Cooperative Home Light:
Assessment of a Security Function for the Automotive Field

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Abstract—Crime and feeling of security are omnipresent and can be influenced by lighting conditions. However, lighting improvements are generally concentrated on street lighting. Meanwhile, a vast variety of new technologies, including innovative lighting systems and connected mobility, are entering into the automotive field. Hence, opportunities are not limited only to provide traffic improvements, entertainment features or driver assistance functions but also measures to tackle (vehicle-related) crime and to increase feeling of security. In this paper, we suggest a security function, namely the cooperative home light (CHL), which makes use of new technologies and has the potential to tackle crime as well as to increase drivers' feeling of security. We also provide an overview of an implementation. However, because of the underlying challenges, the main focus of this paper is to assess the CHL. Therefore, we introduce our three-steps approach consisting of a transfer of related work, a customer survey and results from our proprietary simulation environment in order to assess the CHL.

Keywords—Security functions; Tangibility of security; Vehicle-to-X communication; Automotive lighting.

I. INTRODUCTION

Crime and fear of crime are omnipresent in our society, provoke personal injury, economic losses and reduce quality of life. Thereby, vehicle-related crime is a worldwide ongoing problem not respecting national borders and affecting everyone. Criminals usually adjust their skills to stay ahead of countermeasures. Therefore, continuous elaboration on security measures is a priority to challenge criminals.

Considering security within the automotive field, a lot of resources and effort are invested in two fields. The first field can be summarized to in-vehicle security, i.e., making electronic control units secure. The second field focuses on securing Vehicle-to-X (V2X) communication. Security, not only in the automotive field, is essential and forms the basis for reliable use cases. But the main drawback of security is that it is not tangible, especially not for customers. Therefore, the importance of security is mostly not appreciated, and sometimes even neglected until security measures get compromised.

Our daily life is increasingly dominated by new technologies. The vision of accident-free driving and the guarantee of our mobility leads to an increasing number of advanced driver assistance systems. Meanwhile, these systems have also penetrated to mid and even low class vehicles. Consequently, a multitude of sophisticated sensors and actuators are available in a wide range of vehicles. New technologies do not enter only into the automotive field but also into the consumer market at an even faster pace. Especially, smartphones play a growing role in our daily life and have become a constant companion. Thanks to V2X communication, our society, including mobility, becomes increasingly connected.

The aforementioned technologies are mainly used in academia and industry to elaborate on use cases in three categories considering the automotive field. The first category of use cases aims at improving traffic efficiency (e.g., reduce traffic jams), and thus, enhancing customers travelling experience and ecological friendliness. The second set of use cases aims at providing the driver and passengers with infotainment features. Reliable internet connection opens the door for social networks or even movies in the vehicle. Assistance functions form the last category, and are nowadays the main reason for the increasing penetration of technologies in the automotive field. Besides assisting the driver while driving, assistance functions mainly aim at reducing the number of accidents as well as their impact. The elaboration moves towards fully automated driving with zero accidents, and consequently no fatality.

Until now, existing countermeasures dealing with vehicle-related crime are mostly concentrated on the vehicle itself, and focus on physical target hardening. Therefore, they neither involve other vehicles, occupants and infrastructure nor do they make use of other sophisticated technologies.

To close the aforementioned gaps, we elaborate on a forth category of use cases, namely automotive security functions, which must not to be mixed up with safety functions. In our opinion, new technologies also provide the potential to develop use cases which fight vehicle-related crime, increase drivers' feeling of security as well as make security tangible, and thus, visible to customers.

The cooperative home light (CHL) is one possible security function. The CHL combines the opportunities of vehicles' advanced lighting systems, V2X communication and positioning technologies so that several vehicles cooperatively light the surrounding. This way, the CHL aims at extending the existing basic home light (BHL), which makes only use of the own vehicle to light the surrounding. In [1], we have outlined the idea for the CHL including a suggestion for effectiveness evaluation based on a proprietary simulation environment.

In this paper, we propose a possible realization of the CHL considering the underlying technologies. However, the main focus of this paper is not on the development of the CHL itself since, as we will see in the following sections, the underlying technologies are being widely elaborated in academia and industry. Instead, the main focus of this paper is on the assessment of the BHL and CHL as security functions. Therefore, we implemented a simulation environment, which was presented in [1], as well as conducted a customer study and made use of the opportunity to transfer related work. We further assessed whether the CHL provides an improvement of fighting crime and increasing persons' feeling of security compared to the BHL. Additionally, customers' satisfaction, and thus, the tangibility of security was investigated.

The remainder of the paper is structured as follows: Section II outlines the CHL including related work on the underlying technologies. Section III shows the implementation of our three-steps approach to assess the BHL and CHL. Section IV presents results of the assessment. Finally, the paper is concluded in Section V with open challenges for the CHL function.

II. DESIGN OF THE COOPERATIVE HOME LIGHT

Most vehicle manufacturer provide a so called coming / leaving home function, which is referred to in the remainder of this paper as basic home light (BHL). Of course, the functionality differs from manufacturer specific adjustments, but the basic idea is similar. When leaving the car, e.g., coming home, low beams, taillights and other available light sources keep on lighting (during darkness) for a specified period of time in order to light the driver the way "home". The duration can generally be adjusted by the vehicle owner. Referring to the leaving home light, the aforementioned light sources start lighting as soon as the driver remotely unlocks the vehicle.

The BHL has the drawback to be static. The lighting duration can only be adjusted in the vehicle and is independent of driver's position. Hence, if the duration is to short, the illumination turns off before the driver even reaches the vehicle. Furthermore, the vehicle turns on all light sources although some light sources are probably unnecessary since the driver approaches the vehicle from one direction.

Our idea is to extend the existing BHL by the opportunities of advanced sensors, sophisticated light systems and V2X communication. We suggest to use the opportunity that low beams can be moved vertically and horizontally to light driver's path to the vehicle, of course within the mechanical constraints of the beams. Additionally, only light sources directly influencing the illumination of the path are turned on so that energy consumption is reduced.

To realize the CHL, a bidirectional communication between the vehicle and a sophisticated key fob is assumed. The key fob is a smart device, such as a smartkey or smartphone, and must be in possession of the driver.

Furthermore, position estimation of the key relatively to the vehicle is necessary. Thereby, it is irrelevant whether the position is calculated by the key or by the vehicle
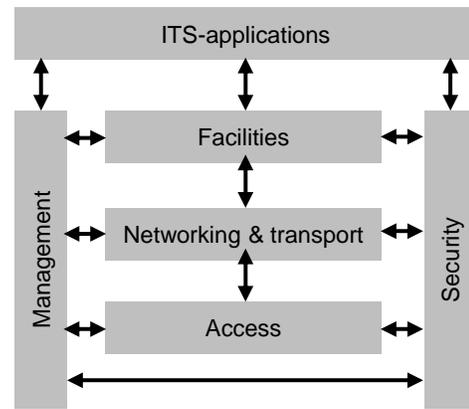

Fig. 1. Simplified communication architecture according to ETSI standardization [3]

since position data is continuously synchronized between both participating partners via bidirectional communication. The CHL is (de)activated similarly to the BHL, in case of "leaving home" as soon as the doors are remotely unlocked. Additionally, the two-way communication between the key and the vehicle as well as the position estimation of the key are triggered. The position of the key is updated at regular intervals.

Due to physical and mechanical constraints, the own vehicle is not always in a position to illuminate the path of the driver. Therefore, Vehicle-to-Vehicle (V2V) communication is used to include vehicles in the surrounding in order to enhance the illumination of driver's path. Since our vehicle is continuously aware of driver's position, it continuously requests participating vehicles to help lighting.

