Connected
Motorcycle
Consortium

CMC Basic Specification

Accident Analysis
- Crossing Traffic and Left Turn

Advanced analysis of accident types: Crossing traffic and Left turn based on GIDAS (German In-Depth Accident Study) database and GIDAS-PCM (Pre-Crash-Matrix) database.

Document Information

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Disclaimer

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1. Background and Objectives

To pursue the goal "improving motorcycle rider safety and comfort", CMC has studied the most frequent PTW (Powered Two-Wheeler) accident scenarios in the GIDAS (German In-Depth Accident Study) database in which PTWs become the victim of accidents(Figure 1). Out of those accident scenarios, crossing traffic and left turn scenarios in which PTWs become the victim are found to add up to 24.1% of the total of PTW accidents. CMC performed a study for crossing traffic and left turn accident scenarios explained in this report, using the GIDAS database and GIDAS-PCM (Pre-Crash-Matrix).
For other accident scenarios in which the PTW becomes the victim, i.e., longitudinal traffic and lane change scenarios, these will be the subject for future study by CMC.
The reason why Left turn is selected prior to other scenarios is that the left turn accidents are likely to become serious or fatal injury compared to other scenarios.

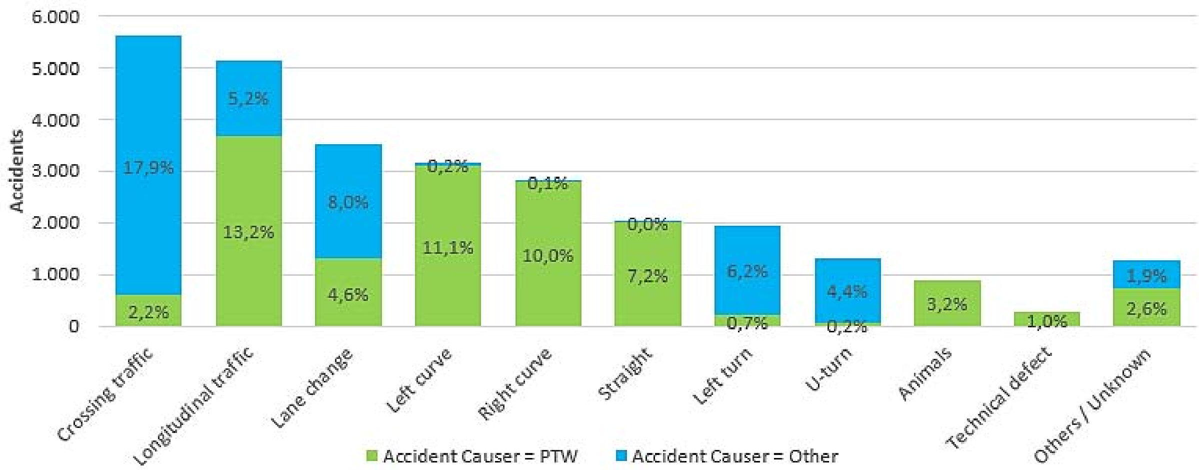


Figure 1: Accident causation in the PTW scenarios

2. Study structure

Accident analysis of the use cases is composed of 2 steps. The first step is a fact-based analysis using the GIDAS database (module 1) and the second step is an analysis using the simulation database GIDAS-PCM, which contains more detailed information for each time step and each participant (e.g., trajectories and manoeuvres of the participants). (module 2).

Module 1

This study uses the GIDAS database which contains precise information of the actual accidents occurred. From the database, the following fact-based data are extracted and studied.

a) Location of the accident: rural / urban
b) Accident scene: straight / bend / junction, etc.
c) Kind of traffic regulation: right of way / stop sign / traffic lights, etc.
d) Kind of road user: M1/N1, M2/N2, motorcycle, bicycle, etc.
e) Main accident causer
f) Main accident causation: mis-obeyed priority / turning, etc.
g) Types of speed limitation: local limit / traffic sign, etc.
h) Maximum permitted speed: 30km/h, 50km/h etc.
i) Speed limit and distribution
j) Speed before the accident and at the time of collision
k) View obstruction
l) Used lane when encountering an accident
m) Road surface: asphalt / cobble stone / sand, etc.
n) Precipitation at the time of the accident
o) Road condition: dry / wet / snow, etc.
p) Cloudiness at the time of the accident
q) Interview result: visibility limitation
r) Interview result: overlooked / distracted, etc.
s) Interview result: misjudgement
t) Interview result: accident-avoidance possibility by other action
u) Interview result: mistakes in executing the avoidance action
v) Interview result: influence from vehicle technology
w) Interview result: influence of road condition

Module 2

This study uses the simulation database GIDAS-PCM and derives the following data.

a) Trajectory of the traffic participants
b) Manoeuvre of the traffic participants
c) Speed of the traffic participants
d) Deceleration / Acceleration of the traffic participants
e) TTC model

Selecting the use cases for analysis

Within the selected accident types, there exist more precise accident types as shown in Figure 2 and Figure 3 for crossing traffic accident and left turn accident, respectively. Which use case to first concentrate on has been decided from the frequency of the specific use case, i.e., accident type 302 for crossing traffic which counts for 38% (n=2,014) of all the crossing traffic accident types and accident type 211 for left turn which counts for 91.5% (n=1,568) of all the left turn traffic accident types.

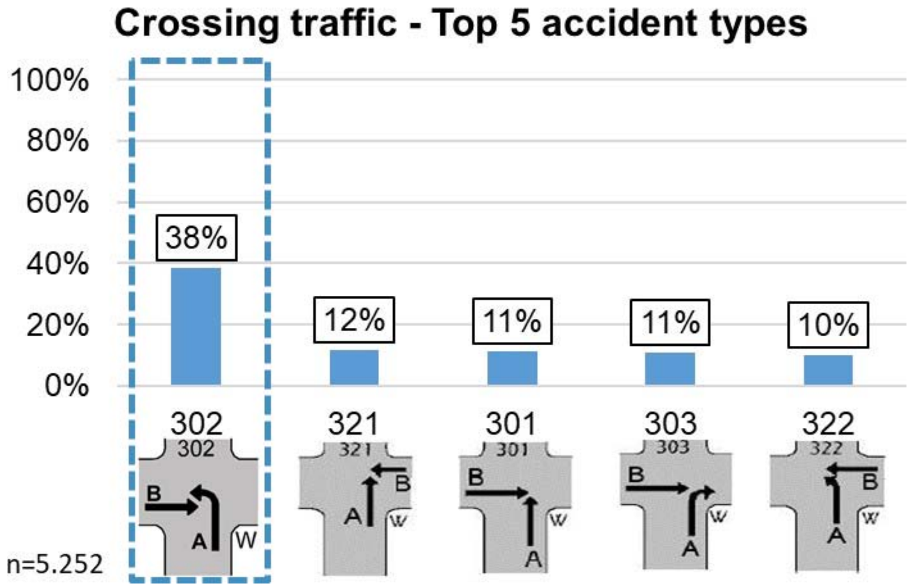


Figure 2: Selection of crossing traffic accident type

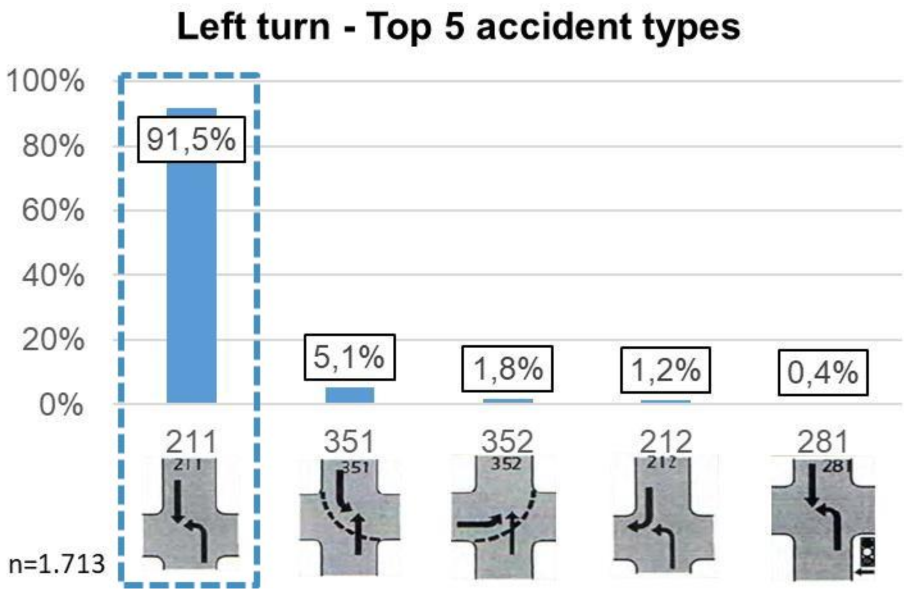


Figure 3: Selection of left turn accident type

3. Use case description

3.1.1 Crossing traffic accident type 302

The crossing traffic accident type 302 describes a conflict between a left turning road user (participant A) who is obligated to wait (“W” in the figure), and a road user (participant B) entitled to the right of way (Figure 4).
It does not matter whether the waiting participant A is obliged to wait by traffic signs (e.g., STOP sign, GIVE WAY sign). The accident type 302 may occur at junctions and crossings of roads, field or cycle paths, railway crossings as well as property exits or at parking lots.

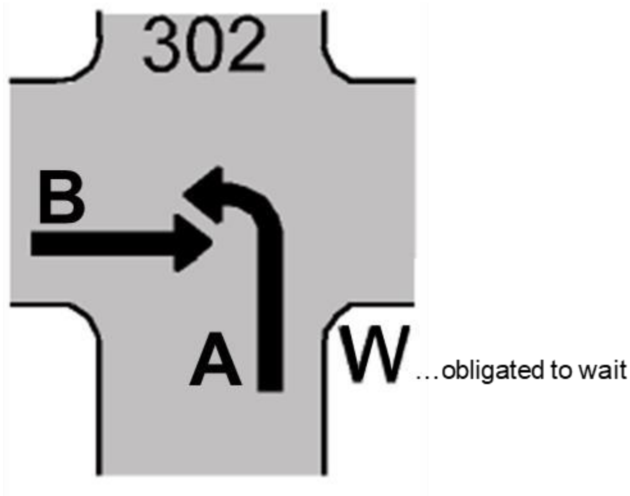


Figure 4: Crossing traffic accident type 302

3.1.2 Left turn accident type 211

The left turn accident type 211 is caused by a conflict between a left turning road user (participant A) and a road user (participant B) coming from the opposite direction (Figure 5).
Accident type 211 may occur at junctions and crossings of roads, field or cycle paths as well as access roads, e.g., to a property exit or to a parking lot.

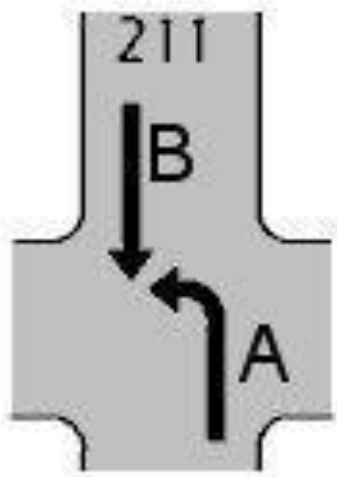


Figure 5: Left turn accident type 211

4. Summary of the Analysis Results

In this chapter, a summary of the analysis results of each accident type is described. Detailed analysis results can be found in Chapter 5 and 6.

4.1 Crossing traffic accident type 302

Findings from the analysis results.

- More than 90% of these accidents occur at junctions, crossings or property exits. (5.1.2 , 5.1.13)
- Accidents are caused by M1/N1 vehicles (Cars and Trucks) in more than 95% of cases and Participant B in Figure 4 is a PTW in more than 90% of accidents. (5.1.4 , 5.1.13 , 5.1.16)
- The speed at collision of participant A is 5-18km/h, while that of participant B is 26-47km/h (75%tile). (5.1.10)
- In more than 30% of accidents, there was a view obstruction from participant A point of view. (5.1.11)
- Weather condition is not a major factor for the accidents (5.1.13 to 5.1.16)
- The last two manoeuvers before collision indicate that participant A did not decelerate before collision, but instead, was accelerating in more than 50% of the accidents. (5.2.2 6.2.2)
- TTC can be calculated at 4.5 seconds before collision (50%tile). (5.2.5)

4.2 Left turn accident type 211

Findings from the analysis results.

- More than 90% of these accidents occur at junctions, crossings or property exits. (6.1.2)
- Accidents are caused by M1/N1 vehicles in more than 90% of cases and Participant B in Figure 5 is a PTW in more than 90% of the accidents. (6.1.4 , 6.1.5)
- The speed at collision of participant A is 12-22km/h, while that of participant B is 27-51km/h (75%tile). (5.1.10)
- There was a view obstruction from participant A point of view in around 17% of accidents. (6.1.11 5.1.11)
- Weather condition is not a major factor for the accidents (6.1.13 to 6.1.16)
- The last two manoeuvers before collision indicate that participant A did not decelerate before collision in more than 40% of accidents. (6.2.2)
- TTC can be calculated at 1.5s before collision. (50%tile). (6.2.5)

5. Crossing traffic accident type 302 analysis

5.1 Module 1

5.1.1 a) Location of the accident

The majority of PTW accidents for crossing traffic occurred on urban roads which accounts for 67.3% of overall 302 type (Figure 6). This could be understood from the fact that in an urban area, more traffic participants exist and more crossing roads exist, all making it more a frequent situation.

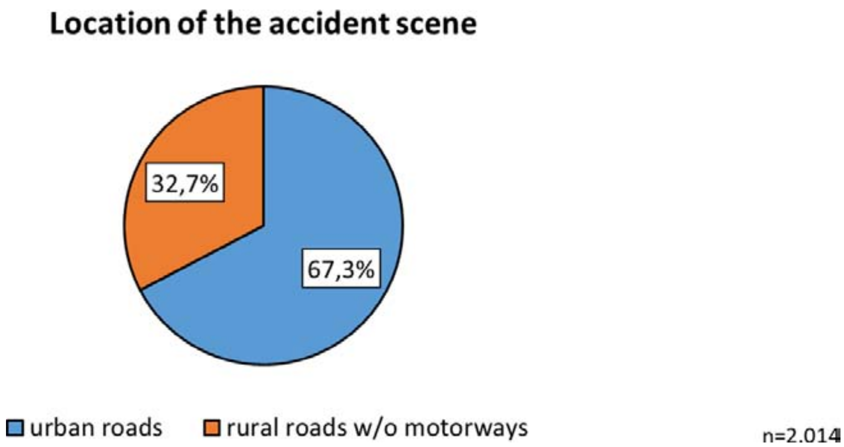


Figure 6: Location of the accident (302)

5.1.2 b) Accident scene

The majority of PTW accidents for crossing traffic occurred at junctions which accounts for 53.2% of overall 302 type (Figure 7). The second frequent scene is at crossings which accounts for 29.5%. Also, accidents at property exits account for 16.1%. It is commonly understood that PTWs, being small in size, are often misjudged by car drivers regarding their speed and distance. In the frame of the MAIDS project (Motorcycle in-depth accident study), in-depth analyses of 921 accidents from five sampling areas across Europe involving PTWs were conducted (ACEM, 2009[1]). Focussing on the other vehicle involved, traffic-scan error was present and contributed to accident causation in 62.9 % of the analysed data. In further 18.4 % an attention failure including distraction and stress was observed. Therefore, to properly time the entry into these junctions and crossings is a challenge for car drivers.

