Automated driving safety - The art of conscious risk taking - minimum lateral distances to pedestrians

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***Abstract*—The announced release dates for Automated Driving Systems (ADS) with conditional (SAE-L3) and high (SAE-L4) levels of automation according to [20] are getting closer. Still, there is no established state of the art for proving the safety of these systems. The ISO 26262 for automotive functional safety is still valid for these systems but only covers risks from malfunctions of electric and electronic (E/E) systems. A framework for considering issues caused by weaknesses of the intended functionality itself is standardized in the upcoming release of the ISO 21448 - Safety of the Intended Functionality (SOTIF). Rich experience regarding limitations of safety performance of complex sensors can be found in this standard. In this paper, we highlight another aspect of SOTIF that becomes important for higher levels of automation, especially, in urban areas: 'conscious risk taking'. In traditional automotive systems, conflicting goal resolutions are generally left to the car driver. With SAE-level 3 or at latest SAE-level 4 ADS, the driver is not available for decisions anymore. Even 'safe drivers' do not use the safest possible driving behavior. In the example of occlusions next to the street, a driver balances the risk of occluded pedestrians against the speed of the traffic flow. Our aim is to make such decisions explicit and sufficiently safe. On the example of crossing pedestrians, we show how to use statistics to derive a conscious quantitative risk-based decision from a previously defined acceptance criterion. The acceptance criterion is derived from accident statistics involving pedestrians.**

***Index Terms*—ADS, safety, ISO26262, ISO21448, SOTIF, jaywalker, acceptance criteria, automated driving, pedestrian**

I. INTRODUCTION

By working in the area of Autonomous Driving Systems (ADS) it is interesting to realize that the words "safe" and "safety" are used very often, but they mean different things for different persons. In this case engineers are looking often in the direction of International Standardization organizations for finding a definition. But even in the ISO-world you might be able to find different definitions related to different purposes. Related to ADS, it has been best practice to use the definition of "safety" in the ISO 26262 standard as: "absence of unreasonable risk" [1]. It is noteworthy that the definition is not "absence of any risk", like some people would guess. One of the reasons might be that a system that would exclude any kind of risk would most likely remain in stand still and could not drive in the public traffic as we know it in the year 2021. If you want to run an ADS system in today's traffic, this also means that you have to deal with the risk that something could happen to your system and/or to the environment of your system or to say it in other words: the system and the designer of the system have to be conscious about the risks they take as will be described in the following pages.

In the context of ISO 21448 [2] which deals with the Safety of the Intended Functionality (SOTIF), conscious risk taking means to restrict the intended functionality in balance with safety. In ISO 26262 a common risk norm exists, e.g., expressed by the target random hardware error rate of $10^{-8}h^{-1}$ [14] for the most critical systems. This means one hardware error in 10,000 years of continuous operation. For the behavior, such a general norm does not exist. Consciousness means to have an acceptance criterion which has to be established for every ADS according to ISO 21448.

Another formulation of the sufficient safety is a positive risk balance [7], as discussed in the next section. Due to the low frequency of fatalities, a pure test driven approach is infeasible to proof a positive risk balance before deployment [25]. It must be combined with sound engeneering and fast reaction to issues in the field [15]. A complementing formal approach to derive limits of the driving behavior is discussed in this paper. A formal analysis can be used to determine reachable areas of other vehicles in multi-lane highway scenarios [18]. The prediction also considers legal constraints. We will use a probabilistic analysis to relax the constraints imposed by the reachable area of potential jaywalkers.

II. ACCEPTANCE CRITERIA

The question 'how safe is safe enough?' is still not commonly agreed in the industry. The to-be-released SOTIF standard ISO 21448 at least requires the definition of acceptance criteria for every ADS project. A very general answer was given by the ethic committee on automated and connected driving of the German ministry of traffic and digital infrastructure (BMVI) [7] allowing and requesting the release of ADS if and only if a positive risk balance can be expected. Similarly, a GAMAB concept (*globalement au moins aussi bon*) has been used in safety related industries such as railway for years [6]. It requires an existing reference system. In the case of ADS this is the manually driven vehicle, steered by a human (SAE-L0).