In the following, we suggest the underlying technologies and approaches needed for the realization of the CHL function.

A. Communication

To enable intelligent transport system (ITS) communication, efforts have been undertaken in the United States, Europe and Japan to establish a set of communication standards. However, these standards are not fully harmonized yet. Hence, we refer in the further course of this paper to the standardization of the European Telecommunications Standard Institute (ETSI) [2]. Figure 1 shows a simplified ETSI ITS communication architecture [3]. To be able to participate in ITS communication, ITS sub-systems need to implement an ITS station which follows the suggested architecture. Thereby, ITS sub-systems can be for example vehicle sub-systems or personal sub-systems, such as smartphones.

The three lower middle entities in Figure 1 cover the communication protocol stack. The security entity provides security services to the communication stack, the management entity and ITS-applications. The management entity is responsible to manage the interaction between entities. Thus, each ITS-application needs an application ID (AID), which is used to verify the right to exist. Depending on the AID, entire processes are accordingly managed by the management

entity within the stack. A registration authority is aimed to be established where each ITS-application needs to be registered and certified in order to receive an AID and to be considered in the communication [4], [5]. Consequently, the CHL has also to go through the registration process to become part of the ITS communication.

The architecture and the standardization process are still in progress, but the basis for V2V and Vehicle-to-Device (V2D) communication is defined and security mechanisms are considered.

1) V2D communication: We suggest the use of a smartphone or a smart key as mobile device. The essential requirement is to support an ITS station. Since the key only communicates with the own vehicle, the common IEEE 802.11a/b/g [6] standard is mostly suitable. The majority of smartphones is equipped with the necessary hardware. Also today's vehicles are equipped at times with hardware to support WiFi hotspots. Further, the access layer in the communication architecture [3] considers WiFi communication so that the basis for V2D communication is given.

2) V2V communication: In the course of the introduction of V2V communication into the market, vehicles will be equipped with onboard communication units (OCUs) to support V2V communication. Thereby, V2V communication is based on IEEE 802.11p according to [3]. To tackle the challenge of communication with other vehicles in order to support the cooperative lighting, we suggest two approaches.

- **Basic approach:** The host vehicle, which asks for lighting support, continuously broadcasts a message with the driver position, while other vehicles do not reply. This way the communication load is reduced and other vehicles do not reveal any information, such as position or lighting capabilities. However, the host vehicle is not able to control the scenario so that redundant lighting may occur and the host vehicle is uncertain whether the way is sufficiently lighted.

- **Sophisticated approach:** The host vehicle requests lighting support and willing vehicles reply by providing the host vehicle with their position information and lighting capabilities. This way, the host vehicle is able to create a map including the surrounding vehicles and to coordinate the lighting process by asking only relevant vehicles considering their lighting capabilities. Of course, this approach comes along with additional communication load and other vehicles need to reveal information, such as their position and lighting capabilities. However, the benefit is a more efficient and managed lighting process.

Independent of the cooperative lighting approach, the standardization process is mainly driven by the goal of introducing assistance applications as day one use cases. Therefore, ETSI defined two message types, the decentralized environmental notification message (DENM) [7] and cooperative awareness message (CAM) [8]. DENMs are event-triggered and transmitted to alert other users from specific traffic events. In contrast, the CAM is continuously broadcasted with a maximum time interval of 1 sec and minimum time interval of 100 ms to ITS stations located within a single hop distance to provide information of presence, position and other ITS station specific data. This way, ITS stations are aware of other stations in the neighborhood. Considering the sophisticated approach, CAM and DENM are not suitable to realize the CHL because not intended for bidirectional communication. So, implementing a tailored message type which supports the CHL is the most reasonable solution. However, considering the basic approach, the use of the CAM is suitable. The CAM is continuously broadcasted, contains necessary information, such as vehicle position, and provides the opportunity to be extended by optional containers including further data, such as driver position.

B. Positioning

First of all, the driver position, i.e., driver's position relative to the own vehicle, forms a fundamental part of the CHL. Additionally, each vehicle participating in cooperative lighting needs to be aware of its position. Thereby, a distinction between indoor and outdoor positioning is reasonable. Outdoors, a fallback to the Global Positioning System (GPS), where the precision varies depending on the surrounding conditions, is the first approach. Most vehicles and smartphones are equipped with appropriate GPS receivers. However, indoors (e.g., in parking facilities), GPS is not suitable because requires a clear line-of-sight to orbital satellites. Hence, additional solutions, which come along with the integration of an additional infrastructure, are needed.

1) Driver positioning: To overcome the lack of GPS indoors, ultra-wideband (UWB) and wireless LAN (WLAN) technologies are possible candidates. In the UWB approach, the token, which is in our case the smartphone, estimates the position based on the time difference of arrival (TDOA). Hence, ideally the own vehicle is equipped with several transceivers to estimate the position of the smartphone relative to the vehicle. But, transceivers can also be mounted within the facility. With the help of Vehicle-to-Infrastructure (V2I) communication, the facility could provide the position to the vehicle, which is able to recalculate driver's position. Several commercial solutions, such as Zebra's Dart [9] or Ubisense [10] exist and show the feasibility of this technology where precisions below 1m are achievable.

In the WLAN approach, the position is estimated with the help of the received signal strength. The feasibility has been shown in research systems, such as Microsoft RADAR [11], [12] and Horus [13], [14]. Ekahau [15] provides a commercial solution based on a tracking-assistant positioning system provided by Kontkanen et al. [16]. The WLAN technology makes position precisions possible within the lower one-digit meter range.

On the one hand, the UWB approach provides better position precision and is preferably used for customer products. On the other hand, this solution requires the

smartphone to be equipped with appropriate receiver hardware, while all smartphones support WLAN technology.

We also found attempts to use smartphones with its integrated sensors to estimate relative movements [17]–[19]. Hence, data fusion of relative and absolute position information has the potential to improve the overall position estimation significantly, independent on the technology for absolute positioning.

2) Vehicle positioning: Considering the CHL, vehicles do not move so that the position is stationary. Therefore, vehicles need to be aware of their last estimated parking position. Position estimation within facilities can be tackled similar to the estimation of driver position, described above. We also found other approaches in literature. Especially considering autonomous parking, research projects such as AIM [20], V-Charge [21] and Audi's automated parking pilot [22] (partly) address positioning challenges. In these projects, a similar approach is used, where the parking facility is equipped with sensors, such as LIDAR or cameras, in order to estimate free parking spots. Further, entering vehicles are provided with a digital map of the parking facility. Making use of this information, vehicles autonomously drive to a free parking spot, supported by on-board sensors, such as cameras, ultra-sonic and radar sensors. Thus, a parked vehicle is aware of its parking position within the facility.

C. Smart grids

A further challenge on the way towards the CHL is the power supply of involved vehicles. Today's common vehicles possess a battery with limited lifetime posing a hurdle for the CHL. However, electric mobility is attracting a lot of attention and is pushed by academia, industry and governments. Hence, smart grids, where electric vehicles (EVs) are connected to, gain continuously in importance. In case of an excess production of energy, especially due to renewable sources, vehicles are intended to be used as temporary energy storage. So, considering the introduction of EVs into the mass market, the involvement of EVs into the power grid seems to become indispensable.

The project E-Energy [23] showed the potential and future challenges of smart grids. Additionally, the solution will tend toward small and especially local smart grids fulfilling and fitting to local requirements. The follow-up research project, INEES [24], [25] has recently started to continue the research work on smart grids involving EVs.