[1] ACEM (2009), MAIDS Final report 2.0, available online https://www.maids-study.eu/pdf/MAIDS2.pdf (last access November 19th 2021).

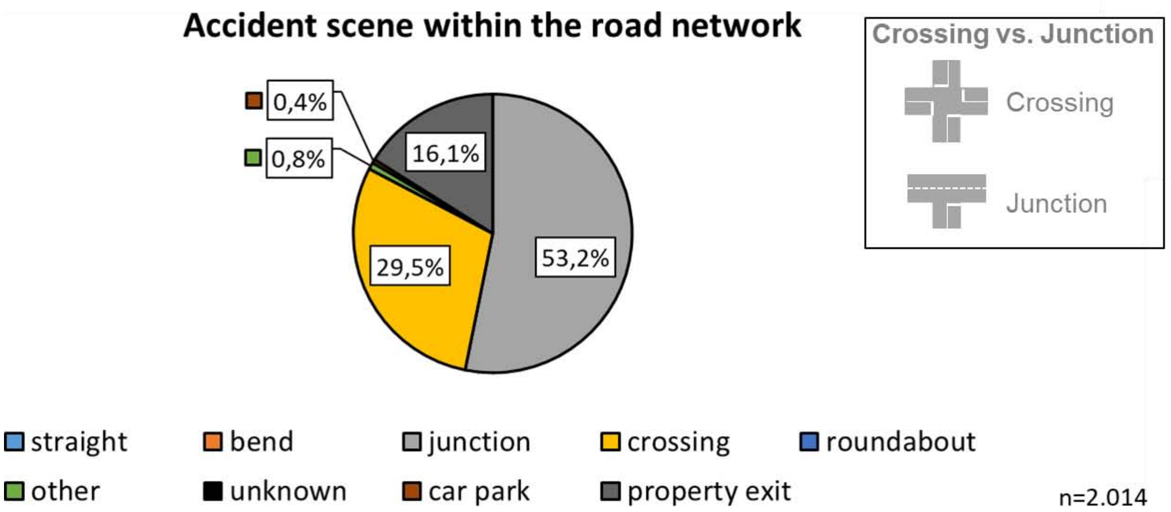


Figure 7: Accident scene (302)

5.1.3 c) Kind of traffic regulation

Right-of-way regulation was the predominant traffic regulation at the accident site involving PTWs which counts for 73.3% of overall 302 type (Figure 8). As mentioned in 3.1.2, the PTW being small in size is often misjudged and even if participant A is following the rule of right of way, it could be that the timing for participant A to enter the junction / crossing may have been improper.

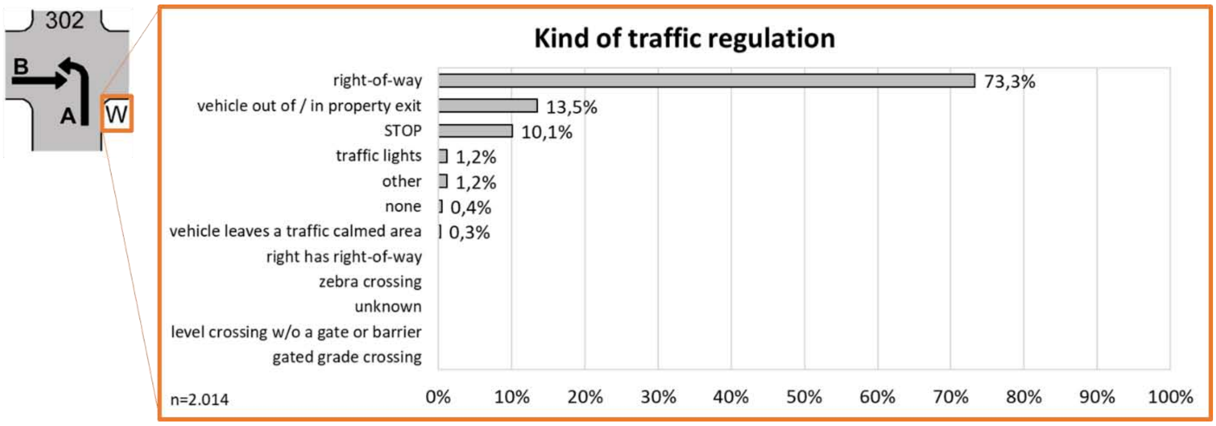


Figure 8: Kind of traffic regulation (302)

5.1.4 d) Kind of road user

Traffic participants in crossing traffic accident type 302 involving a PTW, are shown in Figure 9. From the figure, it can be seen that in most cases, participant A consists of M1 / N1 vehicles (passenger cars / light commercial vehicles) and for participant B, motorcycles.

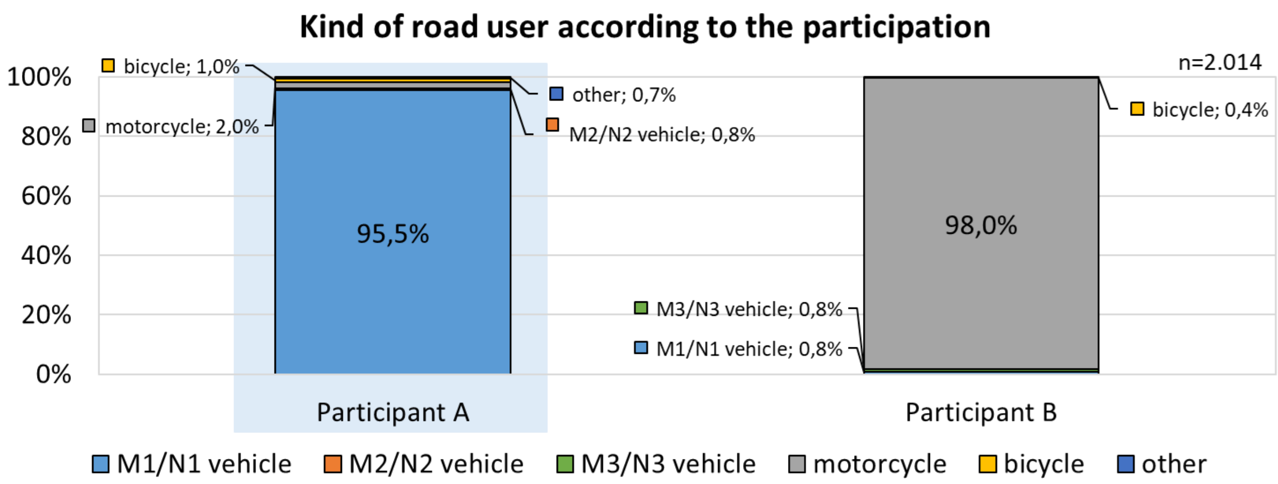


Figure 9: Kind of road user (302)

5.1.5 e) Main accident causer

The main accident causer in crossing traffic accidents is shown in Figure 10. It is clear from the figure that the main accident causer is participant A and in only a small percentage participant B. Figure 9 and Figure 10 indicates that there is a strong need to address car driver's driving behaviour in order to mitigate PTW accidents in crossing traffic accident situations.

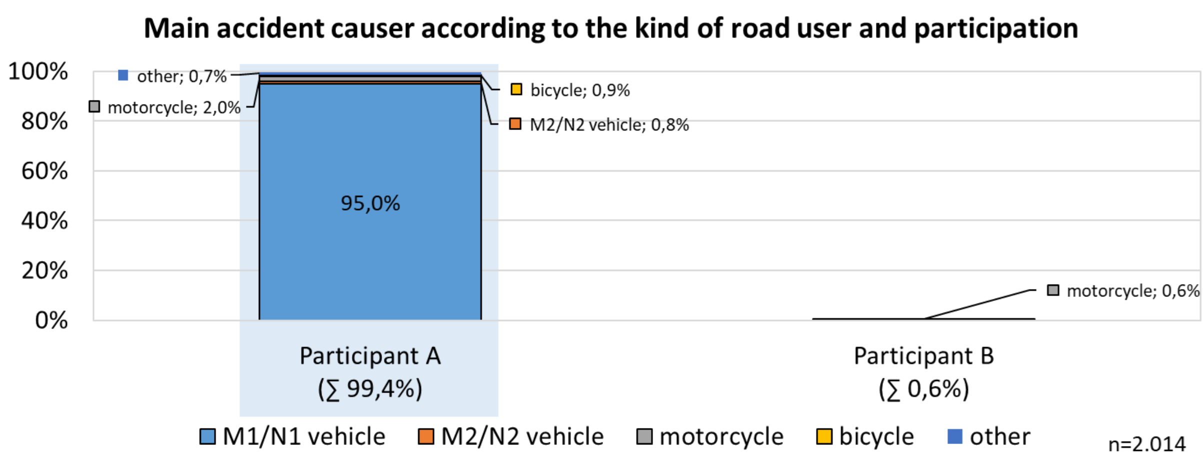


Figure 10: Main accident causer (302)

5.1.6 f) Main accident causation

The causation of the accidents is studied and shown in Figure 11 and Figure 12. From the figures, it is understood that the main reason for the accident was failure of participant A to respect priority and for participant B, it was the speed. Please remind that in 99.4% of cases, participant A was the main accident causer and only in 0.6% of cases, participant B was the main accident causer.

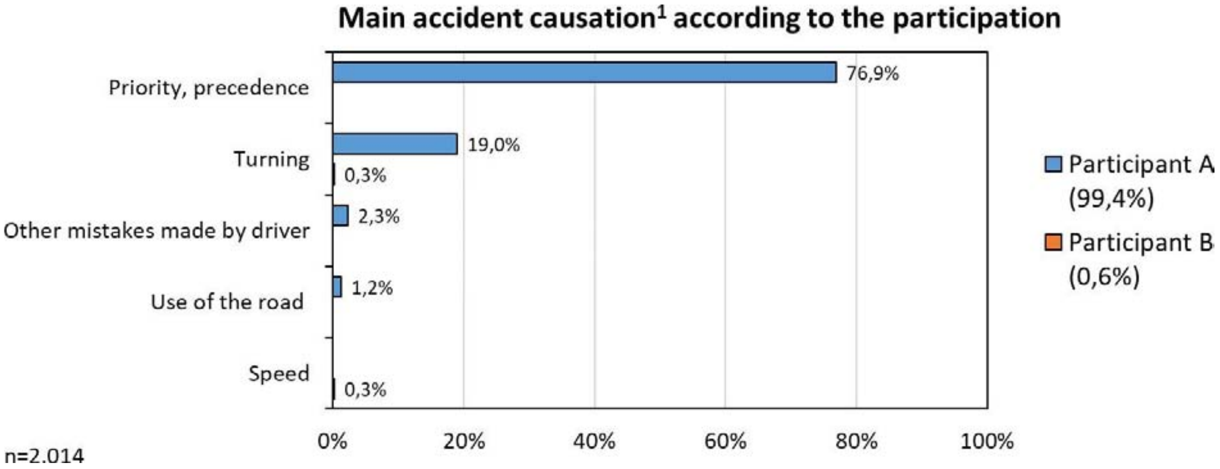


Figure 11: Main accident causation (302)

1: The police and also the technical investigation units in GIDAS have to assign a main accident causer with one main accident causation in each accident.

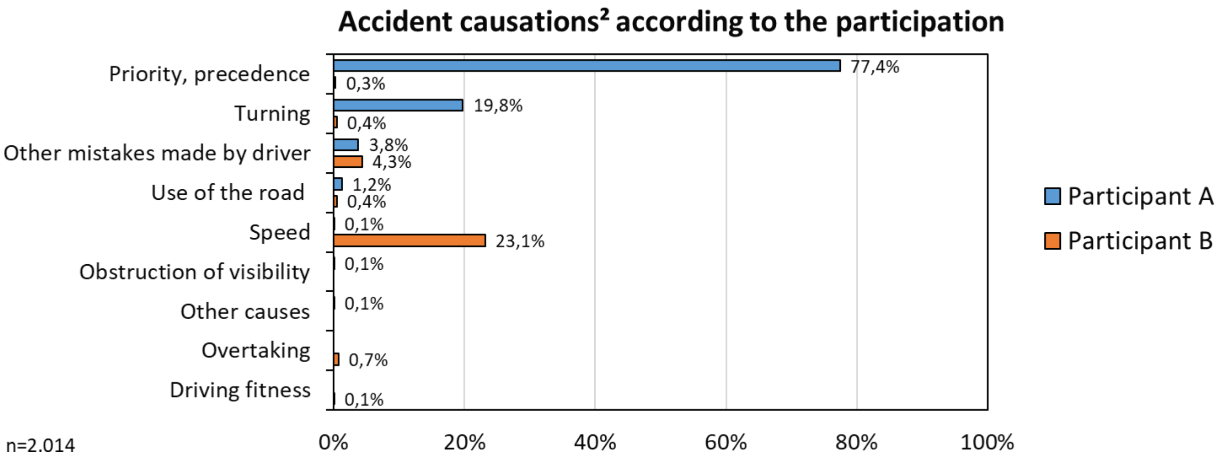


Figure 12: Accident causations (302)

2: The police and the technical investigation units in GIDAS can assign up to 3 accident causations for each accident participant. Consequently, one accident can have several accident causes depending on the participant and so the sum of the accident causations is ≥100%.

5.1.7 g) Types of speed limitation

What provides the speed limit to each participant is shown in Figure 13. Both for participant A and B, the majority of speed limit is provided by local traffic rules and secondly by traffic signs.

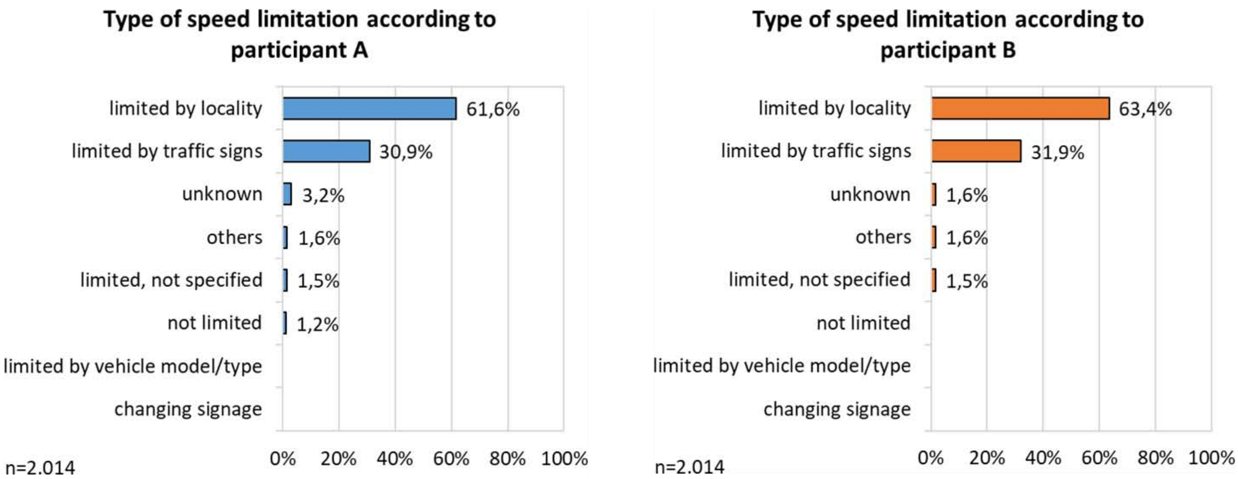


Figure 13: Types of speed limitation for the participants (302)

5.1.8 h) Maximum permitted speed

Maximum permitted speed on the accident site is shown in Figure 14. As from Figure 6 that 2/3 of accidents took place at urban roads, it is reasonable to see that the most frequent maximum permitted speed is 50km/h. However, as participant B has the right of way, a higher maximum permitted speed can be observed with participant B.

