management* systems are an essential part for road safety. Related applications can be *post crash warning* or *emergency vehicle warning* systems. While the former informs the approaching traffic about vehicles that may had an accident or a breakdown, the latter warns drivers about approaching emergency vehicles that should be given the right of way [3].

5.2 Traffic Efficiency

Another benefit of cooperative applications is increased traffic efficiency. Corresponding applications aim for improved vehicle traffic flow, traffic coordination and traffic assistance by managing traffic efficiency and monitoring vehicles and road conditions [13, 3].

The first area of *traffic management* systems may contain *speed management* applications that are supporting the drivers with information about speed limitations and speed recommendations, e.g. for passing green traffic lights, for smooth driving and to avoid unnecessary stops [13]. While these systems improve the traffic efficiency for individual

vehicles, other ones like *co-operative navigation* systems are regarding the overall traffic situation. These systems try to increase the traffic efficiency by supporting the drivers with navigational information, such as traffic information and route recommendations. For this purpose, both V2V and V2I communication technologies are used [13]. In addition, overall traffic can be regulated by *intelligent traffic flow control* applications that are dynamically adapting the phases of traffic light signals. Therefore, infrastructure applications periodically request information about nearby vehicles, which can be used by roadside applications to determine the current traffic flow. Hence, appropriate phases of traffic light sequences can be determined [3].

The second area of *monitoring applications* helps to monitor vehicles and road conditions. The goal of such systems can be the detection of spatial and speed traffic rule violations by vehicles. This is done by infrastructure based *vehicle tracking and tracing* systems that require a long-range communication channel with the backend infrastructure [3]. *Road condition monitoring* applications provide information about the road condition that is used by safety applications. The data is gathered by on-board applications, which are able to detect and sense marginal road conditions, and distributed via V2V communication to other vehicles (e.g. as road condition warning messages) [3].

5.3 Comfort Applications

Besides cooperative systems that deal with road safety and efficiency, comfort applications provide up-to-date contextual information and entertainment services [3].

The group of *contextual applications* contains applications that increase driver awareness about local attractions. Examples of co-operative local services that are using short-range V2I communication with local road side units can be *point of interest notification* or *local electronic commerce* applications. Long-range communication systems like global Internet services can provide data from various Internet sources. Examples are *parking booking* applications that can support the drivers to find and book a nearby parking place. *Restaurant information* applications can locate near restaurants and display additional information about the restaurant, e.g. menu and prices [13, 3].

The range of *entertainment applications* includes gamified learning apps [5] or on-board vehicle devices that can be used by passengers to play *distributed games* with other passengers in surrounding vehicles. Furthermore, *downloading music* applications allow passengers to download their favorite songs via in-vehicle devices from the Internet.

6. FURTHER CHALLENGES

Despite the mentioned benefits of cooperative systems, these have to face some challenges that occur when establishing newer in-car and communication technologies. Here, we want to address three topics that have to be taken into account.

6.1 Driver Distraction

We have already mentioned driver inattention as a crucial factor for road safety. An observational study in the United States involving 100 instrumented vehicles reported that nearly 80% of crashes and 65% of near-crashes included factors of driver inattention [14]. Since these results considered factors like general inattention to the road and cogni-

tive states (e.g. drowsiness, fatigue), one can define driver distraction as a subset of driver inattention which requires an explicit activity (e.g. secondary tasks) that competes for the driver's attention [14, 24]. Nevertheless, in other studies, the definition of distraction varies in terms of its effect on the driving performance, activities or objects that lead to distraction and as a disruption of the driving task. In addition, different measurement methods and metrics cause differences in the determined amount of distraction. The analysis of police-reported crashes of multiple years (1995-1999 and 2000-2003) suggested that around 11% of crashes were contributed by driving distraction factors [24].

In view of in-vehicle interfaces and collaboration, secondary tasks (e.g. eating, listening to hand-held devices, talking to passengers) are still one of the most frequent sources of distraction. In the study of [14], complex, moderate and simple secondary tasks contributed to 23% of all crashes and near-crashes. Therefore, evaluating the amount of driver distraction and in particular the frequency and complexity of secondary tasks is necessary when designing in-vehicle systems for increased road safety.

6.2 Privacy Issues

Although, communication networks like VANETs are challenged to deal with a range of security issues like authentication, verification of data consistency, availability, non-repudiation and real-time constraints [19], we assume here that the underlying communication protocols guarantee these requirements. However, we will discuss privacy in cooperative systems in more detail, since associated applications may be designed to share more confidential information with other road participants or roadside units than other communicating systems. One example was already mentioned in section 5.1, where the researchers of [11] considered the transmission of an additional state variable to improve their current motion object tracking algorithm. This variable was intended to contain different driver distraction states like answering phone calls or writing text messages. Such information may be used for legal prosecution and therefore may not meet the desired public acceptance. Thus, cooperative systems will have to weight the kind of information that can be shared according to the users' privacy that may be exploited.

6.3 Public Acceptance

Another important factor for establishing future cooperative systems is public acceptance. Newer technologies and technologies that dramatically change the driving experience are new to consumers and can have the potential to raise public acceptance issues. Examples are crash avoidance systems in general and V2V communication in particular. To achieve a state of public acceptance, the extend to which the public understands and embraces the benefits of these systems will need to compensate their risks. Examples for V2V applications that might be important for consumer acceptance are technologies that provide safety, security from new forms of cyber-attacks, reasonable cost increases and privacy protection. Instead of using such systems, it is also important for the customers to understand how these systems work. In addition to individual acceptance, industry acceptance and cooperation may be equally important for supporting the deployment of V2V technologies [10].

7. CONCLUSION

In this paper, we investigated cooperative driving as an approach for future applications that aim for increased road safety, traffic efficiency and comfort. These applications can make use of three different types of cooperation for sharing information.