A. Materials & Methods

In the remaining paper, we use the following notations: x and y stand for longitudinal and lateral distances, v for speed, r for rates, λ for a still to be defined characteristic safety length, a hat $\hat{}$ for requirements, subscripts $_p$ and $_v$ for pedestrian and vehicle, superscripts ^{S3}, ^{D} and ^{M} for concrete values regarding fatality, Germany, and Munich.

To define an acceptance criterion following the GAMAB principle, it is necessary to define a reference system. Here, we consider introducing an ADS for urban driving in Germany. So, a possible unit of the acceptance criterion is the ratio of fatal accidents with pedestrians to the total number of driven km. As an example, we use publicly available traffic and accident statistics for Germany in 2017 [3], [17], [22].

B. *Results*

The Federal Office of Statistics (Statistisches Bundesamt) of Germany reported for the year 2017 a number of 248 pedestrians killed in traffic accidents in an urban environment [22] For the same year, the report on mobility in Germany (MiD) [17] estimates a value of $2,034,000,000km$ urban travel distance per day of which about 43% are driven by individual cars leading to a total distance of $319,236,300,000km$ driven by individual cars in German urban areas in 2017. This leads to a total fatality rate of $7.8\ 10^{-10}$fatalities$/km$. For safety, often rates are calculated per hour of operation. For the transformation, we can use the average speed of 17.2 km/h in German cities in 2008 as published in [3]. Please be aware that this includes waiting times at traffic lights or in traffic jams where collisions with pedestrians are unlikely. Accordingly, the more natural unit is 'fatalities$/km$'. The constant value for the average speed can still be used to express the accident rate in more familiar units:

$$\hat{r}_p^{S3,D} = 1.3\ 10^{-8} \frac{\text{fatalities}}{\text{operation hour}} \tag{1}$$

Note: This calculation is only given to illustrate the process and shall not be used for a real ADS safety case. More rigorous statistics and calculations should be used for actual ADS product development.

C. *Discussion*

In ISO 26262, parts of the ADS will be rated according to the most critical Automotive Safety Integrity Level (ASIL) D [13]. The value of $\hat{r}_p^{S3,D}$ is comparable to the above mentioned target random hardware error rate for an ASIL D rated system which suggests the applicability of ISO26262 for the E/E failures of the pedestrian protection system of ADS. One general question is, how to deal with the acceptance criteria for ADS that are developed for different markets. A simple answer would be to use the most rigorous acceptance criterion, meaning the minimum value of all. An alternative standpoint can be that the exposure to critical situations is the main cause of variations of the rate of harmful accidents in different markets and a variation of the acceptance criteria over markets is acceptable. In the end, this should be an explicit decision of the management. We suggest that at least the level of safety performance that is used to achieve the acceptance criteria should be the same for all markets. This means for example that no money should be saved by cheaper, less performing sensor equipment in emerging markets.

III. REALTIME METRIC

In the previous part, an acceptance criterion has been defined for the safety of ADS with respect to pedestrians. This is an important metric that shall be targeted during the development of the ADS. As the metric relates to the ratio of very rare events over time or mileage, it can only be directly measured some time after the deployment of a sufficiently large (test) fleet. This is called a lagging metric [11]. For the validation, the ISO 21448 requires additional validation target values that can be determined before the deployment (leading metrics). These validation targets should be chosen carefully to make sure that they imply the acceptance criteria. Our aim is even to go one step further and deduce safety parameters for the vehicle behavior from the acceptance criteria. Here, we will look at jaywalkers where we define jaywalkers as a pedestrians that cross the street outside of intersections and dedicated pedestrian crossings. The scenario of an occluded pedestrian is shown in Fig. 1.

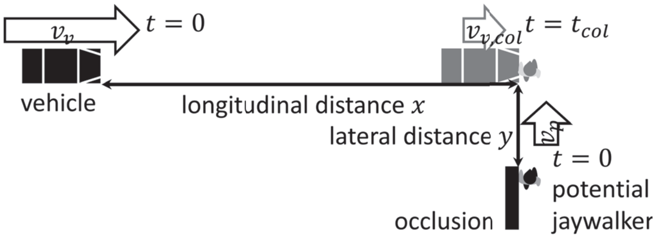

Fig. 1. Scenario of a 'jaywalker', crossing the street from behind an occlusion outside of an intersection or zebra.