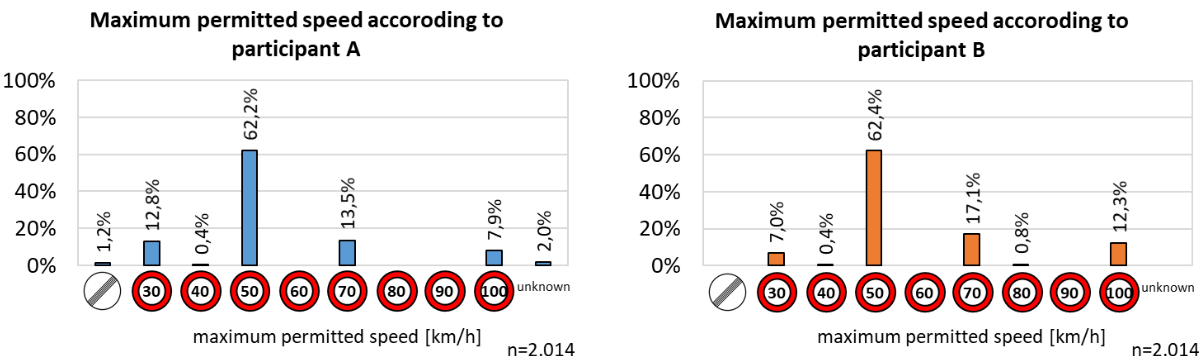


Figure 14: Maximum permitted speed (302)

5.1.9 i) Speed limit and distribution

Figure 15 shows the percentage of participants exceeding the applicable speed limit. Comparing participants A and B, it can be observed that participant B is more often seen to have exceeded the speed limit. This could be understood from the crossing traffic accident type that participant A starts its action by waiting and then to turn while participant B is to go straight passing through.

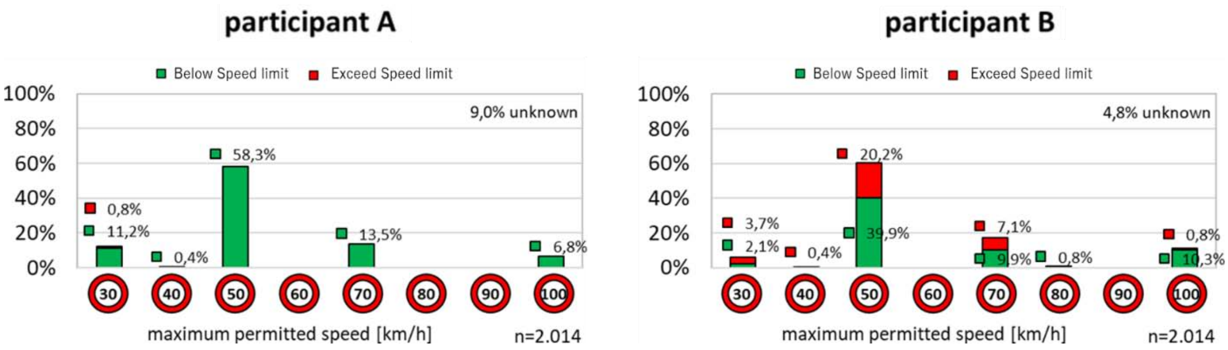


Figure 15: Exceeding Speed limit (302)

Figure 16 shows the distribution of how much participant B exceeded the allowable speed for each given speed limit before reaching the point of incident. Though participant B in the crossing traffic accident scenario has the right of way, in some cases, exceeding the speed limit could be one of the influencing factors for participant B.

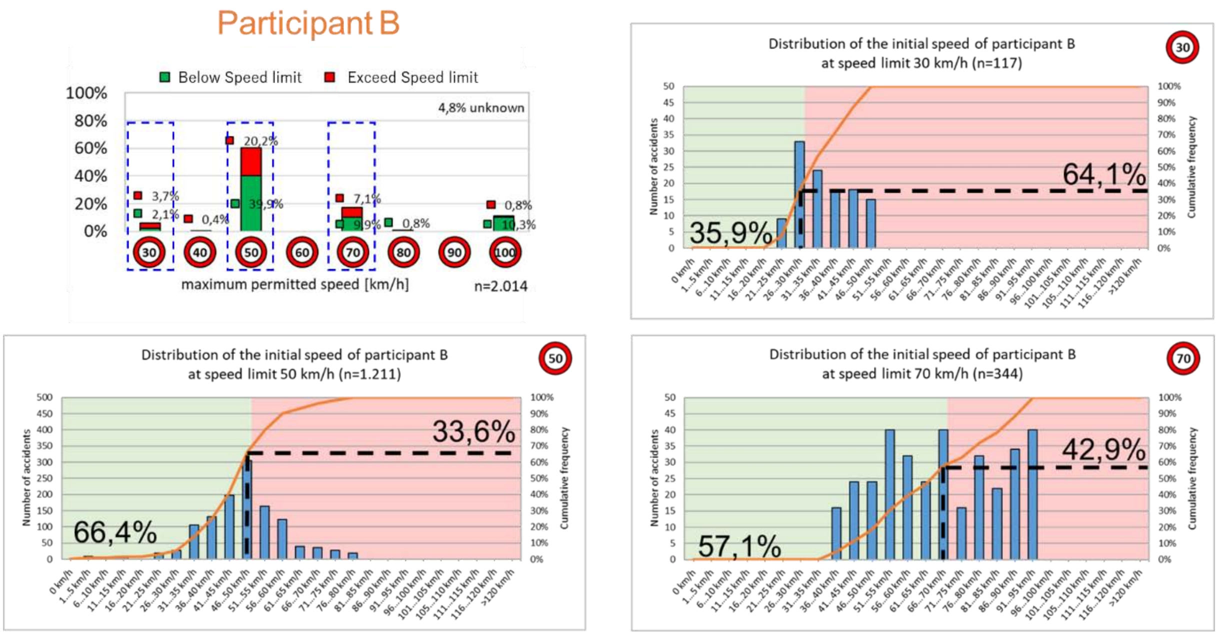


Figure 16: Speed distribution by participant B (302)

5.1.10 j) Speed before the accident and at the time of collision

Figure 17 shows the initial speed of each participant. It is clear from the figure that participant B going straight has higher average speed than participant A who waits to start the turning process.

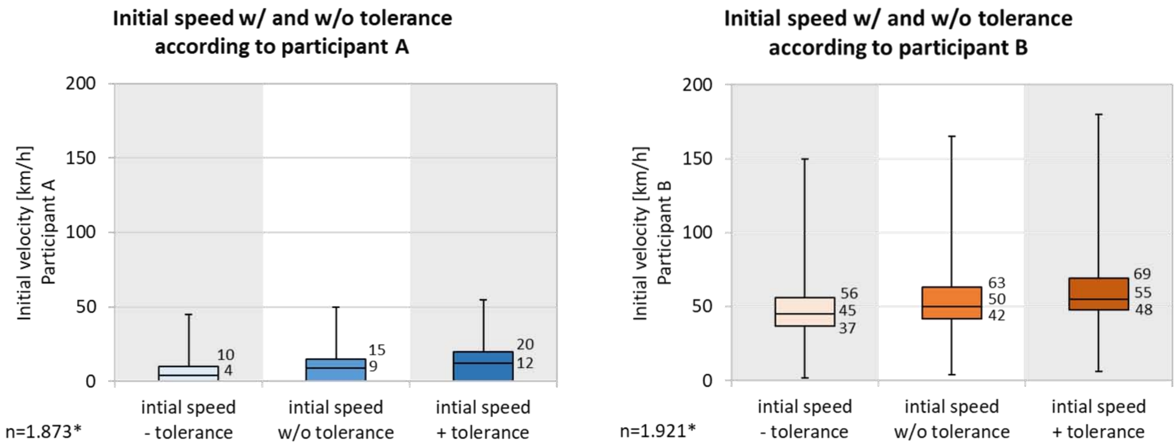


Figure 17: Initial speed of participants (302)

Figure 18 shows the collision speed of each participant. Comparing the initial speed of participant A in Figure 17 and the collision speed in Figure 18, participant A is found to slowly start and collide in a few km/h higher speed. This could indicate that participant A was waiting for a chance to start the process but missed its timing and collided.
Looking at participant B, comparing the initial speed in Figure 17 and the collision speed in Figure 18, it is seen that it starts from 50km/h initially and decelerates to 38m/h for the median scenario which could be understood that participant B has recognised participant A blocking its way and has decelerated.

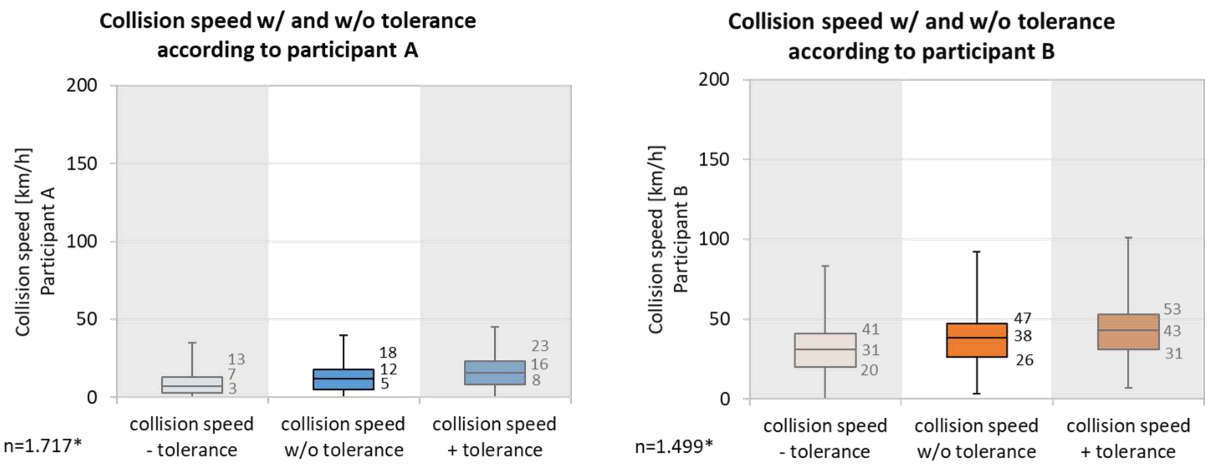


Figure 18: Collision speed of participants (302)

5.1.11 k) View obstruction

Figure 19 and Figure 20 show existence of view obstructions and the types of obstruction respectively. It can be seen that around 70% of the cases had no view obstructions and the rest with permanent obstruction, e.g., buildings, and non-permanent obstruction, e.g., moving and parked cars.

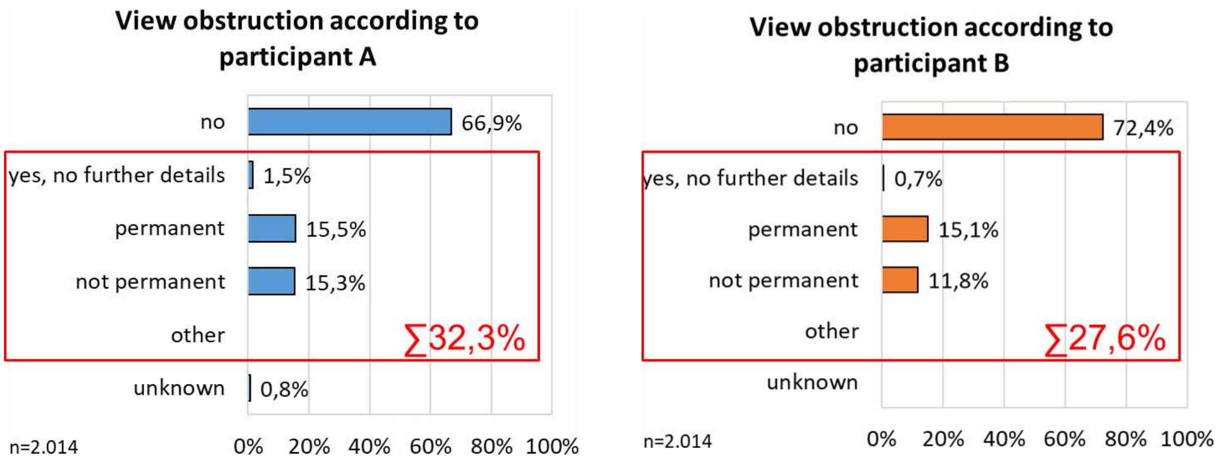


Figure 19: View obstructions (302)

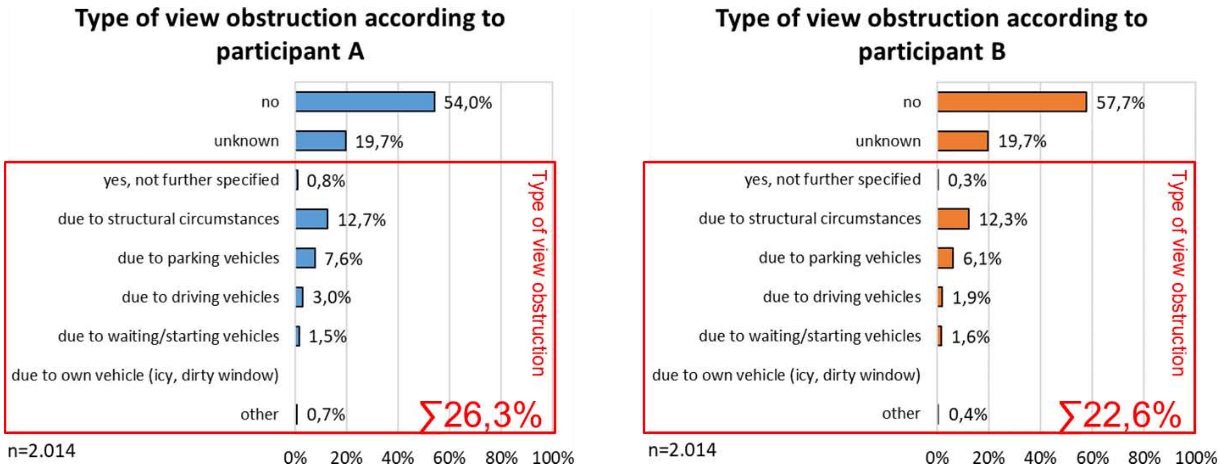


Figure 20: Type of view obstruction (302)

5.1.12 l) Used lane when encountering an accident

Figure 21 shows which lane the participants took when encountering an accident. The majority of this crossing traffic accident scenario participants were driving at a single lane road.