Driver-driver cooperation systems allow drivers to express their intentions and feelings to other drivers. Such systems can be using holographic laser projections for displaying virtual messages on the road or the car surface, flexible OLED and LED glass-like displays for designing the car surface, LED taillights and devices that are able to display instant messages and warnings to other drivers, as well as flexible displays and screen displays.

Car-car cooperation systems are based on wireless technologies, such as V2I and V2V communication. Such V2I and V2V systems enable ITS applications that automatically send data between the communicating parties in order to provide three main services. Road safety can be achieved by collision avoidance systems, road sign notifications and incident management systems. Applications for traffic efficiency can be divided into traffic management systems and monitoring applications. For increased comfort, contextual and entertainment applications can be used to support the drivers with additional information or multimedia.

We further investigated the potential of driver-passenger cooperation that has been confirmed by several ethnographic studies. Therefore, we considered common ground as a major factor for successful human communication and collaboration. The execution of tasks by passengers led to an enhanced feeling of control for both drivers and passengers. In shared tasks, shared discussions can increase the feeling of control for the driver, even if the passenger is mainly performing. These results confirm the approach to provide passengers with more information than the driver, while the driver has an overview about the current status. Social factors are crucial for driver-passenger collaboration. We pointed out the impact of group differences, social roles and relationships among driver-passenger pairs. Less experienced teams were more explicit in their roles as drivers or passengers and close relationships led to more assistance. Teams that shared more common knowledge adapted their task roles, while teams with more shared knowledge adapted their social roles. Child passengers should also be taken into account when designing in-car interaction interfaces. Such interfaces can be touchscreens, free-hand pointing systems or gaze-visualization systems.

In conclusion, cooperative driving is a promising area of research for future applications. It has the possibility to combine new technologies in communications and in-car interfaces with the human ability of problem-solving for more safe and efficient driving. Nevertheless, some topics like cooperation with back-passengers or other road participants (pedestrians, cyclists), privacy issues, public acceptance and driver distraction require further research. Since Maurer et al. [17] and Rümelin et al. [20] announced to improve their pointing and gaze-visualization technologies, future interaction inside vehicles may significantly decrease the cognitive load for the driver. In addition, with the setup of VANETs and the transmission of (extended) vehicle states [11], vehicles in the future might be able to communicate about us by sending messages like warnings, hints, prompts and reacting with appropriate responses in a way that save lives.

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Traffic Flow Optimization via Connected Cars

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ABSTRACT

Traffic congestion is an increasingly factor in today's traffic systems. As current traffic information system can only provide a coarse overview over the current traffic situation, the newly emerged technology of Connected Vehicles and its applications to traffic flow optimization is investigated. Vehicular ad-hoc networks and their characteristics are briefly described followed by 6 different traffic optimization techniques, which aim to improve transport statistics such as flow rate, travel times and road safety at different types of granularity.

Keywords

Intelligent Transportation Systems (ITS), Connected Vehicles, V2X, Traffic Flow, Advanced traveler information system (ATIS)

1. INTRODUCTION

According to the 2012 Urban Mobility Report of the Texas A&M Transportation Institute[13] consisting of data from 498 U.S. urban areas, traffic congestion is the major problem for mobility in urban areas with an estimate of 2.9 billion gallons of wasted fuel, 5.5 billion hours more travel time and an assumed cost of \$121 billion. In the EU traffic congestion accounts for an estimate of 80 billion euros a year, according to the European transport policy white paper for 2010[1]. In order to solve traffic related problems the Federal Highway Administration in the U.S. proposed and defined three general tactics[16]:

- Work on current capacity of roads and extend them.
- Extension of alternative transportation that require less resources (e.g. non-automotive transport).
- More efficient using of current capacities of cities and roads.

Most of the time it is not possible to extend the road network with additional or bigger streets because of the limited

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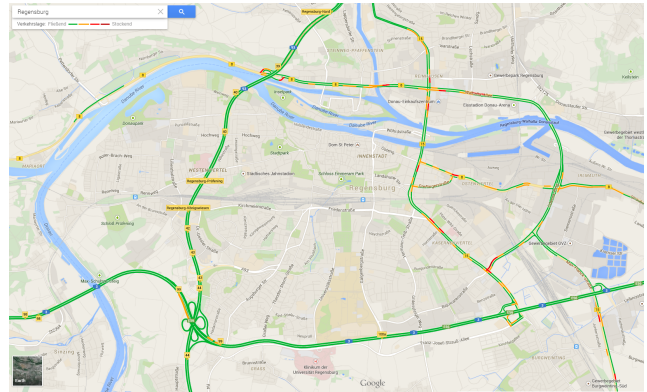


Figure 1: Google maps traffic overlay

available space. Thus the focus is mainly set on the more efficient usage of the current capacities.

Intelligent Transportation Systems (ITS) apply information and communication technologies to provide innovative services relating to different modes of transport and traffic management for users to be better informed and make safer, more coordinated and efficient use of the current transport networks.

Many modern driver assistance systems are already based on an internet connection between cars and a back-end server system. One example for these driver assistance systems is the representation of current traffic information within vehicle navigation systems (e.g. BMW Real Time Traffic Information¹) or through the web browser (e.g. Google maps traffic overlay) as seen in Figure 1. These mentioned traffic information systems lack the ability to control the traffic on a finer granularity as they can only provide an overview over the current traffic situation.