D. Lighting

Depending on the equipment level, vehicles usually possess at least the mandatory lighting systems for outside illumination, which are mandatory by according laws and inter alia regulated by the UNECE regulations [26]. They form a framework for technological requirements of vehicles, including lighting, and are accepted in the European Union and further countries.

Advanced driver assistance systems, such as dynamic cornering lights, which light into corners, or adaptive high
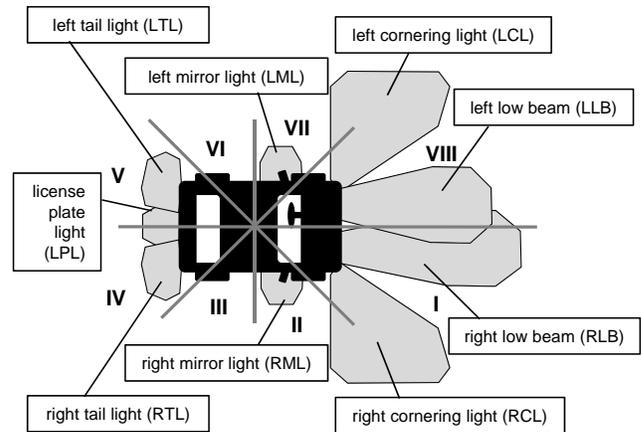

Fig. 2. Light sources and areas of CHL

TABLE I
DEPENDENCY OF LIGHTING ON DRIVER POSITION WITHIN AREA

Light source	Area							
	I	II	III	IV	V	VI	VII	VIII
LLB	x	-	-	-	-	x	x	x
LCL	-	-	-	-	x	x	x	x
LML	-	-	-	-	x	x	x	x
LTL	-	-	-	x	x	x	-	-
LPL	-	-	x	x	x	x	-	-
RTL	-	-	x	x	x	-	-	-
RML	x	x	x	x	-	-	-	-
RCL	x	x	x	x	-	-	-	-
RLB	x	x	x	-	-	-	-	x

x: light source turned on
-: light source turned off
For abbreviations of light sources see Figure 2

beam assistants, which detect incoming traffic and adjust beams accordingly, actively intervene with the vehicle's lighting system. Additionally, lighting systems underlie a steady development so that incandescent systems are continuously replaced by LED systems, partly in combination with xenon lights [27]. Researchers, such as Hörter et al. [28], even work on assistance systems for rural roads which make use of the opportunity of moveable lights to precisely position a light spot on persons and animals on the road(side), and thus make them earlier visible to the driver. Hence, vehicles are and will be increasingly equipped with sophisticated lighting systems.

We suggest to use the light sources depicted in Figure 2 to realize the CHL. The vehicle surrounding is divided into eight areas, numbered with I to $VIII$. Depending on the driver position in the area, specified light sources are turned on. Table I summarizes the dependency of light sources and area.

Additionally to simply turn lights on or off, the capability to move low beams in the vertical as well as horizontal pane improves the CHL. Since the driver is moving, low beams are permanently aligned in the direction of the driver within the mechanical constraints.

1) Horizontal beam movement: Horizontal beam movement is mainly driven by the dynamic cornering light which is intended to be used in rural areas or on highways while driving through corners at higher speed. Low beams are actively moved horizontally into the corner with a maximum angle of commonly 15 degrees [29]. Beams are usually controlled via electromotive actuators so that the mechanism to move low beams is integrated in vehicles with the aforementioned assistance system.

2) Vertical beam movement: To avoid dazzling incoming traffic, manual level adjustment exists besides the more sophisticated static and even dynamic automatic leveling. The static leveling system automatically adjusts the level dependent on vehicle loading. Dynamic systems additionally take into account vehicle's acceleration and deceleration to adjust the tilt angle dynamically. Hence, actuators to adjust vertical beam movement are widely spread in vehicles as well.

III. ASSESSMENT IMPLEMENTATION

To assess the potential of the CHL, we propose a three-steps assessment. In the first step, research work is necessary to identify comparable functions or countermeasures, which were already evaluated and consequently provide evaluation results. These results are transferred under our evaluation conditions and provide a first direction of possible behavior of our security function. In the second step, a survey is conducted in order to find out test persons' valuation whether the function is effective to combat the intended crime as well as reasonable to increase feeling of security. Thereby, test persons experience the function but there are no violent or threatening attacks. The survey further covers acceptance and usability issues related to the potential security function. Knowledge about users' attitude towards a security function is a factor of success. No matter how effective a security function might be, a security function with user handicaps will deter users from making use of it and make the function useless, and thus ineffective. The third step arises from engineering demands being able to measure effectiveness, for example by making use of simulations. Consequently, we simulate our security function and propose metrics to evaluate the effectiveness.

A. Transfer of research work

Surveying the literature, we have not found any approaches realizing a similar function as the CHL, and thus, no immediate evaluation results exist. But, there has been a lot of research on the influence of lighting, especially street lighting, on crime and the fear of crime in the last decades. We think that transferring these results, which are presented in Section IV-A, provides a first glance on the effectiveness and success of making use of vehicles to cooperatively light the surrounding.

B. Customer survey

We designed our own supervised one-to-one interview. We pursue three goals with our survey:

TABLE II
EXAMPLE OF A 5x3 LIKERT SCALE TO RATE IMPORTANCE

Not important at all			Not important			Neutral			Important			Very important		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

1) Estimate whether the CHL is seen as effective to combat robberies and assaults while going to or from the vehicle.
2) Gather subjects valuation about the effectiveness of the CHL to reduce the fear of falling victim to a robbery or an assault.
3) Estimate the user acceptance of the CHL from consumer's point of view.

In the following, we introduce the survey design and concept, explain our choice of subjects, show the survey procedure as well as provide an overview of our analysis approach.

1) Survey design and concept: The experiment is structured in three parts. The first part contains sociodemographic questions to gain deeper information about the subject. Additionally, we use this part to ask questions about the technical affinity of subjects. We assume that gender, age and subjects who rate themselves to have a high technical affinity influence the evaluation. Furthermore, we introduce assistance systems and technologies which provide the basis for the CHL. This is important for the further understanding and evaluation of the CHL as well as to get all subjects on a similar level of knowledge.

The second part finally tackles the assessment of the CHL. Thereby, the questionnaire contains questions to cover the following three constructs:

- Effectiveness of fighting crime
- Effectiveness of increasing feeling of security
- User acceptance

Questions are answered on a five-point Likert scale with according labeling. To get more granularity, we further subdivide each category of the five-point Likert scale into three parts. Consequently, we have an overall answer depth of 15 possible answers. Table II shows an example of a 5x3 Likert scale in order to rate the importance. Using predefined questions with a judgement scale (Likert scale) facilitates the evaluation of a questionnaire but the subject is eventually pushed into a specific pattern.

Therefore, the third part provides comment fields in order to provide the opportunity to freely comment on the benefits, drawbacks and also general feedback coming along with the CHL. Additionally, the examiner documents questions and remarks arising during the survey.

In order that the subject experiences the CHL, we decided to implement in cooperation with the Volkswagen AG department for visual communication a real world animation of one specific scenario making the CHL tangible for subjects. Thereby, we chose to model a parking garage with several parking cars. The animation is made from the first person view where the car owner uses a smartphone to unlock the car, and

Fig. 3. Screenshots from the CHL animation

TABLE IV
SUBJECTS' DISTRIBUTION OF GENDER AND AGE

	Male	Female
Young (< 36)	14	14
Old (> 44)	14	14

the one hand our resources, such as time and money, and on the other hand is large enough to provide reasonable results, we conducted an a priori power analysis. Thereby, we made use of a power analysis program for statistical tests, G-Power [30]. According to Cohen [31], the sample size N is calculated dependent on the required power level $(1 - \beta)$, a previously specified significance level (α) as well as the population effect size (d).