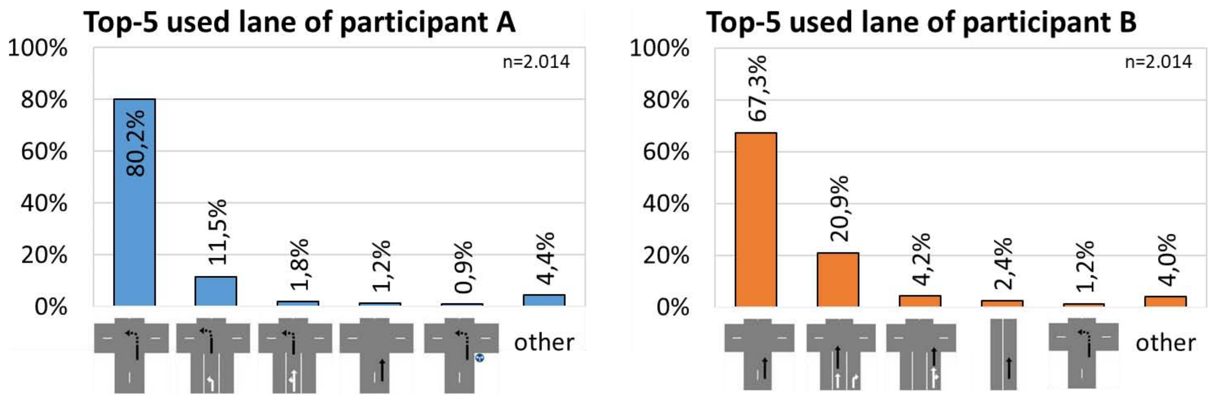


Figure 21: Used lane at an accident (302)

5.1.13 m) Road surface

Figure 22 shows which kind of road surface it was when encountering an accident. The majority of crossing traffic accident scenario participants were driving at a conventional asphalt road. For participant A, 12.6% indicates it was a paving / cobble stoned road which they drove before entering the main road.

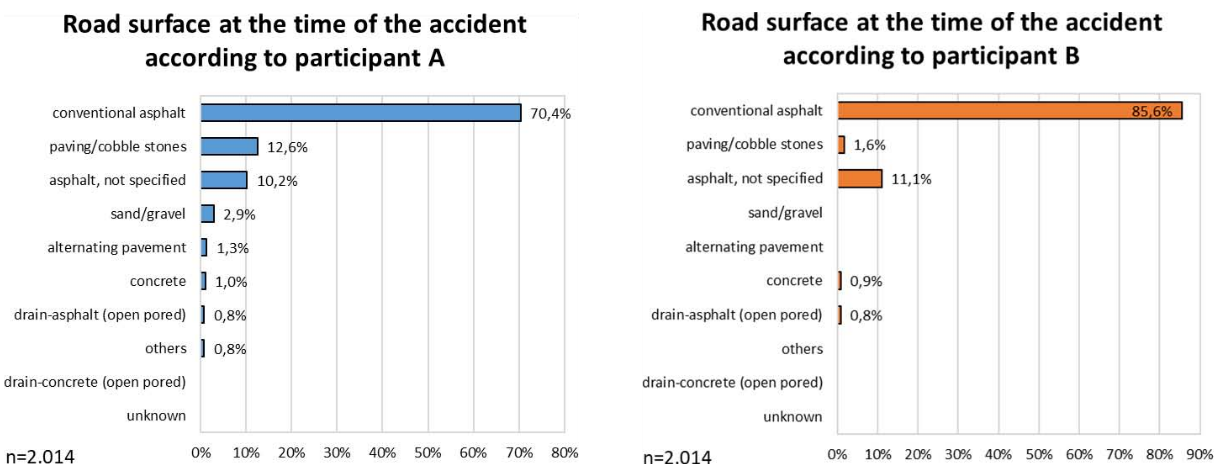


Figure 22: Road surface (302)

5.1.14 n) Precipitation at the time of the accident

Figure 23 shows precipitation at the time of the accident. From the figure, it can be observed that in most accidents it was not raining.

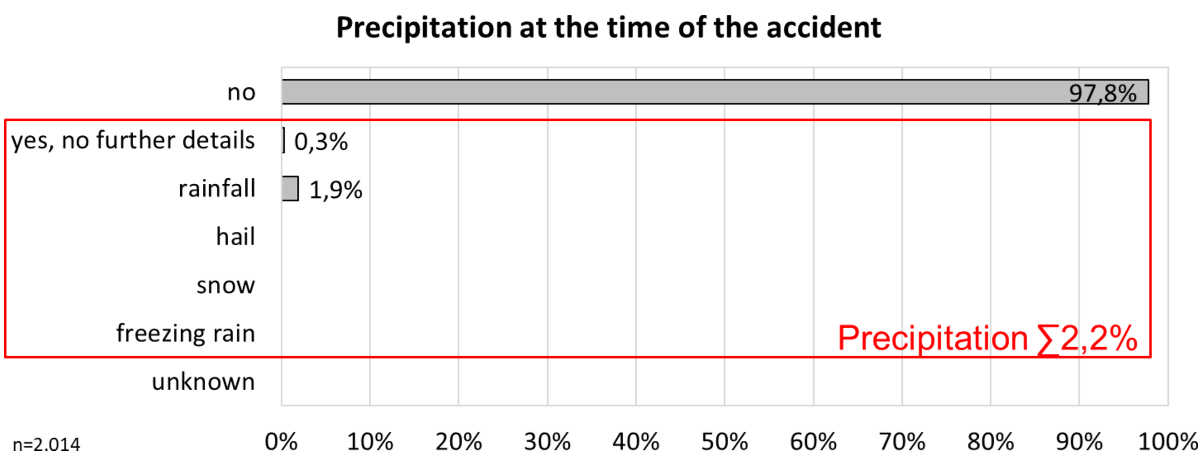


Figure 23: Precipitation (302)

5.1.15 o) Road condition

Figure 24 shows the road condition at the time of the accident. From the figure, it can be observed that in most accidents it was with dry road surface which would allow full brake performance.

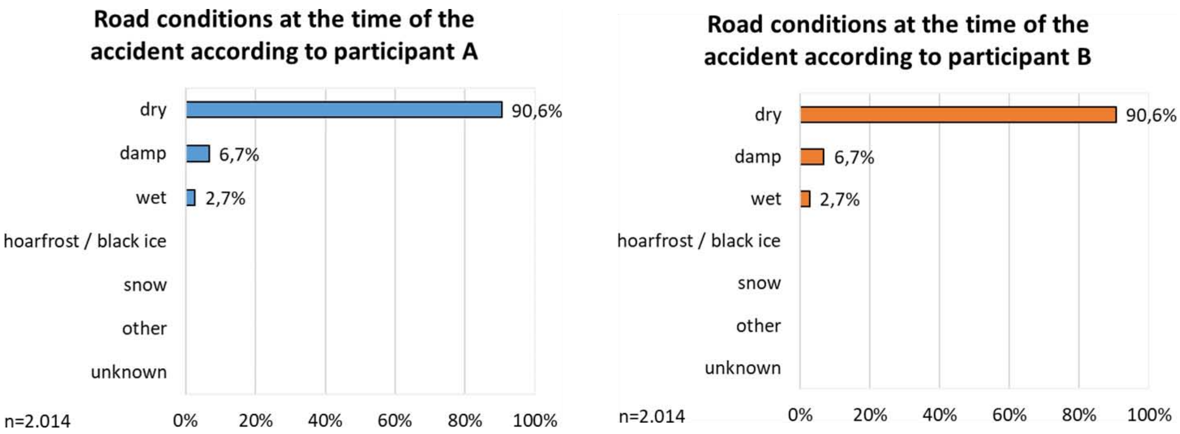


Figure 24: Road condition (302)

5.1.16 p) Cloudiness at the time of the accident

Figure 25 shows cloudiness at the time of the accident. Every fifth accident showed no clouds and few clouds in more than 40% of accidents.

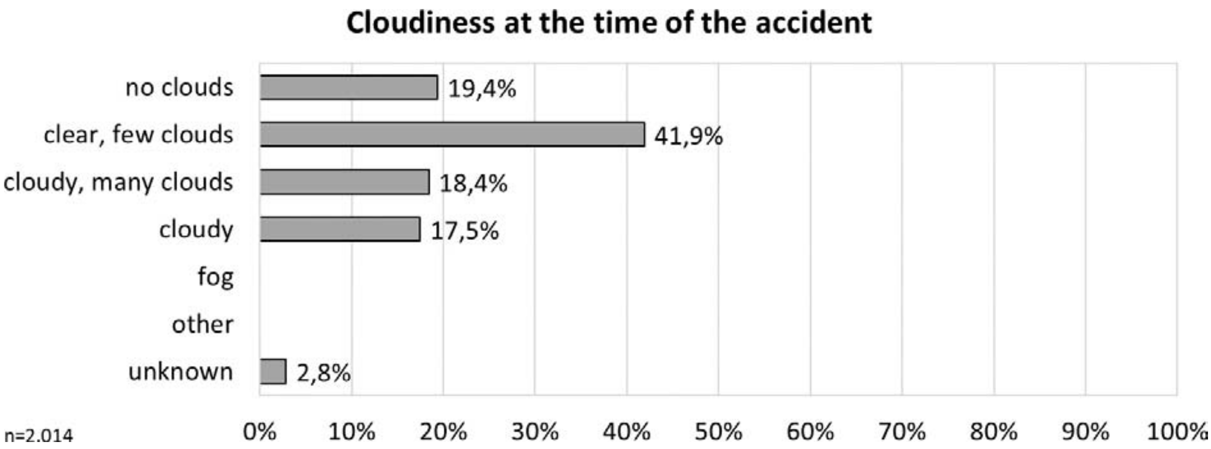
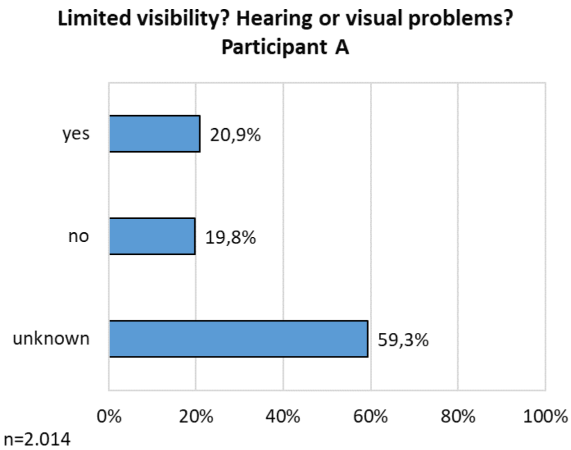


Figure 25: Cloudiness (302)

5.1.17 q) Interview result: visibility / audibility limitation

Figure 26 shows the participant interview results about visibility and audibility limitations. As can be seen in the figure, participant A reports more often a limitation in visibility or audibility than participant B. This may indicate more challenge for participant A in judging the decision for manoeuvring.



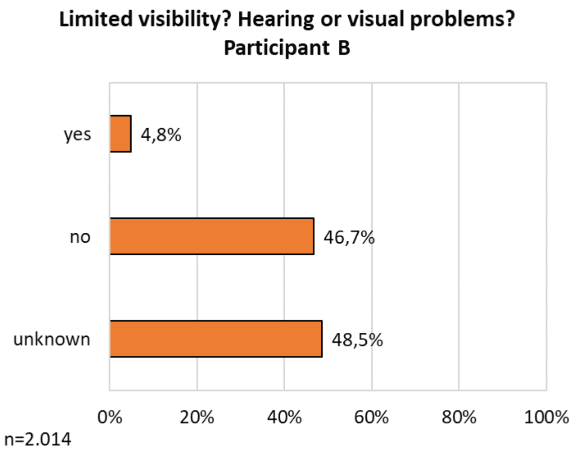
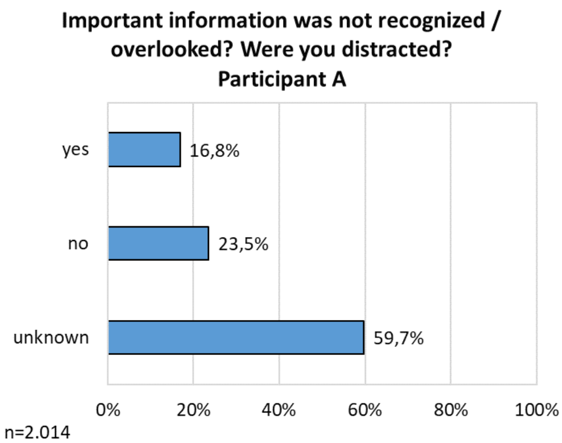


Figure 26: Interview - visibility / audibility limitation (302)

5.1.18 r) Interview result: overlooked / distracted, etc.

Figure 27 shows the participant interview results whether they overlooked important information or if they were distracted. As from the figure, participant A reports more overlooking or distraction compared to participant B.
Figure 28 shows further insight into the influencing factors of participant A, who answered that they overlooked or were distracted. For the factors asked, such as stress, fatigue etc., over 70% of the participant A answered that there was no influence. . This may indicate that in most cases, participant A's overlooking or being distracted simply comes from human error.



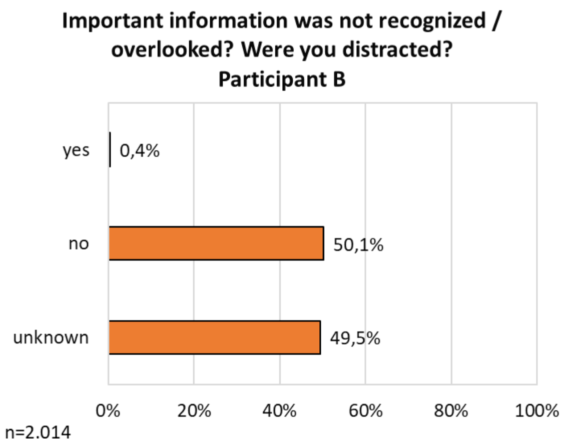


Figure 27: Interview - overlooked / distracted (302)

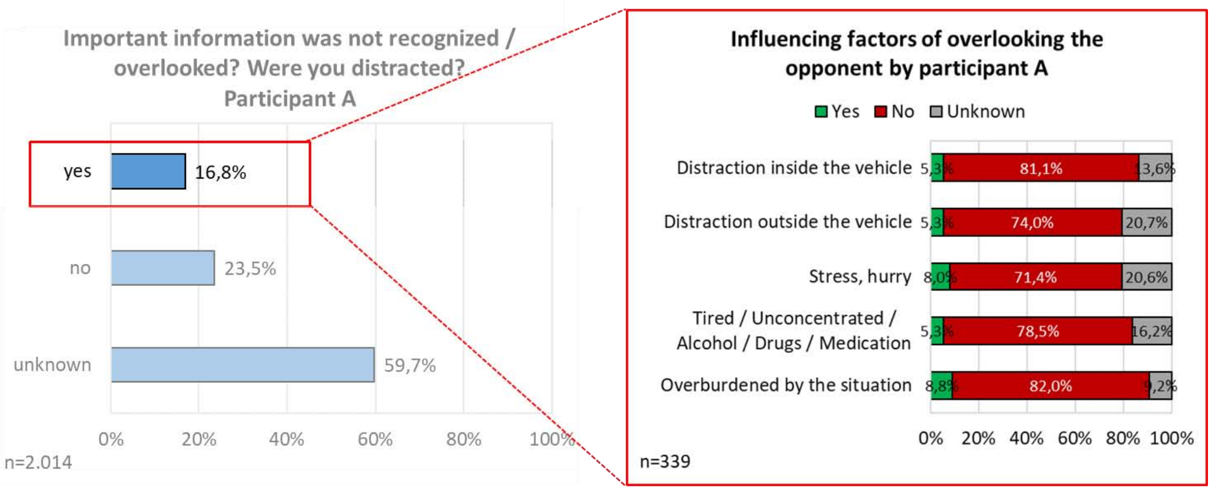


Figure 28: Interview - Influencing factors for overlooking (302)

5.1.19 s) Interview result: misjudgement

Figure 29 shows the participant interview results whether they misjudged the situation or not. For participant A, out of those who answered "yes" or "no", (so taking out the unknown cases), 78% (=31.3/(8.8+31.3)x100) of the participants report they have not misjudged the situation. For participant B, this rate is higher, at 92% (=46.7/(4.1+46.7)x100). It was reported that most of the participants B felt innocent and had assessed the situation correctly.