These deficits can be counteracted with Connected Vehicles technology (CV), a relatively new field of study in Intelligent Transportation Systems. Vehicles communicate over different protocols with other vehicles (V2V), infrastructures (V2I) or both (V2X) to form a vehicular ad-hoc network (VANET), where detailed traffic information can be exchanged timely and efficiently. These allow for new types of transport applications ranging from traffic safety systems to infotainment systems. This work focuses on the optimization of traffic flow and congestion relief applications using

¹<http://www.bmw.de/de/topics/faszination-bmw/connecteddrive/services-apps/rtti.html>

the mentioned V2X technology, by giving an overview over implementations for different types of techniques. At first the CV technology and its components are outlined. Then different techniques for traffic flow optimization are explained, followed by a brief discussion of the applications and their usability.

2. CONNECTED VEHICLES

Vehicular ad-hoc networks are an application of mobile ad-hoc networks but have their own distinct characteristics which can be summarized as[3]:

High mobility The nodes in VANETs are usually moving at high speeds in "random" directions, but are constrained by the road topology and layout.

Changing network topology Due to the high mobility and speeds of vehicles the network topology tends to change frequently. The lifetime of the link between vehicles is affected by the radio communication range and the direction of the vehicles. These rapid changes in link connectivity cause the effective network diameter to be small, while many paths are disconnected before they can be utilized.

Variable network density The network density in VANET varies depending on the traffic density, which can be very high in the case of a traffic jam or low, as in suburban traffic.

Power constraints Compared to mobile ad-hoc networks, the power in VANET is not critical because vehicles have the ability to provide continuous power via the long life battery.

High computational ability Vehicles can be equipped with a sufficient number of sensors and computational resources such as processors, large memory capacity, advanced antenna technology and GPS. This increases the computational power of the nodes of a VANET which help obtaining reliable wireless communication and accurate information of its position, speed and direction.

To support Intelligent Transportation Systems the IEEE 1609 Family of Standards for Wireless Access in Vehicular Environments (WAVE) have been created. The WAVE standards define an architecture and complementary standardized set of protocols, services and interfaces that collectively enable secure wireless V2X communication. WAVE relies on the IEEE 802.11p standard for the lower physical (PHY) and medium access control (MAC) layers. 802.11p defines a way to exchange data without the need to establish a basic service set as in the 802.11 standards to cope with the high mobility and short link lifetimes between vehicles or infrastructures. Therefore authentication and data confidentiality have to be provided by the upper layers (e.g IEEE 1609). 802.11p uses the 5.9GHz band.

Using these communication standards it is then possible to reliably exchange messages between vehicles and infrastructures which is the foundation for intelligent traffic management systems.

3. TRAFFIC FLOW OPTIMIZATION

The main parameters of traffic flow have to be quantified in order to evaluate and compare different aspects of traffic flow. Including others these parameters consist of speed, flow, density, mean speed, and headway. **Flow** describes the rate at which vehicles pass a fixed point in a time interval. **Density** is the concentration of vehicles over a fixed length of a roadway. **Mean speed** is divided into **time mean speed**, which is the arithmetic mean of vehicle speeds passing a point, and **space mean speed**, which is the harmonic mean of speeds passing a point during a period of time. The **headway** is the time that elapses between a vehicle and a following vehicle passing a certain point.

Traffic flow can be analyzed at three different levels of granularity. Microscopic traffic flow examines individual vehicles and their properties like speed and position. Macroscopic scale investigates traffic flow characteristics such as density, flow and mean speed on a traffic stream. Mesoscopic models allow the study of large areas with applications such as congestion relief through alternative routes.

As a result the types of traffic flow optimization can be applied to different types of granularity.

Microscopic optimizations focus on improving the mean travel time for single vehicles by finding optimal vehicle actions such as finding the optimal lane or adjusting the speed to decrease the amount of brakes/accelerations. These optimizations are discussed in chapter 3.1

The goal of macroscopic optimizations is the increase of throughput and reduced travel times for a given traffic stream. As intersections are the main delay of traffic flows in urban areas the focus is set on uncontrolled and traffic light controlled crossing. These optimizations are discussed in section 3.2.

One application to mesoscopic optimizations is the search for optimal routes through congested traffic which is discussed in section 3.3.

3.1 Microscopic Traffic Flow Optimizations

The finest granularity of traffic flow optimizations targets single vehicles and their driving activities. Two different techniques to improve the traffic flow are investigated in this section. Firstly the collaborative interaction to find the optimal driving lane in a highway scenario is described in section 3.1.1. The second technique handles the coordinated approach to a lane drop, which is discussed in section 3.1.2.

3.1.1 Optimal Lane Selection

One driving behavior that can heavily interrupt the flow of traffic are lane changes. The need for lane changes derives from the inequality of desired driving speeds and mandatory lane changes like lane drops or exiting the current road. These lane changes may disrupt the traffic by aggressive maneuvers (i.e. cutting into small gaps) and produce shock wave effects which expand to further upstream vehicles. Jin et al.[7] propose a cooperative real-time lane selection algorithm named Optimal Lane Selection (OLS) in which connected vehicles share information to improve the system-wide operation of traffic. Well-coordinated lane changes can help maintain desired speeds and minimize shock wave impacts.

This is achieved by calculating the optimal lane target for each vehicle based on its location, speed, lane and desired

Table 1: Comparison of results on mean travel times (in seconds) between OLS and non OLS scenarios and different vehicle to capacity ratios

V/C	Scenarios		% Improvement
	NLS Based	OLS Based	
0.5	113.0	112.4	0.57
0.6	113.2	110.7	2.25
0.7	114.1	109.8	3.79
0.8	114.3	110.5	3.35
0.95	118.4	115.3	2.67

driving speed. These parameters are transmitted from each car to a roadside communication unit (RSU) which can exchange these real-time information within a certain range. The RSU calculates the optimal lane for each vehicle and sends its optimal lane advice. The drivers then follow the advice by adjusting their lane in order to decrease the overall amount of needed lane changes afterwards.