The main purpose of the survey is to estimate whether the CHL provides an improvement compared to the BHL. Consequently, each subject has to rate both functions and we have matched pairs, i.e., dependent groups. Since we test for improvement, an one-sided tail is chosen. Further, we decided to chose a significance level of $\alpha = 0.05$ and power of $1 - \beta = 0.95$, which are common levels in social sciences. With these settings, we compute a required sample size of 47 participants, which satisfies our resources and detects effects of medium size ($d = 0.5$).

Furthermore, we aim at testing for differences considering gender and age. We have the opportunity to control these attributes while inviting subjects. Therefore, we want to have equal groups considering both, gender and age. Testing for differences between males and females as well as between young and old participants implies two independent groups. Further, we focus on one-sided testing and taking a significance level of $\alpha = 0.05$, as well. Taking a power of $1 - \beta = 0.95$ and a medium effect size ($d = 0.5$) would require a total sample size of 184 subjects, i.e., 92 participants per group. This is beyond our resources so that we decided for a power of $1 - \beta = 0.8$ and a smaller effect size, $d = 0.8$. According to [31], a type 2 error being four times α, i.e., $\beta = 0.2$, is still reasonable and we detect at least small effects. Taking these values for calculation, we need a total sample size of at least 42 participants (21 per group).

Table III summarizes our beforehand described settings for G-Power to calculate an appropriate sample size. In a nutshell, to be on the safe side but satisfy our resources, we decided to invite **56** subjects for the survey. Thereby, these subjects were equally divided considering gender and age, as can be seen from Table IV.

3) Procedure: We decided to take an experienced examiner who conducts the survey. First of all, an experienced examiner is trained to conduct surveys. Second, the examiner has an open mind, that means, he is not involved in the topic of security functions. Consequently, (indirect) influence on subjects during the survey is minimized.

We deeply introduced the examiner into the survey and conducted several test runs. Although, we do not participate

thus, starts the CHL. Figure 3 illustrates some pictures of the animation. We further implemented two additional animations in the identical surrounding and identical car owners path to the car. One animation includes no function and the other the BHL. The animation without any function is used to get subjects familiar with the surrounding and the walking path in the animation. The animation of the BHL is necessary since we aim at comparing the constructs crime fighting and increasing feeling of security between the BHL and CHL, i.e., we want to estimate whether the CHL provides an improvement compared to the BHL. Therefore, our questionnaire contains similar questions evaluating the effectiveness of fighting crime and increasing feeling of security for the CHL as well as the BHL.

2) Subjects: To recruit subjects, we made use of an internal test person database from Volkswagen, which contains test persons in a lower four-digit range. These test persons are Volkswagen employees covering most areas of operations. With the help of them, surveys or studies are conducted to rate ideas and gain first trends. All test persons are voluntarily registered in the database. Furthermore, all data is treated confidential so that a conclusion on the identity of a certain person is impossible. This anonymity and a detailed instruction of test persons support an independent survey.

To estimate an appropriate sample size, which satisfies on

TABLE III
G-POWER SETTINGS TO ESTIMATE SAMPLE SIZE

Objective	Statistical test	Tail	Effect size (d)	Significance level (α)	Power ($1-\beta$)	Min total sample size
Effectiveness estimation of security fucntions	U-Test (Wilcoxon): two dependent groups (matched pairs), non-parametric	one-sided	0.5 (medium)	0.05	0.95	**47**
Estimation of demographic differences	U-Test (Wilcoxon): two independent groups, same size, non-parametric	one-sided	0.8 (small)	0.05	0.8	**42** (21 per group)

during the survey, the examiner and subjects had always the opportunity to contact us in person to solve arising questions. A further benefit of conducting an interviewed survey is that subjects have always the opportunity to ask questions. Furthermore, the examiner has the opportunity to take care of a completely filled questionnaire, respectively. This is very important to achieve our predefined number of subjects to be able to conduct our statistical tests. The survey is conducted in a separate room to avoid distraction. Thereby, each experiment is conducted successively with one subject. So, the entire survey took about two weeks. The room could be darkened and was equipped with an 42 inch LCD-TV.

Each experiment started with editing the sociodemographic questions by the subject and showing the animation without function to the subject. To show subjects the animation, our first approach was to use an off-the-shelf head-mounted display or video glasses to create a feeling of virtual reality. But, after having discussed with experts within our company and surveyed technical magazines [32]–[34], which tested head-mounted displays and video glasses, we decided against the use of such a device. In our animation, the car owner walks on a static path to the car and we do not consider any interaction, such as head movement. Hence the immersion into virtual reality is limited to the visual experience. Especially off-the-shelf head-mounted displays do not really convey the feeling of being within the scene due to limited display properties. Small resolutions as well as small angles of view even partly convey the impression to stay close in front of a flat screen. An additional drawback is cybersickness [35]. Eyes observe movement although the subject stands still. This contradictory information to sensory organs often leads to sickness. Consequently, we decided to show the animation in our darkened room on the 42 inch LCD-TV.

Next, subjects evaluated the BHL and CHL. Since, the CHL is the more sophisticated function, evaluating the CHL after the BHL may lead to biased results. Therefore, we divided our subjects equally in two groups, A and B. Group A evaluated the BHL first followed by the CHL. In contrast, group B evaluated the CHL first. The procedure to evaluate a function consists of three steps. First, the examiner briefly introduces the function. Second, the according animation is shown to the subject. Third, the subject edits the according questions in the questionnaire. Figure 4 shows the detailed procedure for both
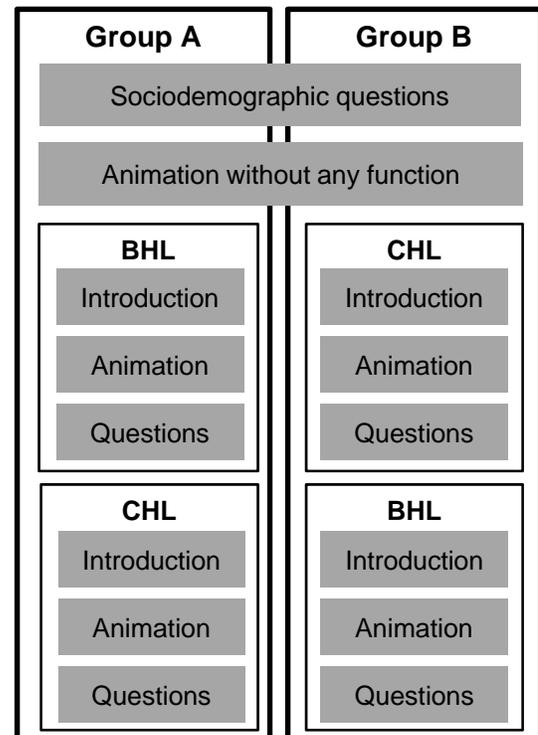

Fig. 4. Procedure of the experiment to valuate the CHL

groups.