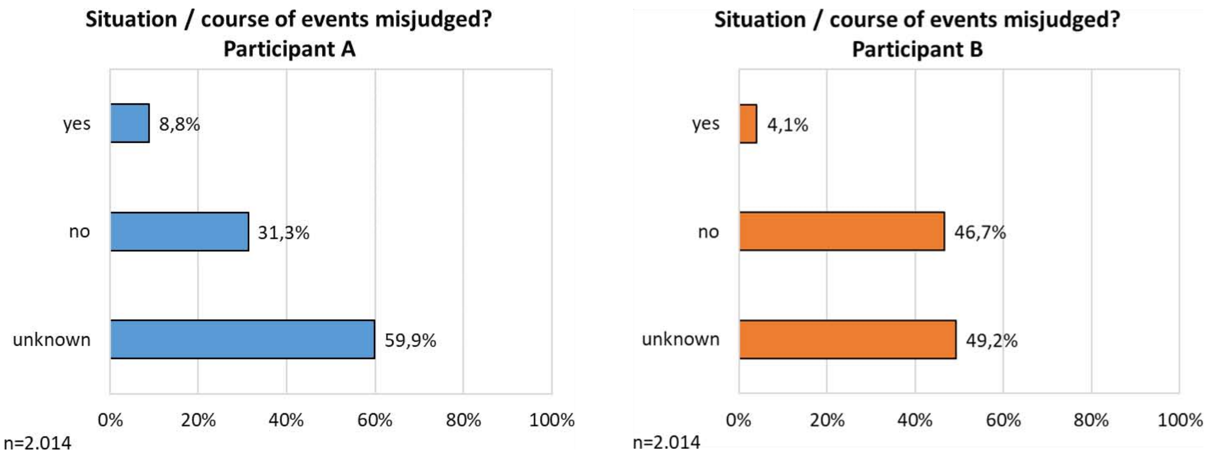


Figure 29: Interview - Misjudgement (302)

5.1.20 t) Interview result: accident-avoidance possibility by other action

Figure 30 shows the participant interview results whether the accident would have been possible to be avoided by other reaction / action. Comparing the number of participants answering "yes" to "no", for both participant A and B, the ratio of "no" is much higher meaning that the accident was not possible to be avoided with other actions taken.

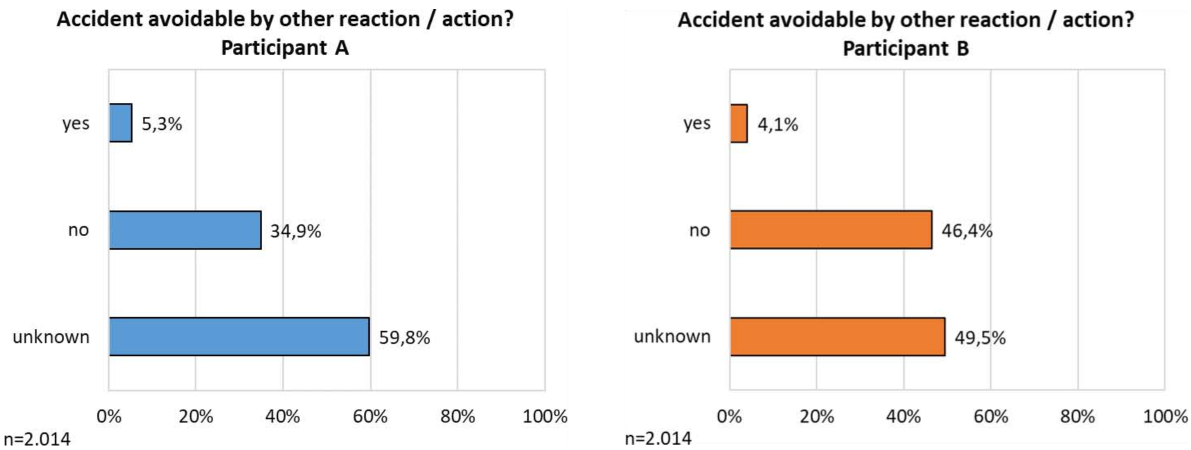


Figure 30: Interview - Accident avoidance possibility (302)

5.1.21 u) Interview result: mistakes in executing the avoidance action

Figure 31 shows the participant interview results about difficulties / mistakes in taking the planned action. Comparing the number of participants answering "yes" to "no", for both participant A and B, the ratio of "no" is much higher meaning that the planned action was not difficult or mistaken to execute. If comparing the "yes" ratio of participant A to participant B, participant B shows a slightly higher number which means that the planned action, e.g., braking or steering was slightly more difficult or mistakenly executed.

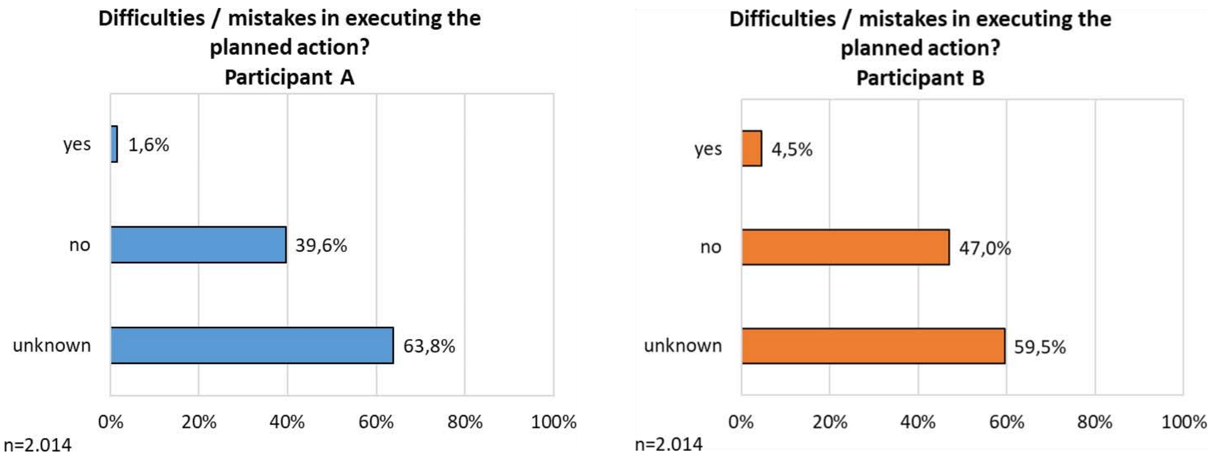


Figure 31 Interview - Mistakes in avoidance action (302)

5.1.22 v) Interview result: influence from vehicle technology

Figure 32 shows the participant interview results about influence of the vehicle technology. This query is asking whether the participants had difficulty in operating a certain function provided by the vehicle or were distracted by the function on the vehicle. The ratio of participants answering "no" for both participant A and B are much higher than those answering "yes" meaning that there was little influence by the vehicle technology leading to an accident.

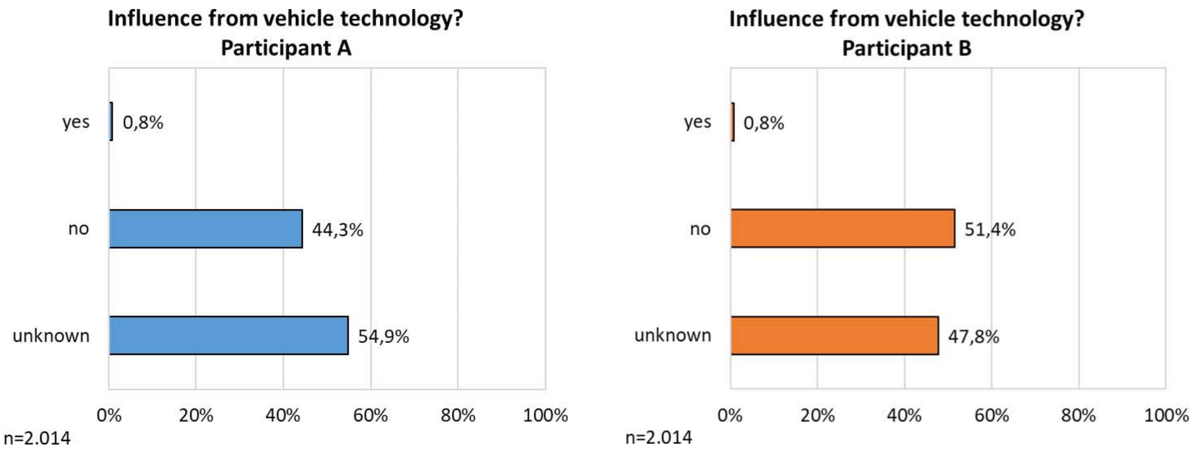


Figure 32: Interview - Influence from vehicle technology (302)

5.1.23 w) Interview result: influence of road condition

Figure 33 shows the participant interview results about the influence of the road condition. The ratio of participants answering "no" for both participant A and B are much higher than those answering "yes", meaning that there was little influence of road conditions such as a slippery road leading to an accident.

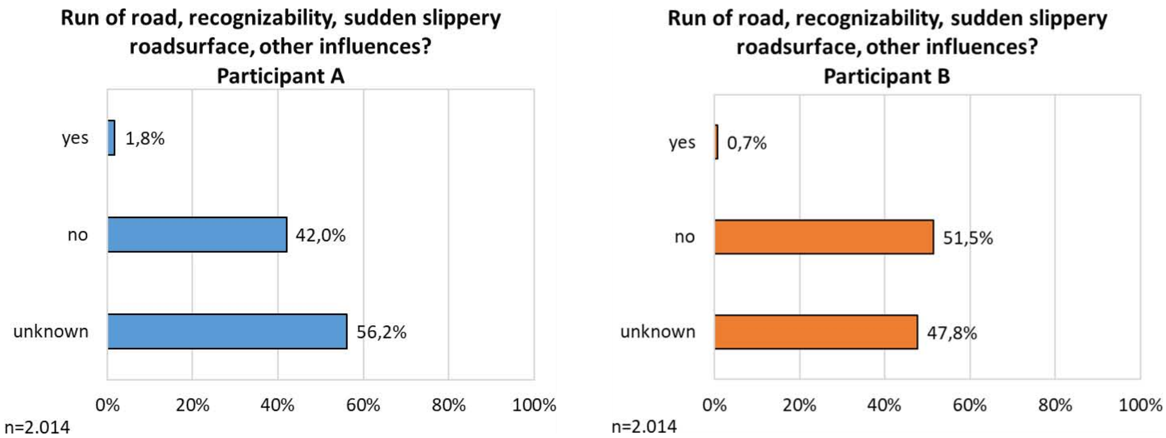


Figure 33: Interview - Influence of road condition (302)

5.2 Module 2

The database for the study of Module 2 is not the factual GIDAS data base but the simulation database GIDAS-PCM, which contains more detailed information for each time step and each participant (e.g., trajectories and manoeuvres of the participants). An overview of both databases is shown in Figure 34.

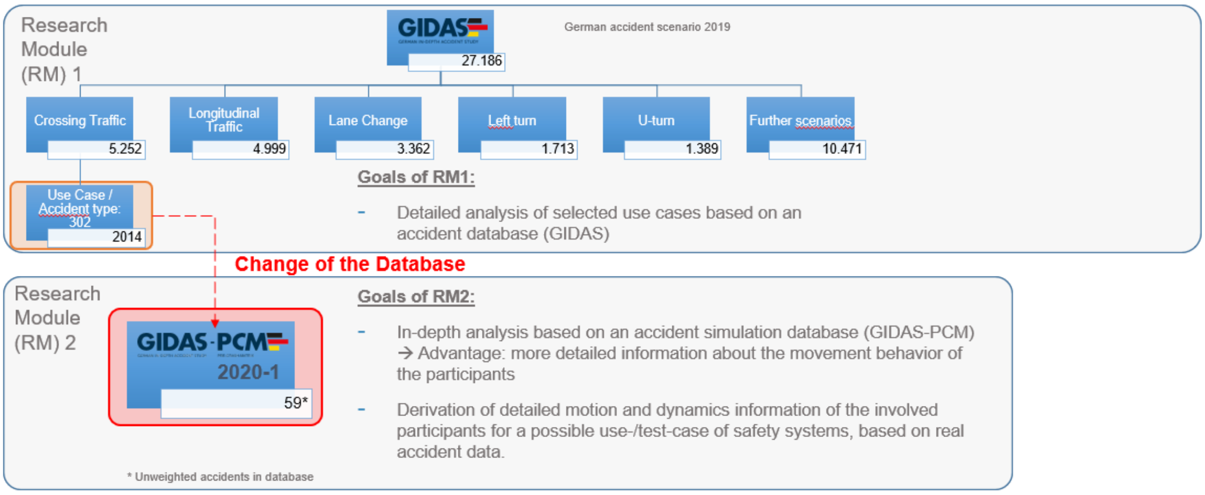


Figure 34: Overview of the database used for Module 2 study (302)

As we have seen in Figure 1, the crossing traffic accident represents 17.9% of accidents in which PTW is the victim. As shown in Figure 35, GIDAS-PCM data shows that the PTW is always participant B in the case of Accident type 302 and participant A is a passenger car

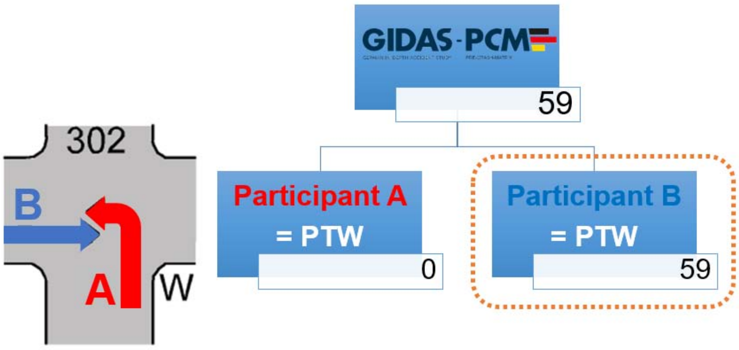


Figure 35: Assignment of the participants (302)

5.2.1 a) Trajectory of the traffic participants

For 59 accidents in GIDAS-PCM for crossing traffic accident 302, the collision point for participant B was aligned to one point and each participant's trajectories were arranged to its position accordingly. Figure 36 shows its results and from this data, the median value is derived and is shown in Figure 37.