Jin et al.[7] tested the algorithm on a simulated 3-way highway of 2000 m length with one roadside communication unit with 300 meters communication range and connected vehicles with a speed of 50 mp/h using the microscopic simulation tool SUMO[9]. In the simulation, the mean travel times of different road congestion levels (50%, 60%, ... 100%) with and without their proposed algorithm were compared. Besides the mean travel times, the reduction of energy consumption and the emission of pollutants were simulated (CO, HC, NOx, PM2.5) with MOVES[15] (Motor Vehicle Emission Simulator).

Their simulation results can be seen in Table 1. The simulated mean travel time was reduced by 0,57% at 50% road congestion, with up to 3.79% improvement (118.4 s to 115.3 s) at 70% of the maximum density. At higher congestion levels the vehicles could not always find the needed space in their suggested lanes, which reduces the success rate of a lane change. At a level of 0.95% of the maximum capacity of the road, an improvement of 2.67% in mean travel times was still detected.

Similar to the travel times the reduction in pollutants peaked at 70% road congestion. Energy consumption and CO2 emissions are reduced by around 2.2% while CO and HC emissions are reduced by up to 17%. Jin et al. demonstrate how connected vehicles can improve the traffic flow through microscopic actions like well coordinated lane changes. However they do not take into account different penetration rates of interconnected vehicles, which could be useful for the transition years between current and next generation cars. They only simulate their algorithm on a 3-way highway with relatively low speed limit (50 mp/h) and equally treated vehicles. Different simulation runs with trucks, or 2-way highways and varying penetration rates of V2X technology could have given more insights into the usefulness of this approach.

3.1.2 Lane drop merging assistance

The second microscopic optimization next to optimal lane changes is the coordinated approach to a lane drop. Schuhmacher et al.[14] provide a Merging assistance algorithm which advises drivers on the individual speed limits and merging positions ahead of a lane drop. The current traffic control strategies in front of lane drop consist of

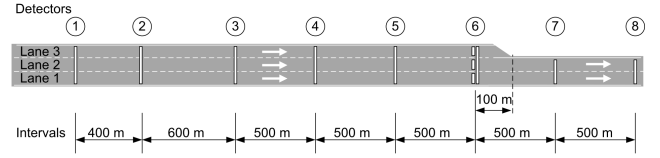


Figure 2: Reference scenario map with distance intervals

Gradual speed limit reduction Usually used at highway lane drops. The speed limit in front of a lane merge is decreased in several stages to achieve a harmonization of traffic with decreased frictions between vehicles and an increased traffic safety.

Late merge strategy Drivers are advised to stay in their lane up to the lane drop. This allows the usage of all available lanes until the lane drop. This strategy performs particularly well with heavily congested traffic and low speeds.

Early merge strategy Warning signs indicating the lane drop are placed far ahead encouraging the drivers to switch the lane early. This reduces forced merges in the vicinity of the drop. This strategy is preferred at low traffic demands with higher speeds.

Schuhmacher et al. present a method which reduces traffic jams and increases the capacity in front of a lane drop by switching to a more effective strategy with the usage of V2X communication for controlled merging procedures. The reference scenario is based on an empiric study[4] of a freeway lane drop between Heathrow and London, where the passing lane of a 3-way highway transitions to two lanes. The length of the sections and the placement of traffic detectors can be seen in Figure 2 which was taken from [14].

Their approach uses a Road-side Unit (RSU) 350 m in front of the lane drop (between detector 5 and 6 of Figure 2) and On-board units (OBUs) in the vehicles to allow the communication of traffic control messages. The communication parameters are chosen with respect to the IEEE 802.11 family of standards and the 802.11p amendment for Wireless Access in Vehicular Environments (WAVE). Specifically the RSU and OBUs communication range is set to 500 meters. The OBUs are aware of their position (e.g. through GPS) and can not only receive messages from the RSU but also forward messages to other OBUs to achieve a multi-hop communication.

The implementation of the merging assistance is a combination of dynamic merge strategies and dynamic gradual speed limits. The main part of the merging assistance algorithm is implemented in the RSU. It analyzes the current traffic conditions by monitoring the time mean speeds of vehicles at the detectors and transmitting traffic control messages to the OBUs accordingly. These messages consist of the gradual speed limit, the merging positions (e.g. at which point in front of the lane drop the lane switch should occur) and additional messages as "Stay in Lane" for upstream vehicles and special "Do Not Pass" messages for heavy vehicles after the merge point, which reduces frictions during the merge procedure as no heavy vehicles are permitted on the lane being merged to.

The algorithm works in different stages based on the time

mean speed TMS of vehicles at detectors 5 and 6 (the two in front of the lane drop). The TMS are re-evaluated every 5 seconds. v_5 and v_6 describe the TMS of detector 5 and 6 respectively. DEM stands for Dynamic Early Merge, DLM for Dynamic Late Merge.

DEM Stage 1 $v_6 > 80\text{km/h}$

The traffic directly in front of the lane drop (at detector 6) is flowing freely with speeds over 80 km/h. The merge point is set to 400 m in front of the lane drop and a no passing zone for heavy vehicles 400 m ahead of the lane drop is established.

DEM Stage 2 $v_6 \leq 80\text{km/h}$ and $v_5 > 80\text{km/h}$

The TMS reduction at detector 6 indicates increasing traffic density resulting in merging problems and braking vehicles. To counteract the merging point is shifted 400m upstream to a distance of 800 m to the lane drop. Ahead of it a "Stay in Lane" zone is established. After it the "Do not pass" rule for heavy vehicles apply. In addition the gradual speed limit reduction is applied to 110, 100, 90 km/h at distances of 2500, 2000, 1000 m ahead of the lane drop, respectively.