4) Analysis: We have several items (i.e., questions) to measure the same construct, for example fear of crime. Hence, we have to combine data from related items. To test whether several items propose to measure the same construct, we calculate Cronbach's alpha, the coefficient of internal consistency. The value varies from zero to 1 where a value of 1 shows total reliability between the according items. However, very high reliabilities, such as 0.95 and higher, indicate that items are eventually redundant [36]. To estimate whether related items are reliable, Nunnally and Bernstein [37] recommend a value between 0.7 to 0.8 for basic research. According to [38], a well-accepted value for Cronbach's alpha is between 0.70 and 0.90. Also Ferreira and Palhares [39] suggest a value higher than 0.7 although references exist accepting values lower than 0.7. So, in our opinion an alpha
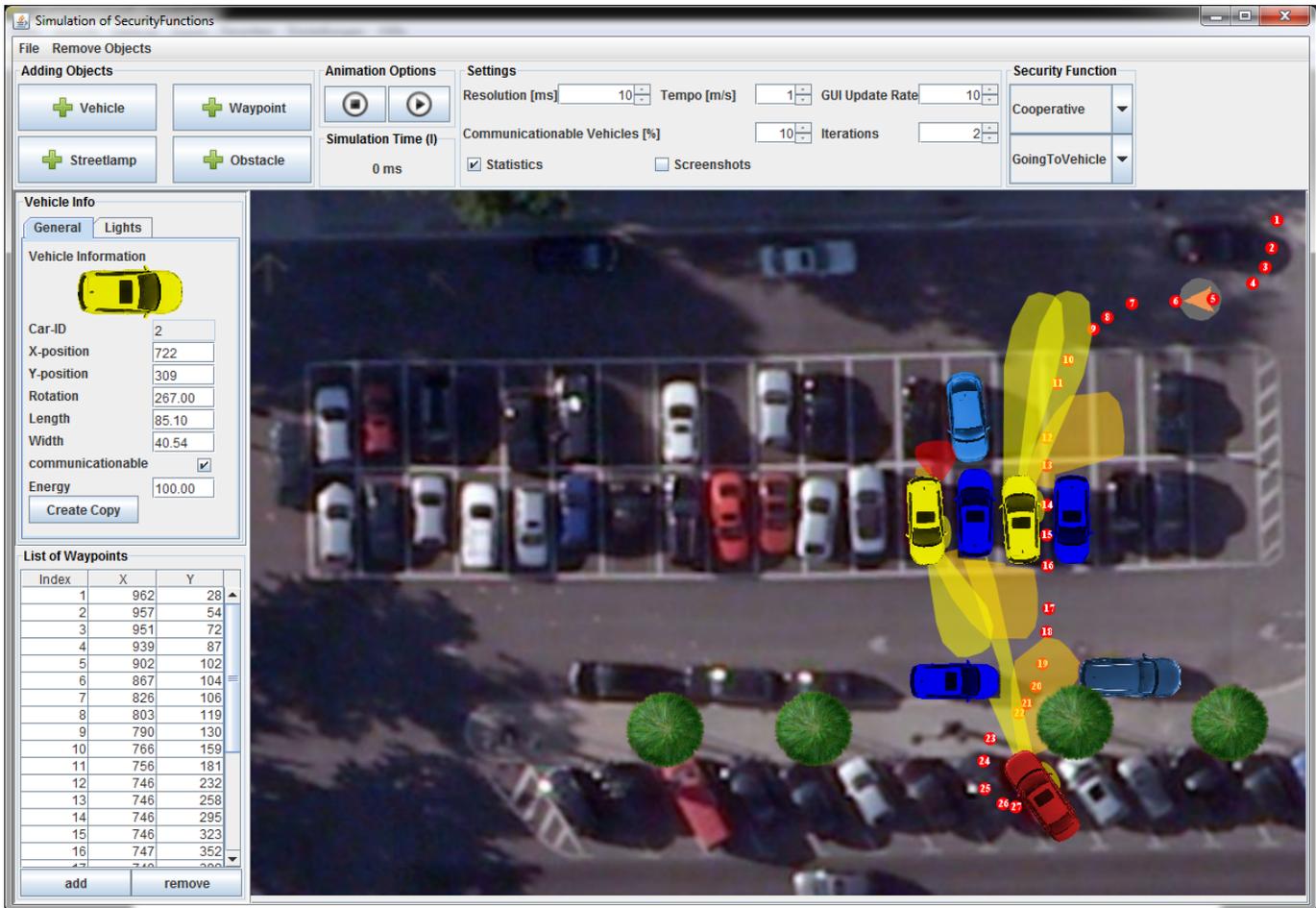
Fig. 5. Simulation environment to simulate the CHL

value between 0.7 and 0.95 is a suitable choice to estimate reliability as well as eventual redundancy between items.

C. Simulation environment

We define the duration of the driver in a lighted surrounding as a measurable criterion. The CHL is classified as effective, in terms of reducing crime as well as increasing feeling of security, when the driver is in a lighted surrounding. Thereby, the improvement compared the the BHL considering the number of participating vehicles is of interest. In other words, driver's duration in a lighted surrounding dependent on the penetration rate of vehicles participating in V2V communication is our measurement criterion. Thus, we need a simulation environment which enables us to model freely different parking constellations with an adjustable number of vehicles participating in communication. Additionally, we need to be able to model drivers path to or from the vehicle and to configure the lighting capabilities of vehicles. To the best of our knowledge, there is no simulation environment supporting a simulation of our security function. Consequently, we decided to implement a proprietary simulation environment [1], [40], which is illustrated in Figure 5, to be able to model diverse parking constellations, and thus, evaluate the CHL. As

can be seen, the simulation environment is implemented in two dimensions, that means from bird's eye view.

1) Parking Constellations: The number of possible parking constellations is infinite since the driver's path can be manifoldly modeled and vehicles can be positioned in different ways. Therefore, we provide in our simulation environment the opportunity to load a background image from Google maps [41] or Bing maps [42], for example. Thereby, the background image is scaled to fit into our simulation environment. Hence, we have the opportunity to add, i.e., overlay, and freely position vehicles at positions where vehicles are parked when the picture was taken. Furthermore, we can insert rectangle obstacles, such as walls, and circular obstacles, such as trees. Regarding parking constellations up to areas of 100m x 100m is in our opinion a reasonable approach since typical remote keys and low beams work nearly up to this distance.

2) Vehicles: Each vehicle has a set of light sources which can be used to light the environment. Light sources are limited to the light sources shown in Figure 2. Each vehicle can be configured separately so that vehicles with different equipment levels can be simulated. However, for reasons of simplification, all vehicles are equally equipped. Furthermore, we provide

four types of vehicles in order to fit the vehicle class from the real parking constellation. We consider only passenger cars, namely low, mid and high class cars as well as sport utility vehicles (SUVs).

3) Lighting and shadowing: Lighting is approximated by a surface created with the help of a polygon. Thereby, the lighted area can be adjusted for each vehicle separately. However, we equip each vehicle with equal lighted areas according to Figure 2 in order to limit the frame of influencing simulation factors. This implies that all vehicles are equipped with the same lighting technologies. Furthermore, we implemented in our simulation a ray tracing approach to consider shadowing effects.

4) Driver's Path: Driver's path is modeled via waypoints, which are freely inserted in the simulation environment and serve as anchors. The path is linearly interpolated between these waypoints. A polynomial interpolation was discarded due the tendency for oscillation [43]. The driver does not move from one waypoint to the next. Instead, the driver moves along the trajectories between waypoints by covering a distance calculated from the adjustable walking speed as well as the adjustable simulation resolution. Thereby, we use a walking speed of 1m/s and a simulation resolution of 10ms.