This choice is motivated by the analysis that 70% of fatalities with pedestrians are caused outside of intersections as can be seen in the German in Depth Accident Study (GIDAS) [4], while pedestrians are generally the most common fatalities in urban traffic accidents (308 pedestrians followed by 272 cyclists in German urban area) [23]. In traditional automotive functional safety engineering, the goal is to cause zero fatalities. The safety target to come close to this goal is usually just limited by the technical effort. The below example shows that this does not hold for SOTIF. Let us assume an urban traffic situation with a car that drives at the speed limit of $50km/h$. What would be the minimum lateral distance to occlusions that the car driver can accept in order to prevent a collision with a jaywalking pedestrian that runs from behind the occlusion (Fig. 1)? This purely safety related question does not consider the distribution of responsibility between the vehicle and the pedestrian as is done in the Responsibility Sensitive Safety approach (RSS) [21], or as would be asked in a legal case following such an accident. The authors follow the recommendation of the ethic committee [7], that only asks for a total risk balance for the society as a whole.

A simple calculation according to (6) shows that we would need a lateral distance of at least $8.6\ m$ to an occlusion in order to prevent collisions with pedestrians that could come from behind with running speed. Experience as human drivers tells us that this is over-cautious and does not reflect our expected human-like behaviour. One approach may be to directly measure the behaviors in driving studies and imitate them [9], [12], [16]. This approach may lead to similar driving performance as a human in the sense of time required to come from A to B. But, to give the same safety level of safety, an ADS would also need to have the same skill as a human to interpret a scene, e.g., expect a child behind a ball, hear the brakes of a decelerating bike, hear the clapping of a car door after someone has left it, see something moving through the windows of a parked car, expect children behind a school bus, etc. In our approach we want to be agnostic and try to formally derive a safe lateral distance directly from the acceptance criterion with the help of general traffic statistics.

A. Formal model of the maximum permissible vehicle speed

To determine the maximum reasonable speed to pass an occlusion, the conflict between safety and travel time has to be resolved. This can be translated to an optimization task to find the maximum speed that still satisfies the constraints given by the acceptance criteria. For this purpose, it is necessary to estimate the rate of fatal pedestrian collisions r_p that would result from passing occlusions as a function of lateral distance y and approaching vehicle speed v_v. We use three statistical inputs to calculate this rate as follows:

(1) We consider a constant flow of jaywalkers j_p across the street see fig. 4. The flow density can depend on location, situation, and interaction with the vehicle. Effects of jaywalkers avoiding to cross the street from behind occlusions or of their ability to react to the vehicle to stop their crossing maneuver are expressed in the controlability factor C. An experimental estimation of j_p and $\bar{C} = 1 - C$ will be found in section III-D.

If for a first simplified assumption all pedestrians that enter the path of the vehicle within a range D ahead of the vehicle would have a fatal collision with the car, the resulting fatality rate would be $j_p \bar{C} D$.

Only collisions with the vehicle front are considered. The vehicle needs the time $t_{col}(x, v_v)$ to reach the collision zone in distance x. A pedestrian walking along the orthogonal distance y, would need a minimum speed $v_{p,min} = y/t_{col}$ to reach the collision zone before the vehicle. If $\Phi_v(v_p)$ is the probability that the speed of a pedestrian is less than v_p, the rate of collisions can be given as $j_p \bar{C} \int (1 - \Phi_v(\mathrm{v_{p,min}}(x, v_v, y)))\, dx$ by integrating over the longitudinal distance.

(2) We use the pedestrian speed distribution $\Phi_v(v_p)$ by [5] measured at signalized intersections. We extrapolate the distribution to the a cut-off-speed at $7.7m/s$, the running speed of a 20a old mail [10]. It is important to model the tail at high speeds as can be seen in the relatively high proportion of accidents with pedestrian speeds beyond $3m/s$ found in the GIDAS data base [4].