DEM Stage 3 $60\text{km/h} < v_6 \leq 80\text{km/h}$

and $v_5 \leq 80\text{km/h}$

The slightly congested area with decreased TMS between 60 and 80 km/h extended up to detector 5. The distance of the merging point and the "Stay in Lane" zone ahead of it is set to 1300 m. Heavy vehicles are not allowed to pass after the merge point. Gradual speed limit is at 100/90/80 km/h at 2500, 2000, 1000 m.

DLM $v_6 \leq 60\text{km/h}$

Under 60 km/h TMS the traffic condition is assumed to be heavily congested. At this stage it is more efficient to use all lanes as long as possible to maximize the capacity. The merge point is shifted to 100 m ahead of the lane drop, with the "Stay in Lane" and "Do not pass" zones adjusted accordingly. The speed limits are reduced to 90,70,60 km/h at 2500, 2000, 1000 m, respectively.

Schuhmacher et al. simulated their algorithm and the reference scenario with the AIMSUN² traffic simulator. The maximum capacity of a lane was set to 2000 vehicles per hour. The proportion of heavy vehicles was set to 15% and the maximum allowed speed is 112 km/h (70 mp/h). The traffic demand is increased in three stages every 30 minutes. Firstly 3000 veh/h, which is far under the capacity of 4000 veh/h of the reference scenario. Secondly the demand is increased to 3800 veh/h representing dense traffic close to the maximum capacity. And lastly 4600 veh/h which should result in heavy congestion.

In the first simulation run every vehicle is equipped with an OBU and every vehicle obeys the traffic control messages. Compared to a simulation run without the usage of the merging assistance significant traffic improvements were only observed at the highest density of 4600 veh/h. The mean travel time decreased from around 112 sec/km to around 70 sec/km at the end of the simulation run.

Figure 3 taken from [14], illustrates the travel time improvements under different penetration rates of equipped vehicles.

²http://www.aimsun.com/wp/?page_id=21

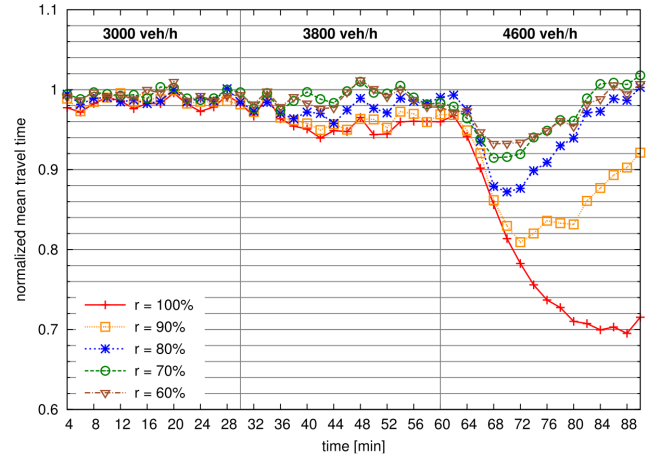


Figure 3: Mean flow rates for different penetration rates

Next to no improvements where noticeable in low traffic demands (0-30 min.) for each penetration rate. Under higher traffic demands of 3800 veh/h a slight decrease in travel time can be observed. After the beginning of high traffic demand (4600 veh/h, 60-90 min.) the travel time for a ratio of 100% equipped vehicles decreased by up to 30%. With a lower ratio of equipped vehicles the mean travel time still decreases by up to 7% if only 60% of vehicles are equipped. It can be observed that except for 100% penetration rate, a traffic breakdown is encountered (e.g. at minute 68 for 80% penetration rate). The merging assistance application can however help to delay the traffic breakdown and thereby is able to absorb temporary traffic peaks.

Schuhmacher et al. present a valid approach to traffic flow optimization by implementing an abstract algorithm for microscopic driver recommendations such as the merging position and adaptive speed limits. Their multi-hop message forwarding communication model can also be extended to eliminate the need of a road side unit. This could be especially helpful for unpredictable lane drops (e.g. accident on lane).

3.2 Macroscopic Optimization

In contrast to the single vehicle, microscopic optimizations of section 3.1, this section focuses on traffic improvements on whole traffic streams. Applications can vary from intelligent traffic lights to intelligent speed limits and speed recommendations at uncontrolled intersections to harmonize the traffic flow.

Intersections belong to the most important components of urban road networks with high accident rates and low efficiency in terms of vehicle throughput. Cooperative vehicle infrastructure systems (CVIS) focus on the improvement of safety and flow rates using Vehicle to Infrastructure (V2I) and Vehicle to Vehicle (V2V) communication. This section describes one approach for uncontrolled and one for traffic light controlled intersections.

3.2.1 Cooperative optimization at an uncontrolled intersection

Uncontrolled intersections are the most common types in

Traffic Flow (veh/h)	Unsignalized Cooperative Optimization Control Method				Actuated Control Method			
	Average delay (s)	Average stops	Average queue length (m)	Average speed (km/h)	Average delay (s)	Average stops	Average queue length (m)	Average speed (km/h)
1500	3.79	0.46	1.62	53.70	7.98	0.54	7.47	48.46
3000	6.11	0.47	4.79	63.70	9.31	0.59	11.22	57.42
4500	9.00	0.56	12.04	63.98	18.20	0.77	31.36	53.84
6000	8.68	0.61	18.80	61.86	23.72	0.94	35.37	30.01
7500	19.48	0.87	45.40	40.13	27.50	0.96	52.76	28.99

Figure 4: Unsignalized cooperative optimization simulation results

urban road networks. CVIS are able to get the real-time individual vehicle states and allow the exchange of individual traffic control messages. This can be used to manipulate individual vehicles trajectories to guide them on a non colliding path through the crossing as proposed by Lee et al.[10]. While this approach can be used for fully autonomous vehicles, it induces problems for self-driven vehicles without accurately driven paths.