5) Communication: The propagation of electromagnetic waves highly varies affected by many influencing factors. For example, Kwoczek et al. [44] investigated the influence of roof curvature, roof racks and panorama glass roofs on the antenna gain in the reserved V2V communication frequency band and found inter alia a high loss of gain caused by glass roof. Additionally, packet collision and channel congestion influence communication. Hence, it is highly challenging to consider and simulate all influencing factors. We implemented a communication manager within our simulation environment, which can be extended by communication models, when necessary. However, we assume no message collision, all vehicles being within communication range, and all messages being correctly received. We consider the basic approach of the CHL where only the host vehicle broadcasts messages to reduce communication load. According to [45], the defined transmission power enables a theoretical communication range up to 1000m, and we target to regard simulation areas with a maximum size of 100m x 100m. Further, we consider only parked vehicles so that effects due to moving objects can be neglected as well.

IV. RESULTS

A. Transfer results

The influence of lighting, especially street lighting, on crime and the fear of crime has been researched widely in literature. On behalf of the US Department of Justice, Tien et al. [46] analyzed over 100 projects and deeply evaluated the results of 15 projects. In 1979, they concluded that improved lighting neither changes the occurrence of crime nor leads to an increase of crime, concerning offenses such as robbery, assault, burglary, car theft and larceny.

Ramsay and Newton [47] suggested on the basis of research made in the years before 1991 that light improvements indeed tend to have a positive influence on the feeling of security but not crime itself.

According to [48], where street lighting evaluations were reviewed having been conducted mainly in the 1990s, increased street lighting leads to crime reduction when measures are precisely targeted. Moreover, referring to newer U.K. research results, more general measures seem to have a crime prevention effect whereas the effect is strongly limited referring to older and U.S. research.

In 2002, Farrington and Welsh [49] evaluated the results of U.S. and British studies for the British Home Office [50] from former decades to estimate the effectiveness of street lighting on crime. They prepared an update [51] for the Swedish National Council for Crime Prevention [52] in 2007 and concluded that the improvement of street lighting reduces crime significantly and seems to have no negative effect providing benefits for law-abiding citizens.

In a nutshell, the research on the effect of lighting on crime has provided equivocal results. However, a positive influence on the feeling of security is generally assumed. The interested reader can find further information and results on the effect of lighting on crime and on the feeling of security in [53], [54].

B. Survey results

1) Effectiveness of fighting crime: To estimate the effectiveness of fighting crime, subjects answered two equal items referring to the BHL and CHL on the 5x3 Likert scale ranging from *not suitable at all* to *very suitable*. The first item asked subjects to rate the suitability of the BHL / CHL to deter a potential attacker from attacking the driver during the way to the car. Second, the suitability of the BHL / CHL to reduce robberies and attacks against the driver during the way to the car was rated. Since Cronbach's alpha is for the BHL 0.85 and the CHL 0.95, the items can be combined accordingly to represent the construct effectiveness of crime fighting.

Regarding the statistical test results, the CHL is rated to be significantly more effective to fight crime than the BHL (p-value: 3.70e-10). Thereby, there is also no difference between group A and B, i.e., both groups show a significant result as well. Figure 6 shows the distribution of the suitability to fight crime. The mean of the BHL 8.0 (sd: 2.7) is significantly smaller than the mean of the CHL 10.9 (sd: 2.4).

Furthermore, we also tested for influence of gender, age and technical affinity. All p-values are above a significance level of 0.05. Thus, there is no evidence that females think that the BHL as well as the CHL is more effective than males. Our older subjects rate none of the function to be more effective either. Lastly, subjects being more technically affine follow the aforementioned trend, i.e., there is no difference between technically affine and not technically affine subjects.

2) Effectiveness of increasing feeling of security: Subjects rated the suitability of the BHL and CHL by editing two items on our 5x3 Likert scale ranging from *not suitable at all* to *very suitable*. On the one hand, items asked to rate the suitability
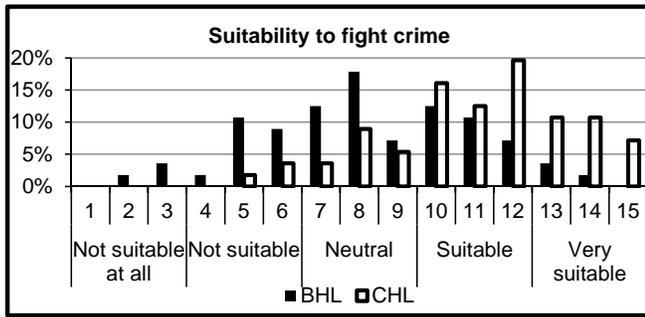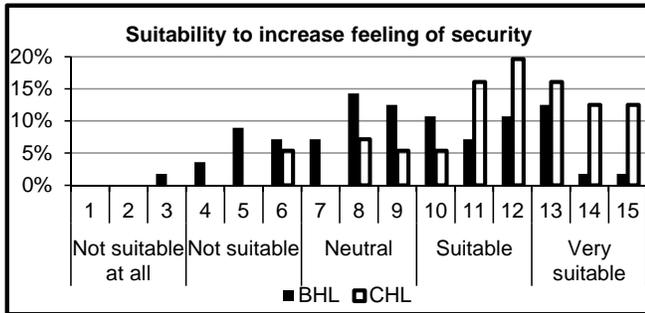
Fig. 6. Suitability to fight crime

Fig. 7. Suitability to increase feeling of security

Fig. 8. Willingness to provide own car for cooperative lighting

to reduce the fear of crime from assaults and robberies during the way to the car, and, on the other hand, the suitability to increase the feeling of security during the way to the car. Cronbach's alpha between both items is for the BHL 0.90 and for the CHL 0.92. Thus, we can combine both items to represent the construct effectiveness of increasing feeling of security for the BHL as well as CHL.

The hypotheses test, which intends to research whether the CHL is more effective than the BHL in increasing the feeling of security, shows a p-value (1.09e-08) smaller than 0.05 so that we accept the alternative hypotheses. Consequently, the CHL is significantly seen by our subjects to be more effective than the BHL. The distribution of the suitability is depicted in Figure 7 where the mean for the BHL is 8.9 (sd: 2.9) and for the CHL 11.6 (sd: 2.4). Considering group A and B separately, the CHL is also rated to be more effective than the BHL in both groups. So, no matter if the BHL or the CHL was rated first, the CHL is significantly seen to be more effective.

Furthermore, neither the gender and age nor the technical affinity influence the effect of the BHL and CHL on feeling of security.

Considering the overall results, the CHL in generally evaluated more effective to increase feeling of security. However, we did not identify any stereotypes considering gender, age and technical affinity.