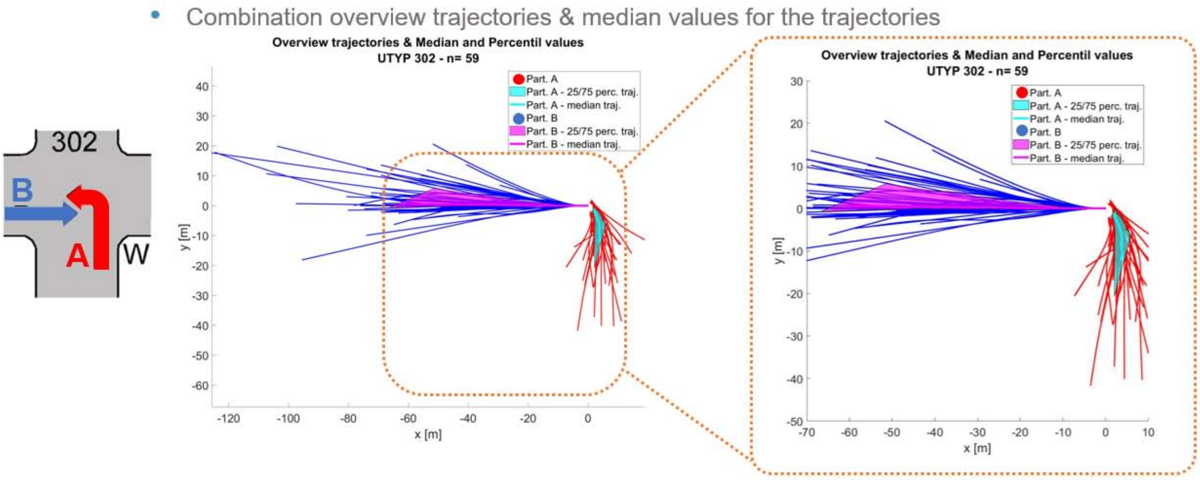


Figure 36: Trajectories of crossing traffic accident (302)

(The trajectories do not cross each other, because they display the centre of gravity trajectory.)

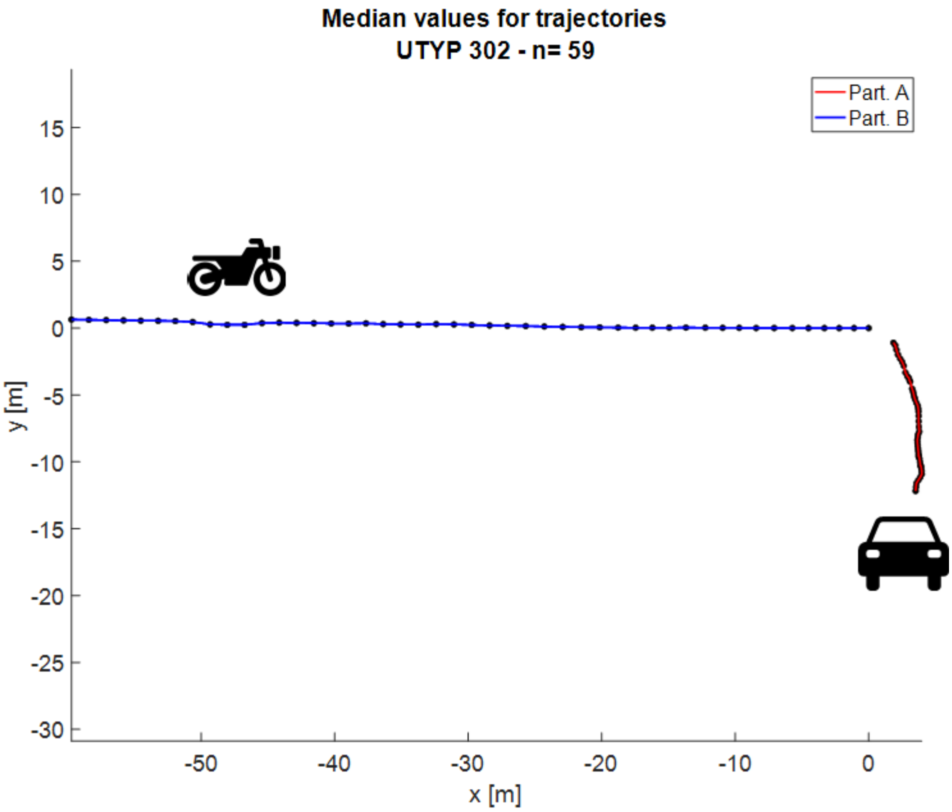


Figure 37: Median values for trajectories (302)

5.2.2 b) Manoeuvres

To understand what actions the participants were performing at each time point, the dynamics data of the participants were analysed and mapped into a manoeuvre catalogue. The manoeuvre catalogue is shown in Table 1 below. For example, MID (Manoeuvre IDentifier) 1 would mean straight forward movement with constant speed.

The criteria for evaluating whether the vehicle is in the movement of forward / backward, straight / left / right, acceleration / deceleration / standstill is shown in Table 2.

Table 1: Manoeuvre catalogue

MID	Lateral	Longitudinal	Movement	MID	Lateral	Longitudinal	Movement	MID	Lateral	Longitudinal	Movement
1	Straight	Forward	Constant	8	Left	Forward	Constant	14	Right	Forward	Constant
2			Acceleration	9			Acceleration	15			Acceleration
3			Deceleration	10			Deceleration	16			Deceleration
4		Backward	Constant	11		Backward	Constant	17		Backward	Constant
5			Acceleration	12			Acceleration	18			Acceleration
6			Deceleration	13			Deceleration	19			Deceleration
7	-	-	Standstill								

Table 2: Limits for the variables of the manoeuvre catalogue based on GIDAS-PCM

- VX - Longitudinal speed VY - Lateral speed
- AX - Longitudinal acceleration AY - Lateral acceleration

Variable	Type	
Longitudinal	Forward	Backward
Limit	$VX > 0.1 m/s$ *OR* $\vert VX \vert <= 0.1 m/s$ & $AX >= 0.5 m/s^2$	$VX < -0.1 m/s$ *OR* $\vert VX \vert <= 0.1 m/s$ & $AX <= -0.5 m/s^2$

Variable	Type		
Lateral	Straight	Left	Right
Limit	$\vert AY \vert < 0.5 m/s^2$	$AY >= 0.5 m/s^2$	$AY <= -0.5 m/s^2$

Variable	Type			
Movement	Constant	Acceleration	Deceleration	Standstill
Limit	$\vert AX \vert < 0.5 m/s^2$ *AND* $\vert VX \vert > 0.1 m/s$	$AX >= 0.5 m/s^2$	$AX <= -0.5 m/s^2$	$\vert AX \vert <= 0.1 m/s^2$ *AND* $\vert VX \vert <= 0.1 m/s$

Figure 38 shows the top 5 of the last two MIDs before a collision for participant A.
The most frequent manoeuvre was MID 2 followed by MID 9 which counts for 17%. In this manoeuvre, before starting MID 2, i.e., straight forward acceleration, the vehicle was at a standstill meaning that it was seeking for a chance to start its vehicle. The second and third frequent manoeuvre was MID 1 and MID 1 followed by MID 8 which counts for total of 27%. In these manoeuvres, participant A was at a constant speed from the beginning till the collision meaning that it disregarded the obligation to wait.

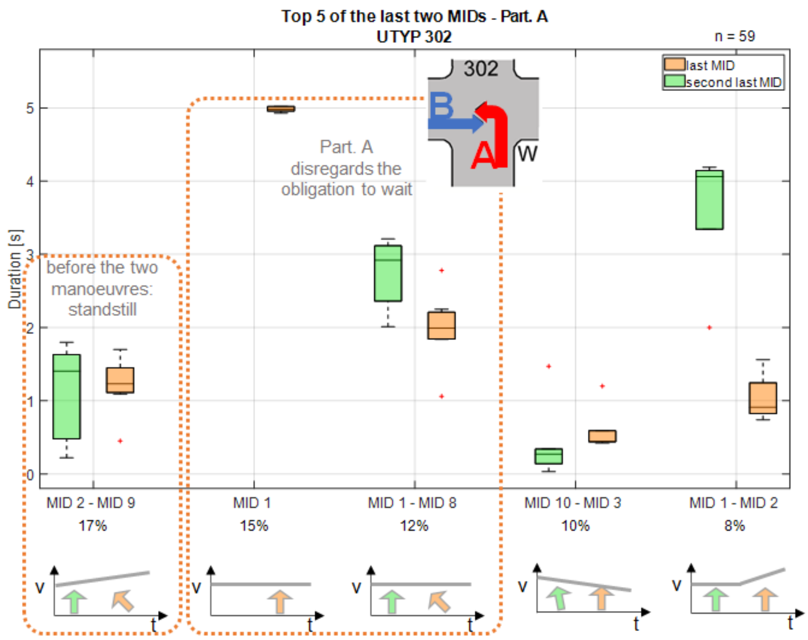


Figure 38: Top 5 of the last two MIDs for participant A (302)

Figure 39 shows the top 5 of the last two MIDs before a collision for participant B.
As the participant B is moving straight through a crossing, the vehicle is at a constant speed in the beginning and as in MID 1 followed by MID 3 which counts for 39% and MID 8 followed by MID 10 which counts for 17%, the rider recognises participant A at a certain point and starts to decelerate. MID 1 only or MID 1 before a collision would mean that the participant B did not have time to react to participant A moving or was too late to recognise participant A moving towards participant B.

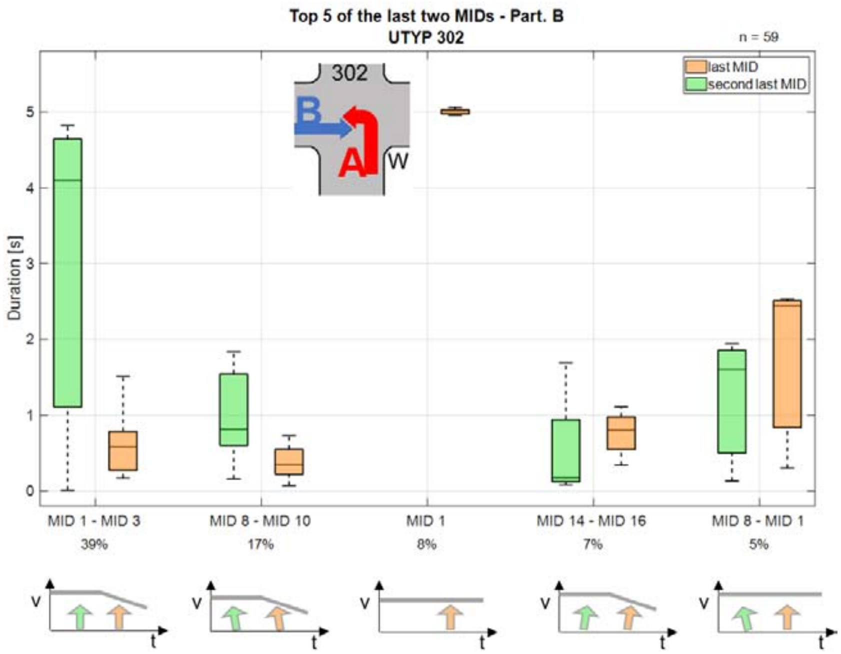
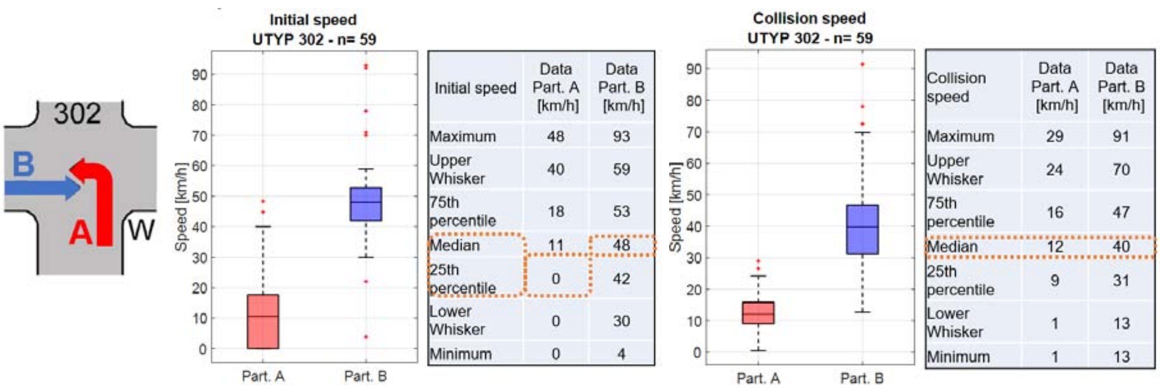


Figure 39: Top 5 of the last two MIDs for participant B (302)

5.2.3 c) Speeds

The initial speed and collision speed of each participant is shown in Figure 40. Participant A starts from 11km/h initially and collision speed is 12km/h for the median scenario. Considering from manoeuvre analysis in 5.2.2 , as participant A most frequently starts from standstill, the initial speed of 0km/h is applied instead of 11km/h for the median scenario. Looking at participant B, it starts from 48km/h initially and decelerates to 40km/h for the median scenario.



Initial speed	Data Part. A [km/h]	Data Part. B [km/h]
Maximum	48	93
Upper Whisker	40	59
75th percentile	18	53
Median	11	48
25th percentile	0	42
Lower Whisker	0	30
Minimum	0	4

Collision speed	Data Part. A [km/h]	Data Part. B [km/h]
Maximum	29	91
Upper Whisker	24	70
75th percentile	16	47
Median	12	40
25th percentile	9	31
Lower Whisker	1	13
Minimum	1	13

Figure 40: Initial and collision speed of participants (302)

Figure 41 shows the median values of trajectories with speed information indicated. All the information mentioned so far are inputted together for understanding the whole picture of the median scenario for crossing traffic accident 302.

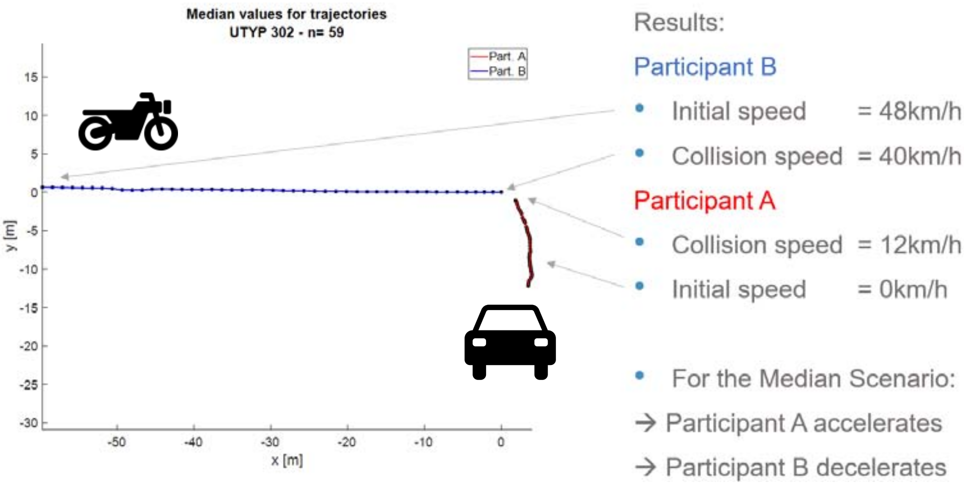
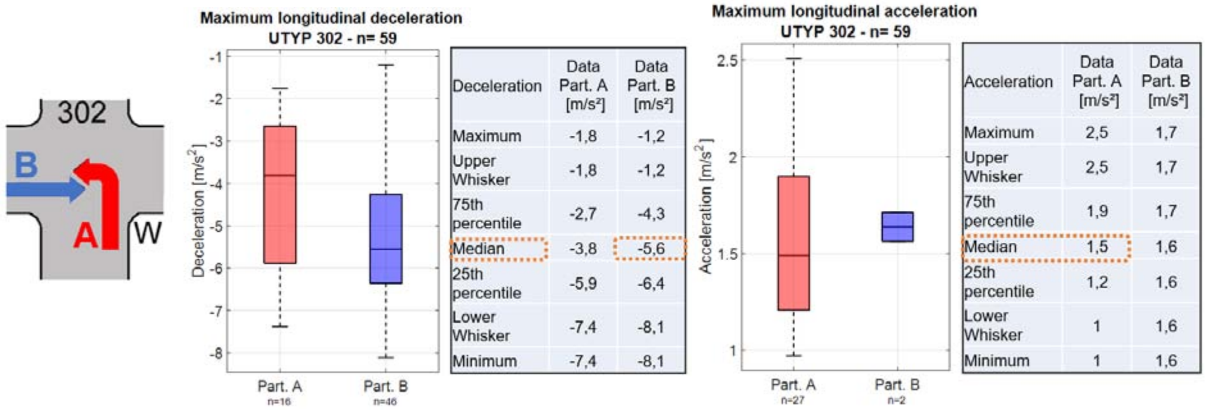


Figure 41: Results of median values for trajectories and speeds (302)

5.2.4 d) Decelerations / Accelerations

Figure 42 shows the analysis results of each participant's maximum deceleration and acceleration value. For the median scenario, participant A accelerates with 1.5m/s^2 from standstill and participant B decelerate with -5.6m/s^2 before the collision.