(3) The probability that a collision with a pedestrian detected in longitudinal distance x results in harm with a given severity level S mainly depends on the vehicle speed at the time of collision $v_{v,col}$. Here, we use the probability $P_{S3}(v_{v,col})$ for fatality of a collision at a given speed as determined by [19]. Adding this probability into the above Integral over contributions from all longitudinal distances x while passing the occlusion yields the harmful accident rate:

$$\begin{aligned} &r_p(v_v, y) = \\ &j_p \bar{C} \int (1 - \Phi_v(v_{p,min}(x, v_v, y)))\, P_S(v_{v,col}(x, v_v))\, dx \end{aligned} \tag{2}$$

The system behavior fulfills the acceptance criterion if (3) is met.

$$r_p(v, y) \leq \hat{r}_p \tag{3}$$

With a reference value for the rate of harm for crossing pedestrians $\hat{r}_p$.

To separate the environment specific flow density and the controlability from (2), we can define the characteristic safety length $\lambda_p := r_p/(j_p \bar{C})$ of the system in the environment. Correspondingly a required characteristic safety length $\hat{\lambda}_p := \hat{r}_p/(j_p \bar{C})$ allows to reformulate the acceptance criterion (3) to:

$$\lambda_p = \int (1 - \Phi_v(v_{p,min}))\, P_S(v_{v,col})\, dx \leq \hat{\lambda}_p \tag{4}$$

To derive the maximum permissible vehicle speed, the inequations (3) or (4) can be modified to an equation and solved for $v_v =: v_{v,max}(y, \hat{r}_p)$ or $v_v =: v_{v,max}(y, \hat{\lambda}_p)$, respectively.

A set of possible driving behaviors with different driving speeds can be calculated and selected according to different environments. With sufficient knowledge of the environment, the appropriate driving behavior characterized by λ_p can be selected at run-time.

The the dynamic braking behavior provides the time to collision t_{col} and remaining speed $v_{v,col}$ used in (2) and (4) as follows.

TABLE I
LIST OF PARAMETERS AND VALUES

symbol	definition	value
a_0	Maximum deceleration	variable, $8m/s^2$ used[a]
t_r	Reaction time	variable, $0.25s$ used[a]
$v_{p,lim}$	Maximum pedestrian speed [10]	$7.7m/s$

[a] Sample value used for the calculation.
Actual value may vary at runtime and has to be constantly monitord.

The pure deceleration time to full stop is v_v/a_0. Together with the reaction time t_r and the maximum pedestrian speed $v_{p,lim}$, the distance, a pedestrian can run after being detected within time to full stop of the vehicle can be given. For $v_v = 50km/h$:

$$v_{p,lim} \left(t_r + \frac{v_v}{a_0} \right) = 15.3m \tag{5}$$

During the phase of deceleration, the vehicle drives a distance of $\frac{1}{2} v_v^2 / a0$. The time, a vehicle needs to drive this distance without deceleration is $\frac{1}{2} v_v / a0$ which results in the following distance, a pedestrian can run when the vehicle drives the same distance as in (5) but with constant speed ($v_v = 50km/h$):

$$v_{p,lim} \left(t_r + \frac{v_v}{2a_0} \right) = 8.6m \tag{6}$$

During the deceleration phase of the vehicle, the kinetic energy is reduced. With the remaining speed $v_{v,col}$ after traveling the distance x:

$$\frac{1}{2} m\ v_{v,col}^2 = \frac{1}{2} m\ v_v^2 - m\ a_0\,(x - t_r v_v) \tag{7}$$

Solving (7) for $v_{v,col}$ gives $\sqrt{v_v^2 - 2a_0\,(x - t_r v_v)}$. Considering cases with distances that allow full stop, no reaction (radicand of the square root becomes negative) and some deceleration, the speed of the vehicle at the time of collision becomes:

$$v_{v,col}(x, v_v) = \\ = \begin{cases} 0 & \text{for } x \geq t_r v_v + \frac{v_v^2}{2a_0} \\ & \quad \vee\, x \leq 0 \\ v_v & \text{for } x \leq t_r v_v \\ \sqrt{v_v^2 - 2a_0\,(x - t_r v_v)} & \text{otherwise} \end{cases} \tag{8}$$

The time to drive a longitudinal distance x during the deceleration can be expressed as difference between the time to full stop initially and from the remaining speed $v_{v,col}$:

$$t_r + \frac{v_v}{a_0} - \frac{v_{v,col}(x, v_v)}{a_0} \tag{9}$$

We can use (9) to calculate the minimum speed a pedestrian needs to reach the collision zone before the vehicle using the same cases as in (8).