Cai et al.[5] propose a method where drivers are guided by a cooperative negotiated "right of way" information on an installed On-Board Unit (OBU) coupled with speed guidance to preemptively solve conflicts. This reduces the intersections average vehicle delay, number of stops, length of the queue and increases the average speed of vehicles.

Vehicles approaching the intersection transmit in small intervals (0.5 s) their current position, speed and desired route to the intersection's traffic controller. For each vehicle the road-side unit calculates an optimal speed, under the assumption that a minimum and maximum speed and a certain acceleration/deceleration rate exists and a minimum headway needs to be retained. These speed guidances are then sent to the OBUs in the vehicles.

Cai et al. simulated their approach against a non cooperative intersection. Their results are shown in Figure 4. The queue length, amount of stops and average delay were decreased while increasing the average speeds of vehicles under all traffic conditions.

The results were however achieved under strong assumptions. First of all the interference of pedestrians and bicycles is not considered, which are a strong factor in urban areas. Secondly Cai et al. focus only on isolated intersections without left and right turns or the influence of adjacent intersections. And lastly a penetration rate of connected vehicles of 100% is assumed. This alleviates the results strongly.

3.2.2 Adaptive Traffic Lights

The message exchange with an infrastructure unit can also be extended to traffic light controlled intersections using the same technique as Cai et al. to convey the state of physical traffic lights directly to a display at the driver. Another possibility to optimize flow is communication with crossing pedestrians, especially in case of push-to-cross lights[6]. These stand in contrast to computer vision traffic signal detection and recognition, which can be error prone under difficult lighting and weather conditions. Olaverri-Monreal et al.[12] present an in-vehicular traffic light implementation with the focus on the design aspects of a Human Machine Interface (HMI). In a driving simulator the design aspects are evaluated regarding the driving performance and accep-

tance of the novel virtual traffic lights.

The virtual traffic lights have to take care of the following characteristics:

Design The design components size, shape, color, composition, lighting and contrast have to provide a clear and easy to understand message. A Head Up Display (HUD) was chosen to display the few required elements (distance to traffic light, traffic light state).

Placement and operation To avoid a road vision obstruction in the central field of view, the images were projected 2.5 to 4 meter away from the drivers eyes in the lateral field of view.

Maintenance and uniformity The maintenance of the system is similar to other electronic devices in the vehicle. The installation of the sensors and the V2V communications allows similar functioning of all the traffic lights virtually displayed.

Color code Luminance requirements need to be followed to ensure that the projected images are visible in all weather conditions.

Signal timing Vehicles are detected at traffic lights, which is used to determine priority and traffic light phase duration. The virtual traffic light system uses a robust detection system based on beaconing and location tables through a geographic routing protocol. Additionally traffic light warnings alert the driver if a traffic violation occurs. Each vehicle maintains an internal database with information about intersections where a virtual traffic light can be created. If a vehicle approaches a intersections and does not detect a virtual traffic light, they consult their location table and the road map topology to infer crossing conflicts and then create a collaborative virtual traffic light. This requires lane-level accuracy on the location tables and digital road maps with lane-level information topology.

Two in vehicular traffic light designs can be seen in Figure 5. Design A1 and B1 show a traffic light ahead warning with a label indicating the remaining distance. Design A2 and B2 show the driving priority through green or red colored arrows. Design B3 shows the driving permissions through a traffic light image. This design was then tested in an urban driving simulator. An in-vehicle view of a virtual traffic light is shown in Figure 6. To determine the driving performances Olaverri-Monreal et al. focused on speed metrics and brake activity, because the ability to adapt to new road circumstances such as traffic signs or intersections can be

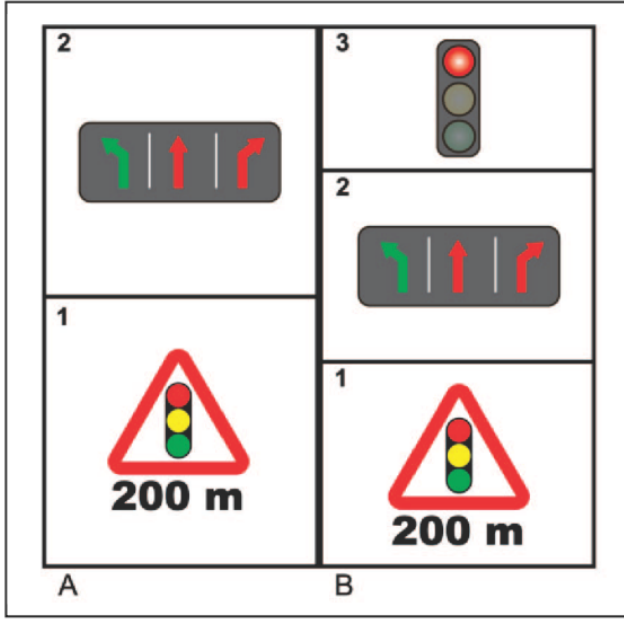


Figure 5: Different virtual traffic light designs



Figure 6: In-vehicle view of the virtual traffic light projected on the windshield

observed in the variation of speed.

From the 10 tested persons 9 declared the presented information as clear and intuitive and was not considered distracting or unsafe. The brake activity and deceleration rate differed only slightly from the simulation run with the physical traffic lights. In general the test group adapted well to the shift from physical to virtual traffic lights

3.2.3 Adaptive traffic light control for priority vehicles

Intelligent traffic lights can further be extended to not only improve the traffic flow at intersections based on demand, but to also control the traffic flow based on different parameters such as the presence of emergency vehicles approaching this intersection. Top priority is given to emergency vehicles and their demanded lanes. This enables priority vehicles to drastically reduce their travel time to destination especially in heavily congested areas.