Deceleration	Data Part. A [m/s²]	Data Part. B [m/s²]
Maximum	-1,8	-1,2
Upper Whisker	-1,8	-1,2
75th percentile	-2,7	-4,3
Median	-3,8	-5,6
25th percentile	-5,9	-6,4
Lower Whisker	-7,4	-8,1
Minimum	-7,4	-8,1

Acceleration	Data Part. A [m/s²]	Data Part. B [m/s²]
Maximum	2,5	1,7
Upper Whisker	2,5	1,7
75th percentile	1,9	1,7
Median	1,5	1,6
25th percentile	1,2	1,6
Lower Whisker	1	1,6
Minimum	1	1,6

Figure 42: Deceleration / Acceleration analysis results (302)

Figure 43 shows the overview of median scenario of crossing traffic accident 302 with all the information so far derived.

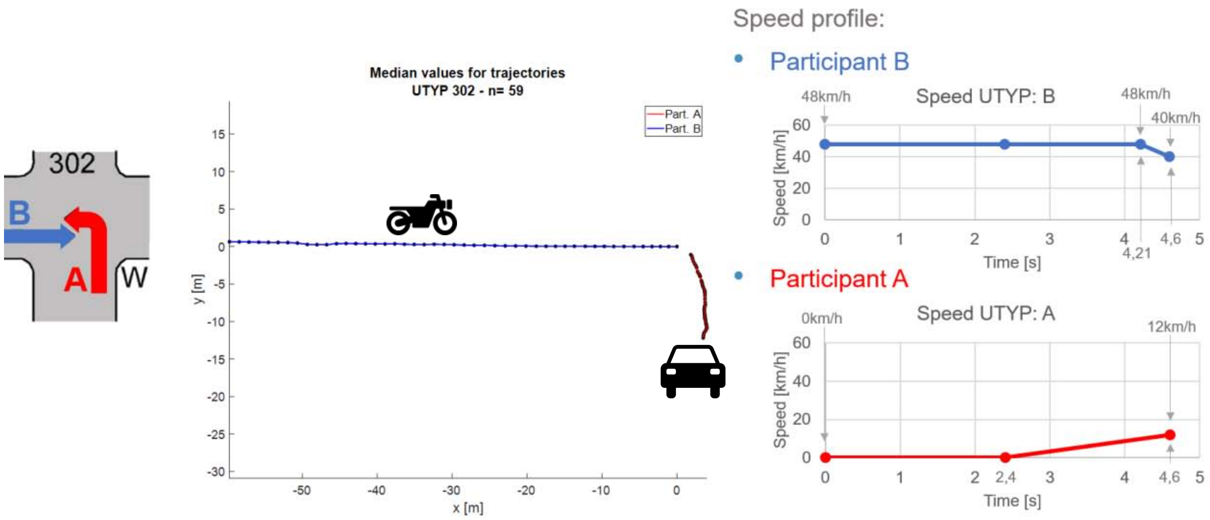


Figure 43: Overview of median scenario of crossing traffic accident 302 with trajectory, speed and deceleration / acceleration information

5.2.5 e) TTC model

Time to collision (TTC) is an important safety indicator as sufficient TTC will provide time for the vehicle operator to recognise the danger ahead and will make room for reaction time. Figure 44 shows the basic TTC calculation model used in this analysis. A tube for each traffic participant is extended as linear straight motion with the current speed values and determines whether the two participants enter the critical conflict zone at the same time. If so, TTC is provided as a division of distance by relative speed.

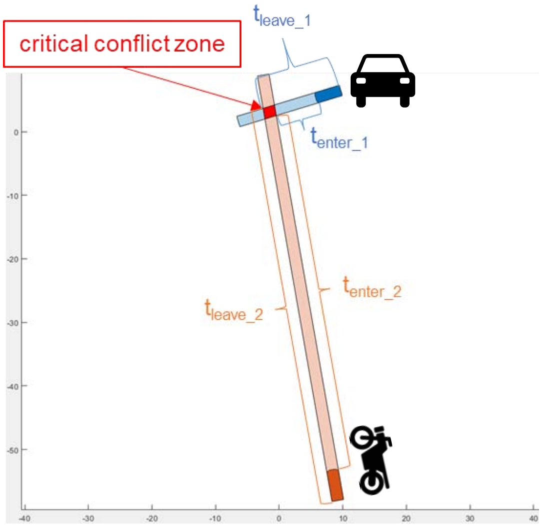


Figure 44: TTC calculation model

Figure 45 shows the TTC calculation result in a heat map for crossing traffic accident 302. The graph shows relatively linear rise from the point of collision and high density in the area of severely critical. However, 62% of the cases were able to be with TTC range > 2.6s in uncritical range[2].

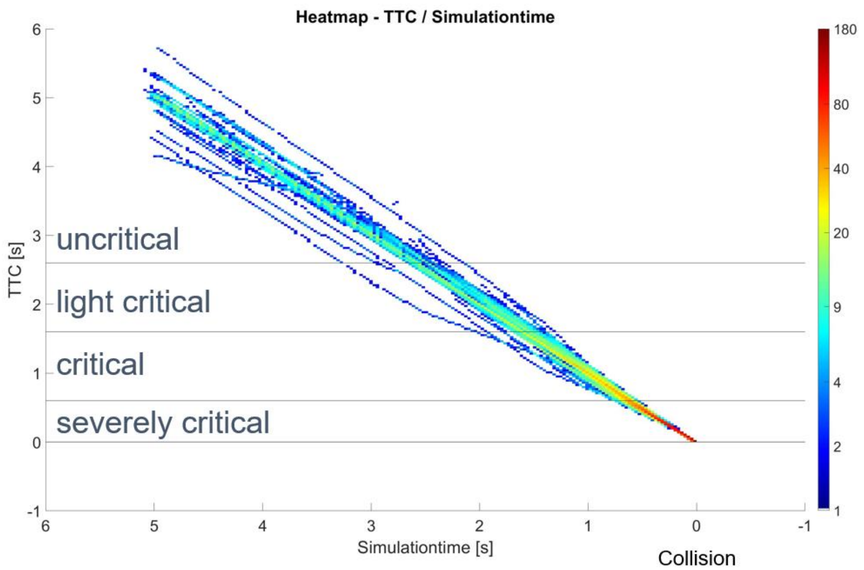


Figure 45: TTC calculation result for crossing traffic accident 302

[2] Breuer, J. ; S., Gleissner: VDI-Berichte 1960, S. 397 | Neue Systeme zur Vermeidung bzw. Folgenminderung von Auffahrunfällen. Düsseldorf : VDI Verlag, 2006

Figure 46 shows cumulative case numbers of TTC and where it crosses the 50% line. It reads from the figure that in 50% of the crossing traffic accident type 302 cases, the vehicle operator can be informed 4.5 seconds before the collision.

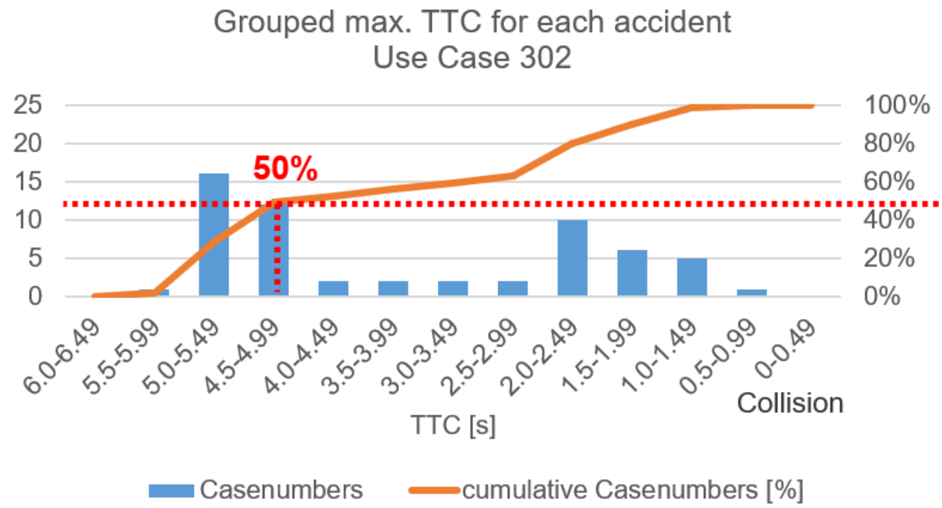


Figure 46: Cumulative case numbers of TTC for each accident (302)

6. Left turn accident type 211 analysis

6.1 Module 1

6.1.1 a) Location of the accident

The majority of PTW accidents for left turn accidents occurred on urban roads which accounts for 79.0% of overall 211 type (Figure 47). This could be understood from the fact that in urban areas, more traffic participants exist and more occasions of turning left, all making it more a frequent situation.

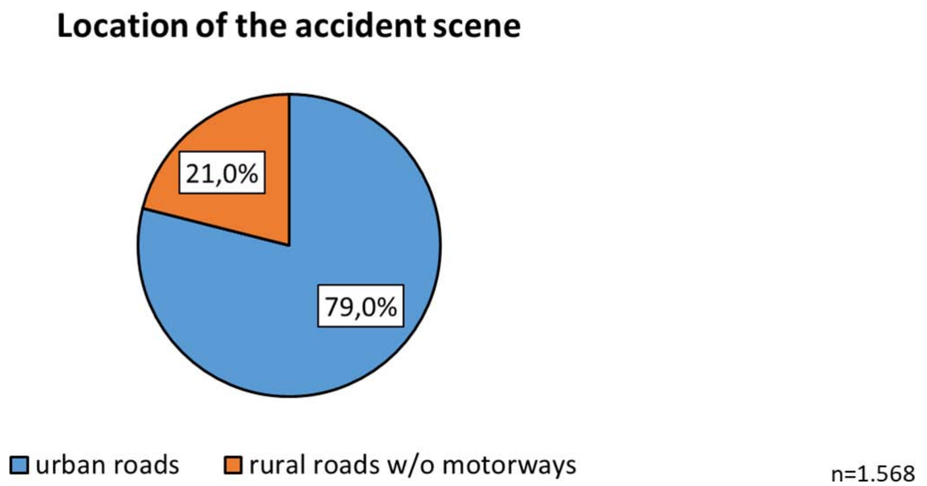
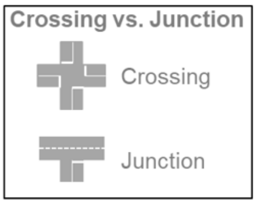


Figure 47: Location of the accident (211)

6.1.2 b) Accident scene

The majority of PTW accidents for left turn occurred at crossings which accounts for 42.9% of overall 211 type (Figure 7). The second frequent scene is at junctions which accounts for 35.9%. Also, accidents exiting from property areas accounts for 20.4%. It is commonly said that PTW being small in size is often misjudged by car drivers its speed and distance and may hide behind a foregoing vehicle, therefore, to properly measure the timing for the car drivers to turn left is a challenge. It is a common observation that PTWs, being small in size, may hide behind a foregoing vehicle and are often misjudged by car drivers regarding their speed and distance. Therefore, to properly time the left turn is a challenge for car drivers.



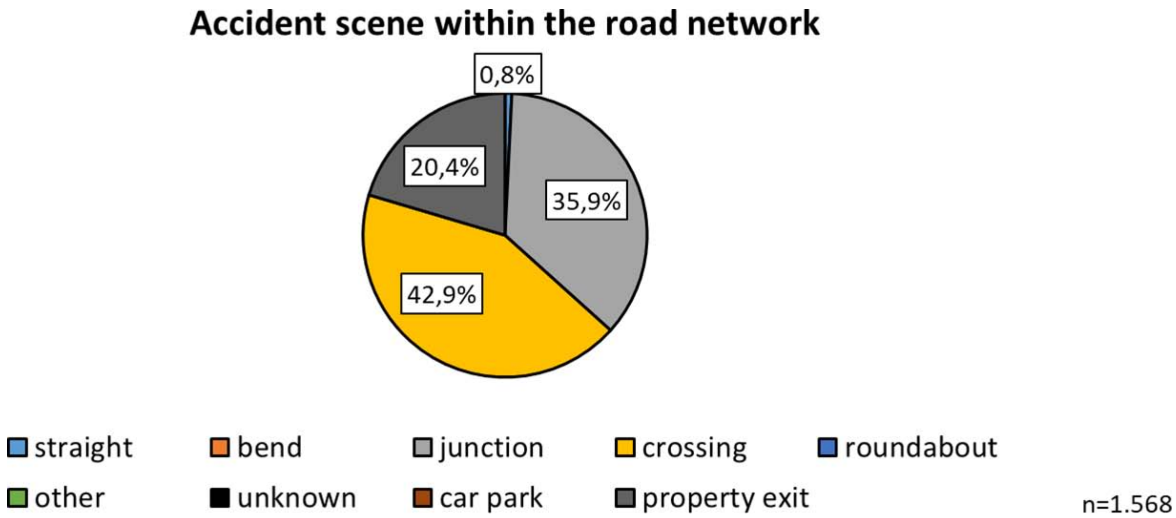


Figure 48: Accident scene (211)

6.1.3 c) Kind of traffic regulation

Right-of-way regulation was the predominant traffic regulation at the accident site involving PTWs, which accounts for 50.8% of overall 211 type (Figure 49). As mentioned in 4.1.2, PTWs being small in size are often misjudged and even if participant A is following the rule of right of way, it could be that the timing for participant A to make a turn may had been improper.