3) User acceptance: To find out more about the user acceptance, we focus on two categories. The first category covers subjects' willingness to provide their own car to light the way to someone else. We use three questions each with a 5x3 Likert scale going from *not willing at all* to *very willing*.
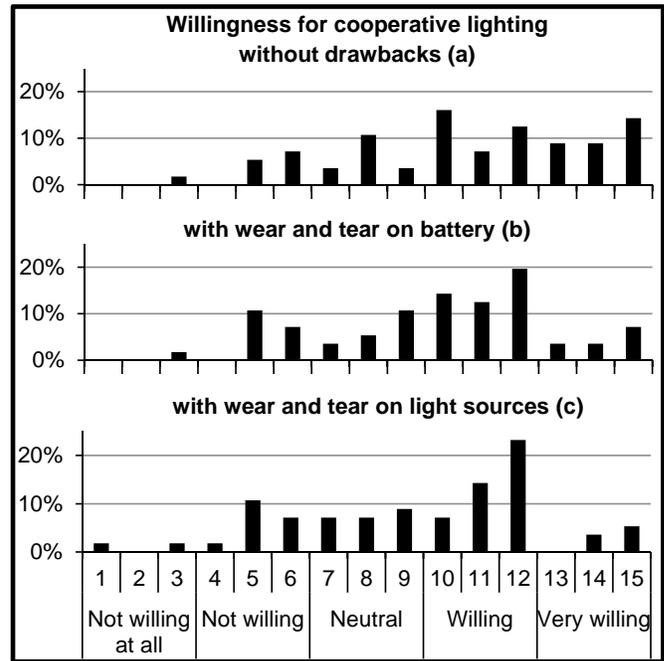
First, we asked subjects to simply rate their willingness to provide their car to others for cooperative lighting. As can be seen in Figure 8(a), the willingness is indeed widely spread. However, there is more or less a tendency to be willing to support cooperative lighting. A few questions later, we asked our subjects again to rate their willingness. But, this time we arranged an explanation in front of the question explaining that there is an energy management avoiding a complete discharge of the battery so that the car can still be started. We additionally point out that battery life time is reduced due to more load cycles, and thus, leading to an earlier battery exchange. According to the results shown in Figure 8(b), the willingness decreased. Conducting a statistical test, the decrease is significant (p-value=0.00345). The third question is asked subsequently. This time, we point out that light sources are increasingly switched on and off. This leads to a decreasing life time, and thus, to an earlier exchange of light sources. Figure 8(c) shows the according results, which decreased again compared to the second question (p-value=0.00536).

Summing up, it seems that subjects generally slightly tend to provide their car for cooperative lighting since they see a benefit. But, the enthusiasm in the beginning decreased with the clarification of possible (economical) drawbacks.

The second category covers the maximal surcharge subjects are willing to pay for the CHL. Therefore, we asked our subjects to mark the maximal surcharge on a number line ranging from 0€ to 1000€ they were willing to pay for the CHL. Figure 9 shows the result where the surcharge is shown related to the according subject ID.

We have few subjects that of course are not willing to pay anything and vice versa a few subjects who are willing to pay
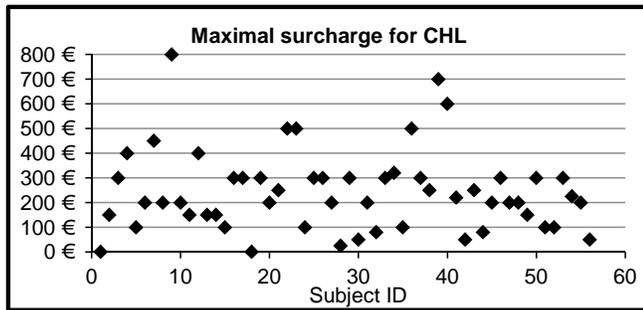
Fig. 9. Willingness for maximal surcharge of the cooperative home light

Fig. 10. Parking constellation with driver's paths

far above the average amount of 244€. However, the majority ranges between 100€ and 300€. Hence, since subjects marked the maximal amount, a customer price of around 200€ seems to be acceptable for the majority. However, a car manufacturer and supplier need to manage a realization far below the estimated customer price. So, a realization based on existing hardware components seems to be unavoidable to keep the surcharge low.

4) Subjects feedback: Several subjects state that they like to make use of the BHL, especially in order to find their car. One subject added that after having finished work and going to his car, which is parked at the parking area in front of the company with thousands of further cars from the same make and even model, the BHL is ideal to identify his car in the mass. So, subjects mainly think of the BHL at the first glance as a car finder. Nevertheless, some subjects admitted to feel more comfortable due to the lighted surrounding by the BHL. But, they did not think about it immediately since this has become kind of natural.

Furthermore, some subjects unlock the car first when the car is in their range of sight. They are afraid of pointing by the light the unlocked car to a potential attacker. Further, since the doors are immediately unlocked the attacker can enter the car before the subject arrives. Hence, an additional button on the remote control or additionally pressing the same button is suggested to unlock the doors. The lighted car shows a potential attacker that the car owner is approaching and consequently hands the victim to the attacker on a silver platter. This way the attacker knows where to wait.

Some subjects criticized the CHL complicating to find the own car due to the fact that several cars are switching on their lights. Thus, the own car needs a unique lighting, e.g., a unique interior lighting (color). Additionally, subjects worry that the CHL leads to confusion, especially when several persons make use of the CHL. One subject was afraid that handling the challenge with several users needs additional exchange of (position) data. The multitude of light sources creates a lot of shadows which also might be irritating. Hence, the desired effect gets lost. One subject also mentioned that the light of other cars irritates since it is unknown whether the car switched the lights on because of the CHL or someone really started the car and wants to leave the parking lot.
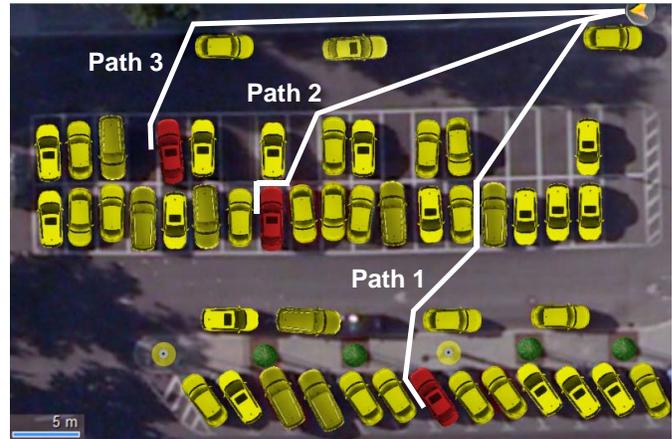
Considering the CHL, most subjects are also concerned about additional costs due to shortened lifetime of battery and light sources. Associated with this, subjects doubt the willingness of providing the car for cooperative lighting, especially when there is no benefit. They also mention the chicken-egg-problem, i.e., the necessity to have an acceptable amount of cars supporting the CHL but first users will not really benefit since the penetration rate is too low. However, two subjects also stated not taking care about the additional abuse and offering their car for cooperative lighting as long as they have a leased car which is driven only a short period of time before being returned.

Further, the parking garage is not considered as the main place where the CHL unfolds its main potential and benefit since a parking garage is generally lighted. Even if some light sources are out of order there is still enough light. The main use is seen on side roads with insufficient illumination, streets with lamps hidden by treetops or other dark outdoor places where no illumination is available or lights are shut down to save money for example. One subject would like to connect the CHL with his carport, his house and his wife's car being also in the driveway. Another subject thinks that the CHL would unfold its potential rather in countries such as Mexico and Brazil than in Germany.

The compatibility with other car and smartphone manufacturers raises also concerns. A preference is noticeable to use the key instead of the smartphone, also in order not to have to many devices. But a smartphone or other device with an appropriate display opportunity could be used to show an availability map of participating vehicles within the CHL network.

Both, the CHL and BHL are mainly seen as additional comfort to feel more comfortable and to find the own car easier. The use of lighting to fight crime and increase the feeling of security seems to play only a secondary role.