$$v_{p,min}(x, v_v, y) = y/t_{col} = \\ = \begin{cases} \infty & \text{for } x \geq t_r v_v + \frac{v_v^2}{2a_0} \\ & \quad \vee\, x \leq 0 \\ \frac{v_v y}{x} & \text{for } x \leq t_r v_v \\ \frac{y}{t_r + \frac{v_v}{a_0} - \frac{\sqrt{v_v^2 - 2a_0(-t_r v_v + x)}}{a_0}} & \text{otherwise} \end{cases} \tag{10}$$

If the lateral distance of the pedestrian is such that he can only reach the potential collision zone before the vehicle if the vehicle decelarates but not if the vehicle continues with constant speed, we have decided to still calculate with a deceleration as the vehicle might need to decelerate also for other reasons. There is no clear preference in this case though. The dynamic parameters t_r and a_0 can depend on vehicle and environment condition and should be verified and updated at runtime.

B. Results

Fig. 2 shows predicted fatality rates using (2) as a function of the lateral distance to occlusions for various speeds with the pedestrian flow density and noncontrolability of $j_p^M = 0.19 m^{-1} h^{-1}$ and $\bar{C}^M = 1.3\%$, as will be estimated in section III-D for Munich.

If the governing remaining risk for an ADS to cause pedestrian fatalities is too high vehicle speed in jaywalking scenarios as described on the left hand side of (3), we can use (1) for the acceptance criterion of fatalities in Germany. Numerically Solving $r_p^{S3,M}(v_{v,max}^{S3,M}, y) = \hat{r}_{S,ped}^{S3,D}$ for $v_{v,max}^{S3,M}$ provides the desired maximum speed $v_{v,max}^{S3,M}(y)$ to guarantee (3). $v_{v,max}^{S3,M}$ also satisfies (4) for the required characteristic safety length which is given for Munich by (12). The result is shown in the solid line of Fig. 3 as a function of lateral distances.

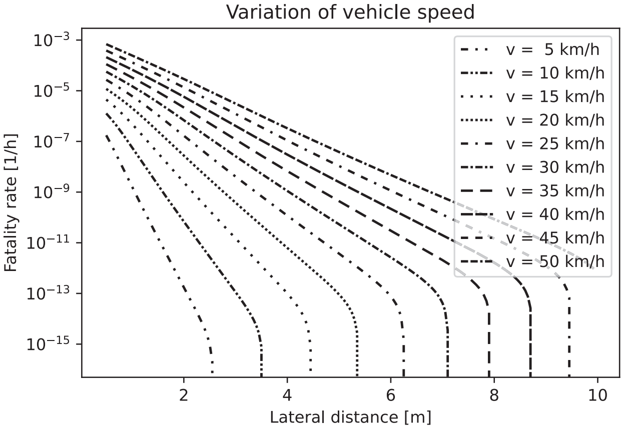

Fig. 2. Predicted fatality rates for the pedesrian flow density and controlability found in Munich.

Fig. 3 shows the maximum permissible speed $v_{v,max}^{S3}(y, \hat{\lambda}_p^{S3})$ for a set of required characteristic safety lengths $\hat{\lambda}_p^{S3}$, this allows to adapt the driving behavior to the pedestrian flow. The curves of these maximum speeds $v_{v,max}^{S3}(y, \lambda_p^{S3})$ are only dependent on very general parameters as the public statistics on pedestrian speeds Φ_v and fatalities P_{S3} and on the vehicle reaction time and deceleration capability. But, which curve to use depends on the pedestrian flow and noncontrollability that may have regional and temporal (time of the day, weekend, holiday, etc.) dependencies and can be selected at runtime.