Ahmed et al.[2] compare two different scheduling schemes for intelligent traffic lights which receive the following information from the vehicles.

- Total number of vehicles within a lane.
- Vehicle type (i.e. priority or non priority)
- Total travel time of a vehicle
- Initial assigned deadline of each vehicle

The first scheme is a static Fixed Priority (FP) algorithm, where vehicles types are assigned to different priority levels.

- High Priority Vehicles (HV)
- Medium or Moderate Priority Vehicles (MV)
- Low Priority Vehicles (LV)
- Nil Priority Vehicles (NV)

The static algorithm firstly serves all edges with HV vehicles present, followed by MV, LV and lastly NV type vehicles.

The second algorithm proposed by Ahmed et al. also classifies vehicles into priority classes, but uses the deadlines of processes to prioritize vehicles. HV vehicles are assigned lower deadlines than MV vehicles. LV type vehicles get intermediate deadlines and NV type vehicles obtain the highest deadline. The algorithm then serves the intersection edge which has the vehicle with the lowest deadline first. This Earliest Deadline First (EDF) approach is a dynamic implementation as it makes its decision based on the dynamic deadlines of priority vehicles.

Ahmed et al. simulated the two scheduling schemes and the standard static traffic lights using the simulator SUMO[9]. They used a complex network as shown in Figure 7 taken from [2]. Different traffic intensities were simulated and the percentage of priority vehicles was set to 14% of the total traffic. In their results seen in Figure 8 it can be seen that both the adaptive traffic light implementation outperform the typical traffic lights in terms of mean waiting steps, mean trip time and mean speed for priority vehicles. It has to be noted that the gain for priority vehicles is achieved at the cost of no and low priority vehicles. The amount of mean waiting steps (Figure 8a)) are reduced by up to 50% compared to the static traffic lights. The mean trip

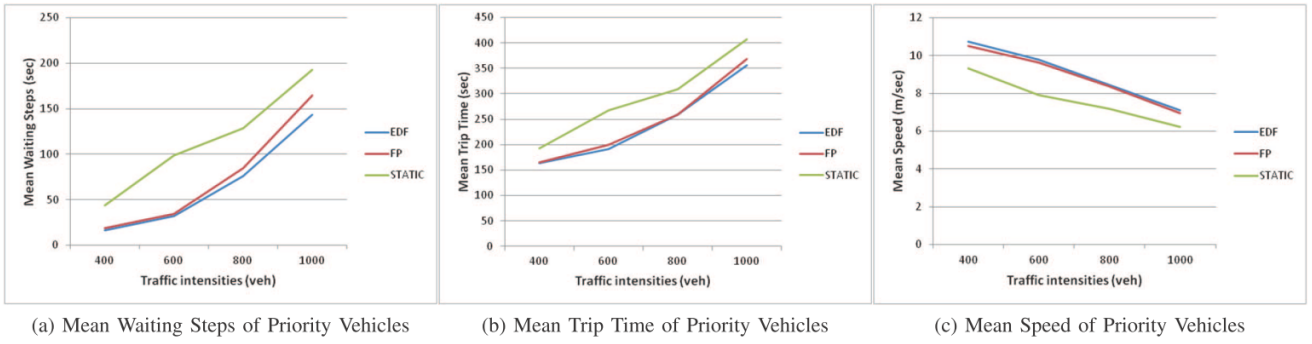


Figure 8: Simulation results for a network of complex intersections using FP, EDF and static scheduler

time and mean speed parameters of priority vehicles are also greatly improved using EDF and FP schedulers. Also the EDF scheduler performs slightly better than the Fixed Priority implementation.

3.3 Mesoscopic Optimization

The previously mentioned optimizations had in common that the vehicles were directly in the communication range of a single infrastructure unit (e.g. one RSU at 3.1.1, the intersection control at 3.2.1 or the intelligent traffic lights at 3.2.3). For mesoscopic models, where the investigated area exceeds this communication range, a reliable and efficient method is required to exchange traffic information timely with as much vehicles as possible. As it is assumed that all V2X enabled vehicles have the ability to share their positional data (e.g. through GPS) current communication models favor Geocast over Cluster-Based or Broadcasting models. Kaiwartya et al.[8] provide an overview and classify the current Geocast routing protocols.

With reliable and timely traffic information over large areas it is possible to identify and avoid congested roadways. Finding the fastest vehicular route to a destination has several benefits, such as reducing traffic congestion, fuel consumption and traffic emissions.

Noori et al.[11] investigated a large scale V2X enabled urban area and developed a dynamic route planning algorithm using V2X communication and real-time traffic information. To achieve this task their proposed methods consists of the following requirements:

- Every road segment has a Road-side-unit at the start and at the end of the segment.
- Every road segment has a Ideal Traveling Time (ITT). The ITT is the time required for a car to go from the beginning of the street to the end of the street under ideal circumstances (when the road is empty and with the maximum allowed speed). This can be calculated via the length of the road segment and the allowed maximum speed.
- Every road segment has a Current Traveling Time (CTT). The CTT is calculated by building the average over the traveling time for the 5 last recent cars in the street. When a vehicle enters a road segment, the RSU transmits the current time and date to the vehicle. The car holds this message and periodically