C. Simulation results

We decided to take and model the parking constellation depicted in Figure 10. It refers to a mixed parking constellation
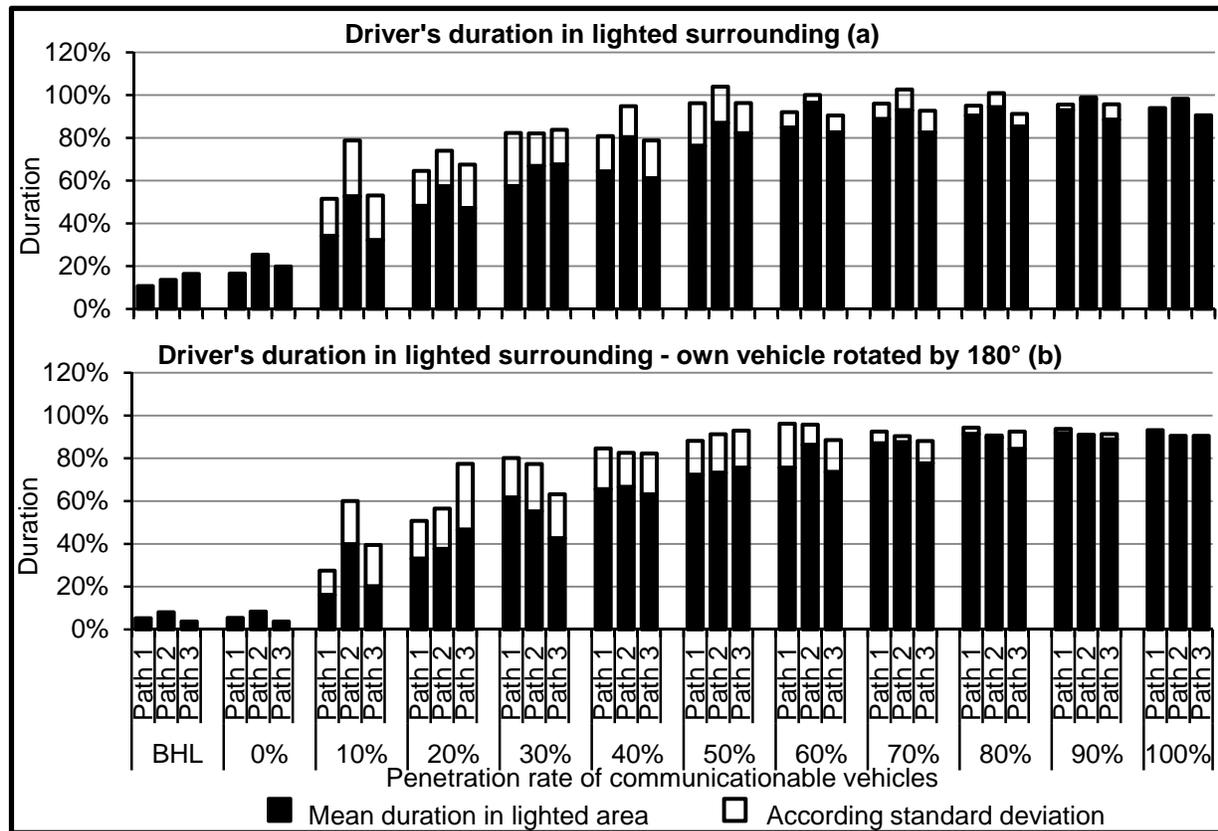
Fig. 11. Driver's duration in lighted surrounding dependent on the penetration rate of vehicles participating in communication

from Berlin. Thereby, mixed means that vehicles are parked side by side, consecutively as well as even skewed. We simulated three paths, each to a different vehicle as illustrated in Figure 10. The starting point of the driver was equal for each of the three simulation settings. The path to driver's vehicle was planned based on our personal assumption a driver would take. However, we avoided equal paths since the lighting behavior is obviously equal on equal paths.

Each path was simulated for the BHL and the CHL with penetration rates of participating vehicles from 0% to 100% in 10% steps. A penetration rate of 0% means that the CHL behaves similarly to the BHL except making use of the opportunity to move low beams into drivers direction and turning on only necessary light sources. A penetration rate of 100% means that all vehicles in the scenario participate in lighting the path. The BHL as well as the CHL with 0% and 100% penetration rate are simulated once since they are clearly deterministic. In contrast, the simulation of the CHL with penetration rates from 10% to 90% was conducted 10 times per penetration rate. Thereby, we randomly estimated in each iteration vehicles which participate in the cooperative lighting within the scenario. As can be seen in Figure 10, the driver approaches the own vehicle from the front considering all three paths. Since low beams and cornering lights are the mostly meaningful light sources, we conducted the aforementioned simulations with a driver vehicle being rotated by 180 degrees,

respectively.

Figure 11 summarizes the results where Figure 11a shows the results for the original parking constellation and Figure 11b shows the results with a driver vehicle rotated by 180 degrees.

First of all, the CHL(0%) provides an improvement in lighting when the driver approaches from the front. This way, the CHL releases the potential to move low beams into the direction of the driver. The influence of the own vehicle is especially obvious in the lower penetration rates where other vehicles are not always able to replace the missing lighting of the low beams when the driver approaches from behind.

Furthermore, up to a penetration rate of 50%, the average duration constantly increases nearly up to 80%. Hence, on average an acceptable lighting coverage is achieved with 50% of vehicles. However, the standard deviation is approximately 20% considering penetration rates smaller than 50%. This shows that the parking position of participating vehicles highly influences the duration of the driver in a lighted surrounding. This is not surprising. In worst case, none of the vehicles participating in communication are in lighting range, and thus, have no influence on lighting the surrounding.

From penetration rates of 60%, the average duration increases only slightly up to a duration of 90% in a lighted surrounding and the standard deviation decreases. That means, high penetration rates do not necessarily provide much

higher lighting durations. But, they provide lower variations. Moreover, a saturation is achieved by 90% of lighting duration.

Based on our simulation results, a penetration rate of 50% of participating vehicles is the most reasonable trade off providing a high duration in a lighted surrounding with low variations.

V. CONCLUSION AND FUTURE WORK

In this paper, we proposed a security function, namely the cooperative home light (CHL), and showed the underlying technologies for implementation. To assess the CHL, we proposed a three-steps approach, which consists of analyzing related work, conducting customer surveys and defining measurable criteria to conduct simulations. We applied this three-steps approach to the CHL and presented the implementation and the results. Thereby, surveying the literature and analyzing the influence of lighting on crime and feeling of security, we found equivocal results. A positive effect on reducing crime was neither confirmed nor rejected. However, the majority confirmed a positive effect on the feeling of security. Moreover, our survey showed an improvement of the CHL compared to the BHL, tackling both, crime and feeling of security. However, it also became obvious that the CHL is primarily not seen as a security function. Instead, the convenience was highlighted by subjects. Hence, the feasibility of the CHL to make security tangible for the customer remains questionable. The simulation results showed that cooperative lighting increases driver's duration in a lighted surrounding. A reasonable penetration rate of connected vehicles participating in lighting the path was estimated to be 50%. Lower penetration rates suffer from variations dependent on parking positions of connected vehicles. In contrast, higher penetration rates provide only slight improvements.

In our future work, we will focus on two directions. First, we will continue our work on evaluating the CHL. We will simulate further typical parking constellations, such as consecutively parked vehicles on public streets and side by side parked vehicles on parking areas. However, our work made also clear that a real world implementation of the CHL is unavoidable to gain deeper insights whether the CHL reduces crime or eventually even leads to abuse, and thus, encourages crime. Therefore, detailed long-term statistical data is necessary. While recording robberies and attacks, a distinction needs to be made whether these crimes were conducted on the way to/from a vehicle or not. Further, information about vehicle's equipment level needs to be known and whether the driver made use of the BHL or CHL. However, our vehicle-related crime analysis [55], which is partly based on statistics, has shown that actual statistical data do not provide the necessary granularity to assess the CHL. Second, we will apply our three-steps approach to assess a further security function, namely the electronic decal [56]. This way, we will be able to compare results with the CHL, and additionally gain deeper understanding about the potential of security functions to fight crime, increase feeling of security and make security tangible for customers.

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