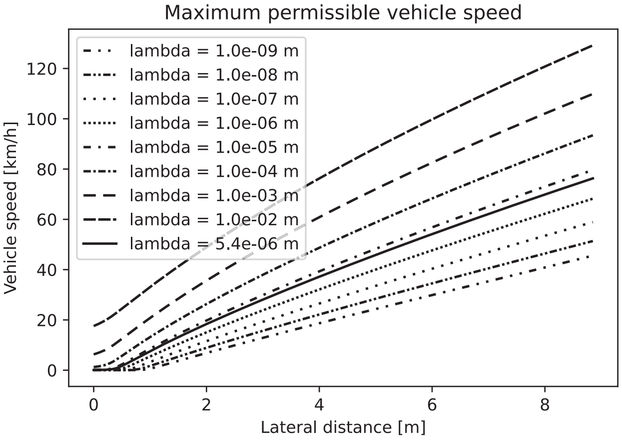

Fig. 3. Prediction of a set of maximum permissible vehicle speeds to achieve each required characteristic safety lengths $\hat{\lambda}_p^{S3}$, including $\hat{\lambda}_S^{S3,M} = 5.4\ 10^{-6} m$ estimated for Munich (12).

C. Experimental set-up to evaluate the flow density of crossing pedestrians

To examplify the approach to determine the ODD specific parameters of pedestrian flow density j_p^M and noncontrolability $\bar{C}^M$, we use a test drive in Munich. We define jaywalking using the following criteria:

- The pedestrian is stepping form the left or right towards a location inside a reasonable path of the vehicle
- There is no zebra crossing or intersection
- The pedestrian enters the vehicle path in a distance between 55 m meters ahead to 5m behind the car, giving a total floating observation range of $D_o = 65m$.

The flow density j_p can then be estimated as number of jaywalkers N_j that have entered the observation zone divided by the range and the duration of the observation.

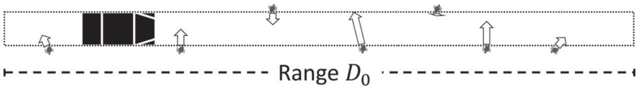

Fig. 4. N_j jaywalkers entering the path of the vehicle within the observed range D_0 during the observation time T lead to an estimated flow density of $\hat{j_p} = N_j D_0^{-1} T^{-1}$.

The number of collisions with pedestrians N_{col}, that would result from a vehicle that does not react to jaywalkers can be calculated as the area covered by the vehicle in the test drive times the density of jaywalkers times the noncontolabity. The area covered is given by the vehicle width of $w = 2m$ times the total distance D_d of the test drive. The average density of jaywalkers can be calculated as the flow density divided by the average pedestrian speed estimated as $\bar{v}_p = 1.2m/s$. In total: $N_{col} = w\ D_d\ j_p \bar{v}_p^{-1} \bar{C}$, which can be solved for the noncontrolability as:

$$\bar{C} = \frac{N_{col} \bar{v}_p}{w\ D_d\ j_p} \tag{11}$$

To cross check the flow density with a bigger data set, we perform data analysis on the BDD100K data set [26]. This data set was generated by they Berkeley Artificial Intelligence Research laboratory and consists of 100,000 video sequences, which makes up 120,000,000 images. Images were shot by cellphones in cars in locations around New York, Berkeley, San Francisco and the Bay Area. It covers multiple types of weather, multiple times of day, and multiple scene types. Annotations are provided for so-called key frames, which are sampled at the 10th second from each video. We can use the annotations to find pedestrians standing on a driveable surface. After selecting all images where a pedestrian bounding box overlaps with a driveable area marking we manually classify the scene of each remaining image.

D. Results

The results of the test drive to estimate the amount of jaywalking in Munich are summarized in table II, due to very short test drive, numbers are only indicative!

From this data, the flow density of crossing pedestrians is estimated as $j_p^M = N/(TD_o) = 0.19m^{-1}h^{-1}$. Most of the observed pedestrians in the large observation range of $65m$ length have not provoked a change of the vehicle trajectory. Using (11) the noncontrolability can be estimated as $\bar{C}^M = 1,3\%$. This results in a required characteristic safety length regarding fatalities of:

$$\hat{\lambda}_S^{S3,M} = 5.4\ 10^{-6} m \tag{12}$$

TABLE II
TEST DRIVE RESULTS

measurement	value
total test duration (T)	$2h$
total distance of test drive (D_d)	$43km$
Number of observed jaywalkers (N_j)	25
Number of pedestrian collisions that would have resulted from not braking on jaywalkers (N_{col})	0.05 [a]

[a] The driver decelerated in one instance to a jaywalking pedestrian. It is conservatively estimated with 95% probability that the pedestrian would have managed to step to the side to avoid a collision.