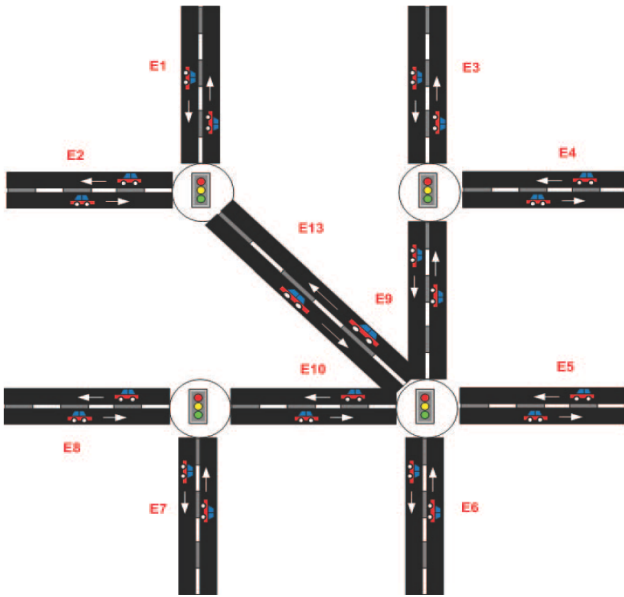


Figure 7: Network containing complex intersections

broadcasts this message until it arrives at the end of the segment. The RSU at the end point calculates the traveling time by subtracting the real time and the starting time for this car.

- The CTT for every road segment is broadcasted and made available to all vehicles in the urban area.
- If a RSU did not receive any data or the time of the last transmission is greater than the ITT, the RSU assumes that there is no car in the street and assigns a CTT equal to the ITT of the segment.

With these requirements the road network forms a weighted graph, with the current traveling time labeling the weight for the edges. The search for the fastest route is then a classic shortest path problem. Noori et al. have chosen the A* algorithm to find the shortest path with the CTT as their cost function. To allow a dynamic route planning this shortest path is re-evaluated after every simulation step with the newest broadcasted CTTs. These changes to the car's route happen until the car arrives at the destination.

Noori et al. imported a realistic vehicle traffic and traffic related information model of the city of Cologne from the TAPAS-Cologne project from the German Aerospace Center, Institute of Transportation System and OpenStreetMap data covering approximately an area of 400 km^2 into the traffic simulator SUMO. This dataset contains car traffic from 24 hours consisting of 700.000 individual vehicle trips. Their simulation scenario investigates the impact of the route planning algorithm at the peak traffic demand between 6 a.m. till 8 a.m. The city map is divided into several zones based on the traffic status. After that 20 different zones are selected and one vehicle is added to each zone with a traveling distance of 5 km.

Three simulations are done to observe the vehicles traveling time:

- In the first run, only the mentioned 20 vehicles travel the city of Cologne without any traffic lights or other vehicles to measure the ideal traveling time.
- The real traffic of Cologne is simulated with over 250.000 individual vehicles with the 20 vehicles included, in order to simulate the vehicles travel time without the route planning algorithm.
- Lastly the dynamic route planning is enabled for the 20 vehicles and their travel time is observed.

Figure 9 illustrates the simulated travel times for the 20 selected vehicles. A reduction of 41.12% in average travel time in low traffic areas (car number 1 - 7), 52,84% for medium traffic (car number 7 - 14) and 60,79% for high traffic areas (car number 14-20) compared to the real traffic of Cologne was achieved in the simulation run. These results show that under perfect circumstances (traffic information is instantaneously broadcasted, all vehicles receive traffic information, every road segment is V2X equipped) the travel time in dense urban areas can be drastically reduced for a few selected cars. The impacts when large fleets of dynamically routed cars use this system are not discussed.

The obtained results are likewise only achievable in simulation runs, because the assumption that every single road segment is equipped with a RSU at the start and end can realistically not be achieved in the near future.

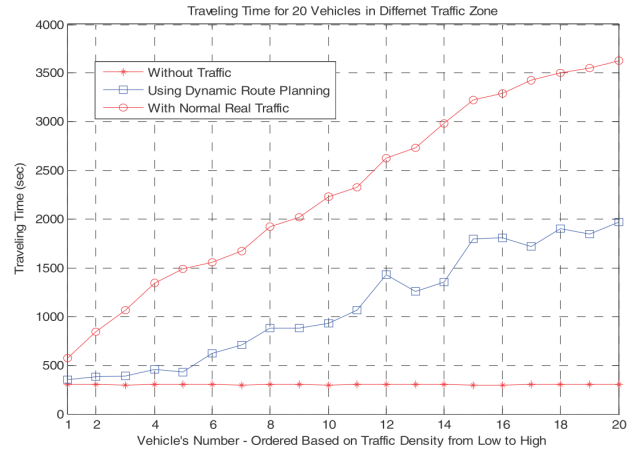


Figure 9: Travel time of vehicles based in different traffic densities

4. DISCUSSION

The research in ITS is still in its early stages. Foundations for large scale VANETs such as routing protocols and security concerns need to be ensured before the focus can be shifted to more complex traffic safety and traffic management systems. Secondly applications to traffic flow optimizations can currently only be simulated, which gives a certain blur to the expressiveness of the results. Still the provided techniques forecast the immense opportunities that Connected Vehicles can give to traffic safety and traffic efficiency.

Some topics that were not addressed in the discussed applications but need to be evaluated is firstly the presence of traffic participants such as bicycles and pedestrians. Especially the approach to in-vehicular traffic lights does not conform well with non-motorized and unconnected road members. An exemplary solution, with the increasing possession of smart phones, could be to involve mobile data into the creation of traffic light control messages.

Lastly it needs to be considered how well traffic control advices are accepted and carried out. For example the question arises how well the optimal lane change algorithm performs with single individuals ignoring or even acting oppositely to the advices.

5. CONCLUSION

This work provides an overview over some example applications to traffic flow optimization using connected vehicles. These applications were divided into different classes based on the type of optimization. For each granularity one or more systems were examined and their results were presented. The results indicate that V2X communication allows for useful improvements to the current transportation system with benefits for road capacity, travel times, flow rates and ultimately fuel consumption and emission of pollutants.

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