In the experiment to evaluate the flow density from the BDD100K dataset [26], we analysed the 69,863 keyframes. We automatically selected the 2,594 frames where the annotation of drivable area overlaps with a bounding box for a pedestrian. Manual selection gave us only 197 images where we judged the pedestrian as jaywalking. The images have a temporal separation of $10s$. Within this time, it may be possible that some pedestrian have slipped through unnoticed. We estimate that it is possible to judge a jaywalking within a time of $3s$ of the snapshot. So, the total observation time is 58h. Using only the observation range of $55m$ ahead of the vehicle, we get an estimated flow density of $j_p^{BDD100k} = 0.06m^{-1}h^{-1}$ which is roughly one third of j_p^M. That there is a regional difference is plausible as the Munich test drive has been biased towards busy narrow roads close to the center of the city. The impact of the difference on the permissible maximum speed can be read from Fig. 3. A judgment of the noncontrolability would require further video analysis of each of the 197 cases.

IV. CONCLUSION AND DISCUSSION

As the chances are very high that the ADS that will be deployed in the coming years are not able to fully avoid accidents, we recommend to be very transparent on the applied acceptance criteria and try to proactively get public acceptance before the deployment. The acceptance criteria can be seen as a kind of contract between the producer/operator of ADS technology and the society. We have demonstrated in this paper how to derive acceptance criteria for an ADS from publicly available statistics. If proprietary statistics are used, they should be published to foster the development of ADS in general, as well as to add transparency to the safety argumentation of the specific ADS.

The RSS-approach derives driving parameters by defining a responsibility boundary between two collision partners, which allows in an ideal model to avoid all accidents with own responsibility [21]. In contrast, we have taken a responsibility agnostic approach. We have shown, that it is possible to derive parameters for the safe driving behavior directly from acceptance criteria based on a positive risk balance. By formulating the acceptance criterion in terms of required characteristic safety length $\hat{\lambda}_p$, it is possible to adapt the behavior dynamically to local and temporal pedestrian flow variations.

We have shown a method, how the flow density could be derived statistically. The test drive has been knowingly several orders of magnitude to short for reliable quantitative results esp. regarding the noncontrolability. This should be repeated, e.g., by a car maker with the ability to use their deployed fleet to collect data in the field.

While the permissible speeds $v_{v,max}^{S3,M}$ derived in this paper seem appropriate for crowded areas in cities, they are rather pessimistic for the large distributor roads. Separate statistics on the different road types, and on different times of the day will be useful.

The need to balance false positives (unnecessary braking) to false negatives (missing to brake) is known from (SAE-L1) Automatic Emergency Brake (AEB) systems [24]. But there, the more severe situation is to predict a crossing pedestrian where there is none, as the driver still keeps the final responsibility to brake. For an ADS, a non predicted crossing pedestrian is the worst case.

Primarily, this paper talks about occluded pedestrians. Practically, an occlusion just means limited knowledge of the environment. This interpretation opens possibilities for application of the formulas to all systems or situations with limited knowledge of the environment. The only information that is required is the longitudinal and lateral distance to objects that could be or could hide pedestrians as could be extracted from a sufficiently reliable Light Detection And Ranging (LiDAR) - Sensor. The safe behaviour of an ADS against crossing pedestrians might be based only on the formulas of this paper. But the resulting driving behavior would be rather pessimistic. The level of pessimism can be reduced with the increased level trusted information related to the answers of the following and similar questions: How high are the chances that there are pedestrians? Is the object detected identified as pedestrian? What is the speed and direction of the pedestrian? Is the intention of the pedestrian related to his gesture and moving profile understood? We expect that first deployments of ADS will have an environment model with limited level of trusted detail resulting in very restrictive speed and other behavior constraints. As the certainty and detail of the environment will stepwise increase, the resulting behavior contstraints will get relaxed. But at all times, the vehicle should be designed to keep the agreed acceptance criteria.

The trajectory planner of the main functional channel of the ADS should be implemented to keep a safe speed as calculated in this paper. The safe speed could in addition be supervised in a safety channel. One possible architecture to keep the vehicle behavior within safe limits can be found in [8].

First results from the analysis of acceptance criteria based on severe injuries and light injuries indicate that they lead to similar values for the maximum permissible vehicle speeds.

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