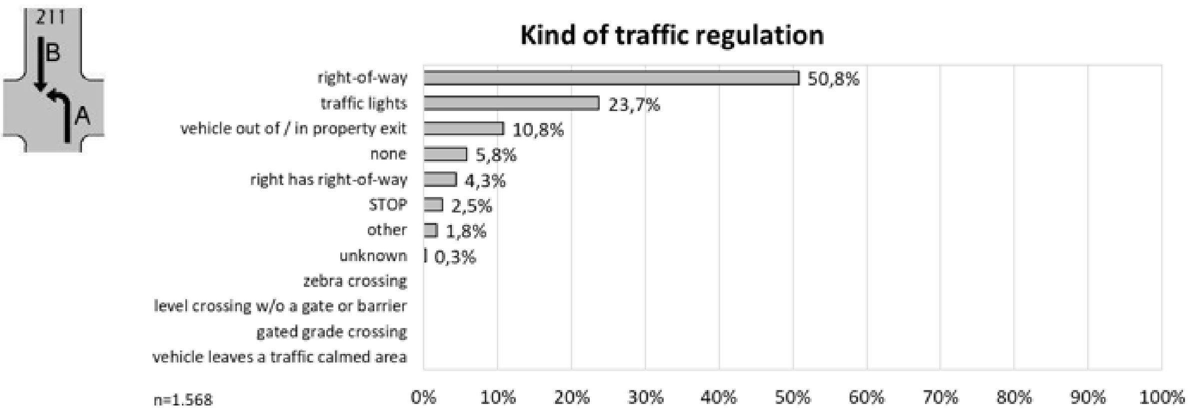


Figure 49: Kind of traffic regulation (211)

6.1.4 d) Kind of road user

Traffic participants in left turn accident type 211 involving a PTW, are shown in Figure 50. From the figure, it can be seen that in most cases, the participant A consists of M1 / N1 vehicles (passenger cars / light commercial vehicles) and for participant B, motorcycles.

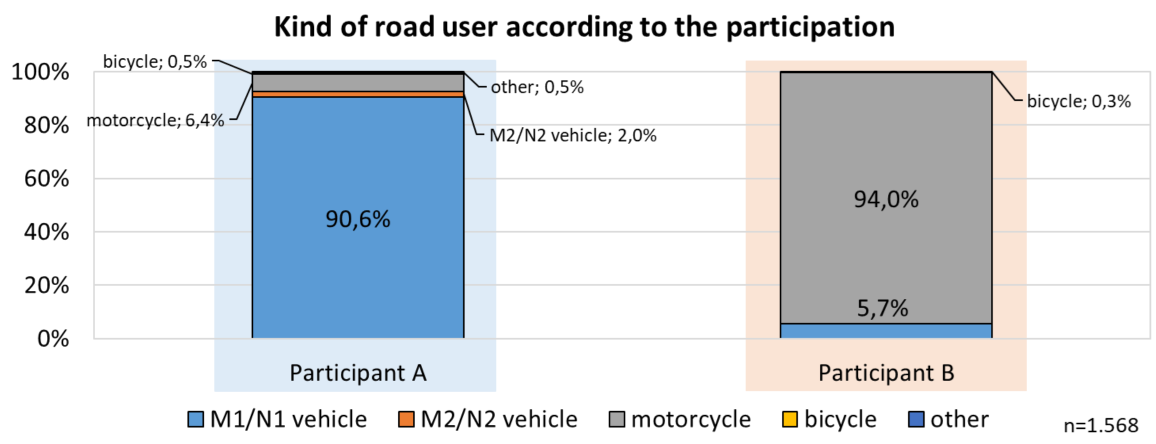


Figure 50: Kind of road user (211)

6.1.5 e) Main accident causer

The main accident causer in left turn accidents is shown in Figure 51. It is clear from the figure that the main accident causer is participant A and in a small percentage participant B. Figure 50 and Figure 51 indicates that there is a strong need to address car driver's driving behaviour in order to mitigate PTW accidents in left turn situations.

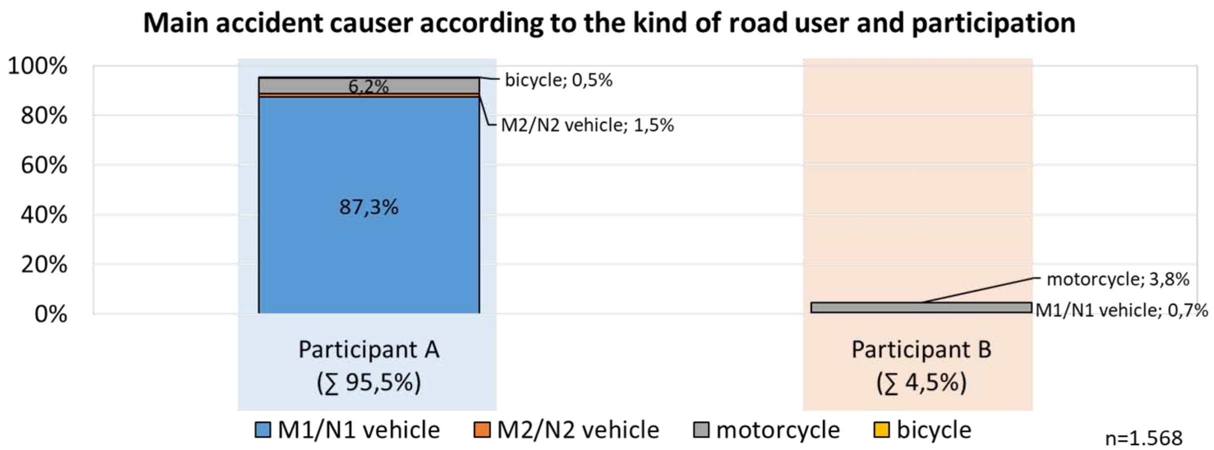


Figure 51: Main accident causer (211)

6.1.6 f) Main accident causation: mis-obeyed priority / turning, etc.

The causation of the accidents is studied and shown in Figure 52 and Figure 53. From the figures, it is understood that the main reason for the accident was failure of participant A to respect priority and for participant B, it was the speed.

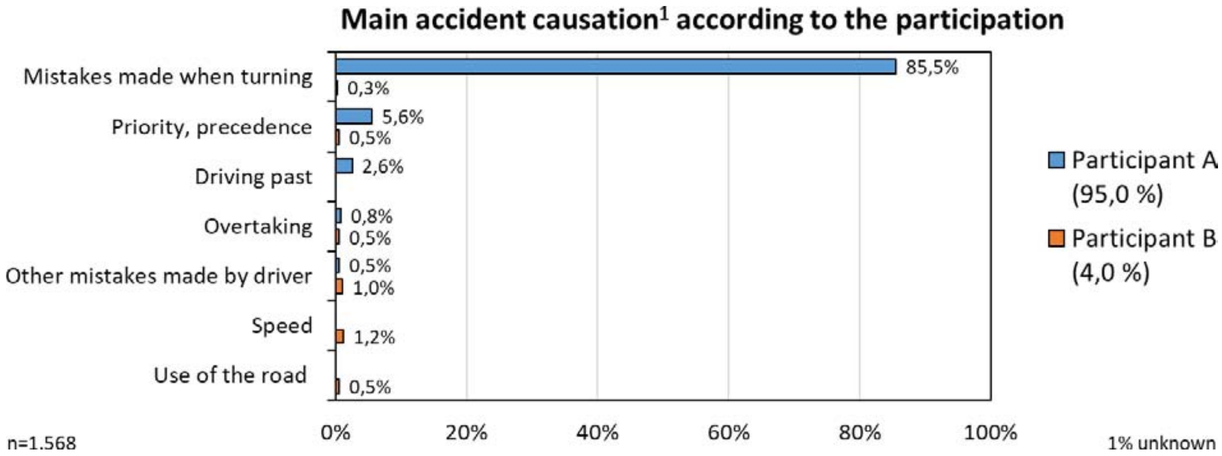


Figure 52: Main accident causation (211)

1: The police and also the technical investigation units in GIDAS have to assign a main accident causer with one main accident causation in each accident.

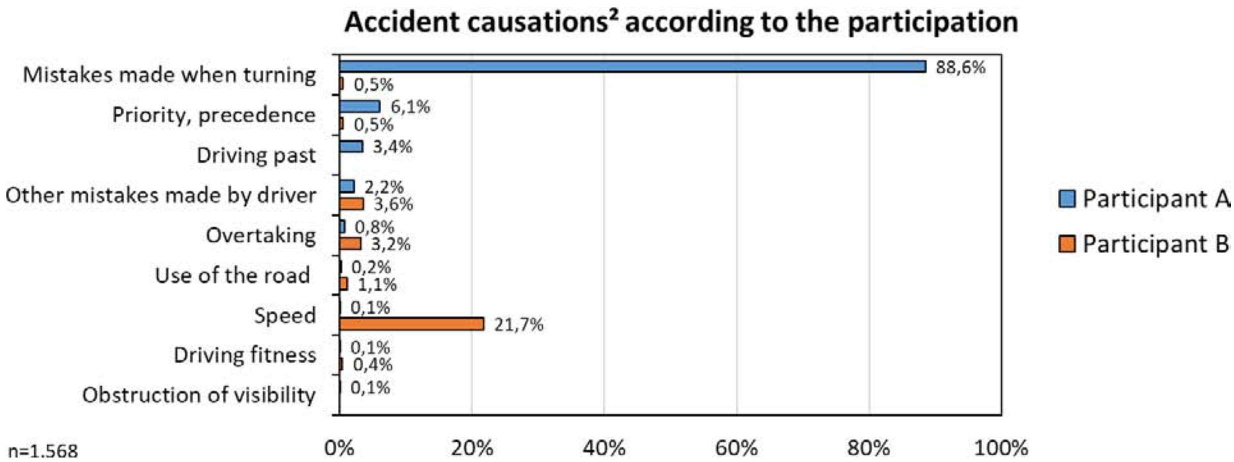


Figure 53: Accident causations (211)

2: The police and the technical investigation units in GIDAS can assign up to 3 accident causations for each accident participant. Consequently, one accident can have several accident causes depending on the participant and so the sum of the accident causations is ≥100%.

6.1.7 g) Types of speed limitation: local limit / traffic sign, etc.

What provides the speed limit to each participant is shown in Figure 54. Both for participant A and B, the majority of speed limit is provided by local traffic rules and secondly by traffic signs.

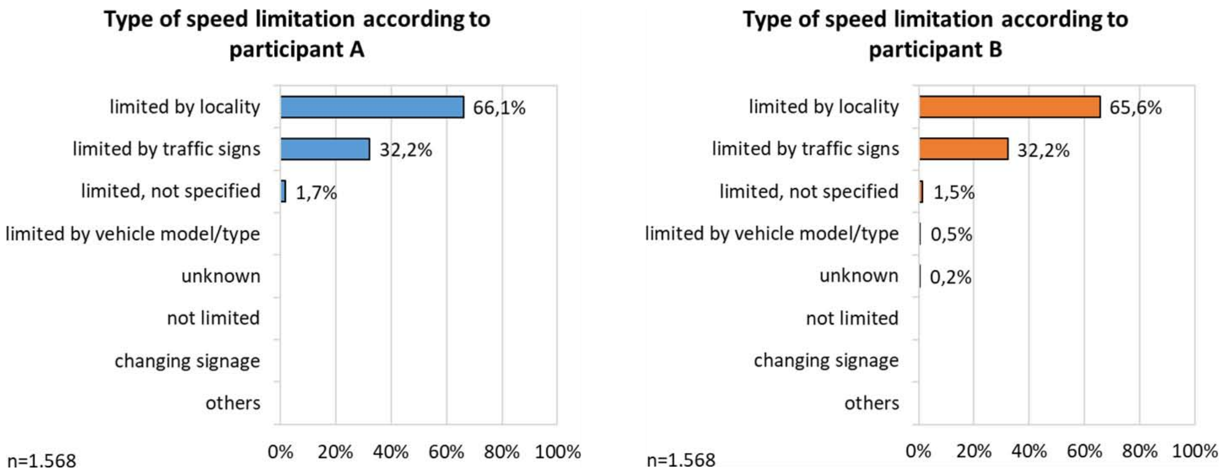


Figure 54: Types of speed limitation for the participants (211)

6.1.8 h) Maximum permitted speed

Maximum permitted speed on the accident site is shown in Figure 55. As from Figure 47 that around 80% of accidents took place at urban roads, it is reasonable to see that the most frequent maximum permitted speed is 50km/h. There cannot be seen a significant difference between maximum permitted speed for participant A and B.

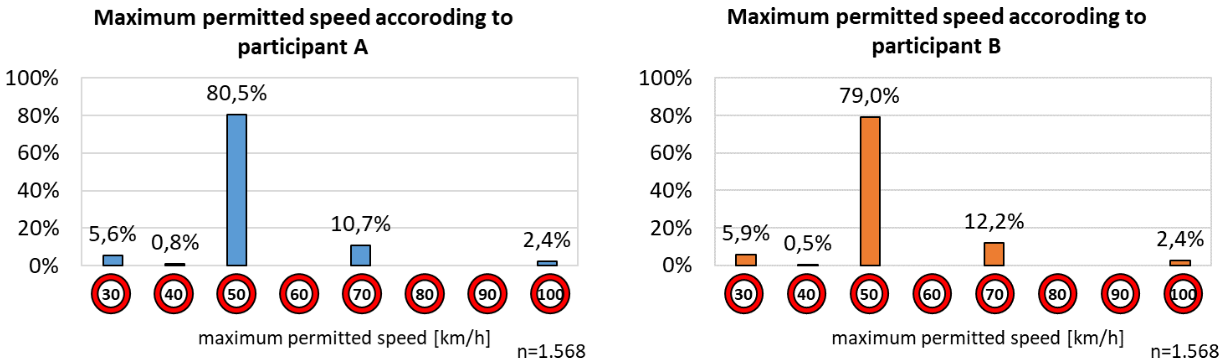


Figure 55: Maximum permitted speed (211)

6.1.9 i) Speed limit and distribution

Figure 56 shows the percentage of participants exceeding the applicable speed limit. Comparing participants A and B, it can be observed that participant B is more often seen to have exceeded the speed limit. This could be understood from the left turn accident type that participant A is in the turning process, they slow down and thus not exceeding the speed limit, whereas participant B is to go straight passing through.

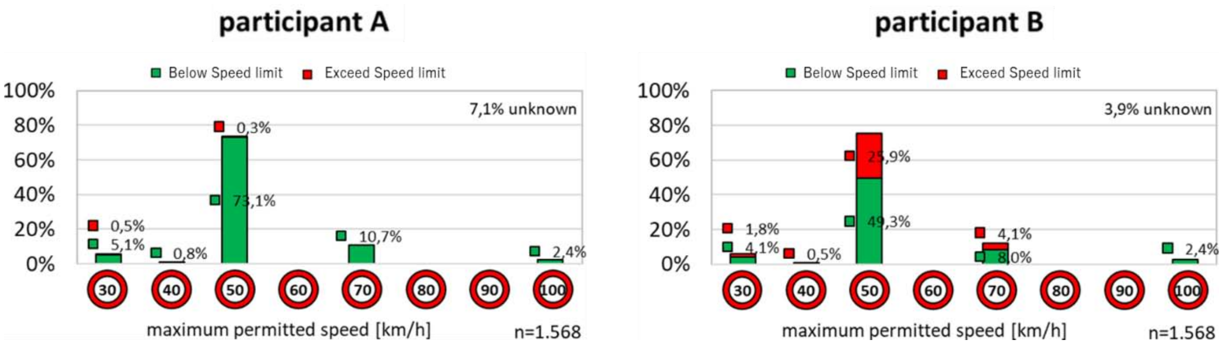


Figure 56: Exceeding speed limit (211)

Figure 57 shows the distribution of how much participant B exceeded the allowable speed for each given speed limit before reaching the point of incident. Though participant B in the left turn accident scenario has the right of way, in some cases, exceeding the speed limit could be one of the influencing factors for participant B.

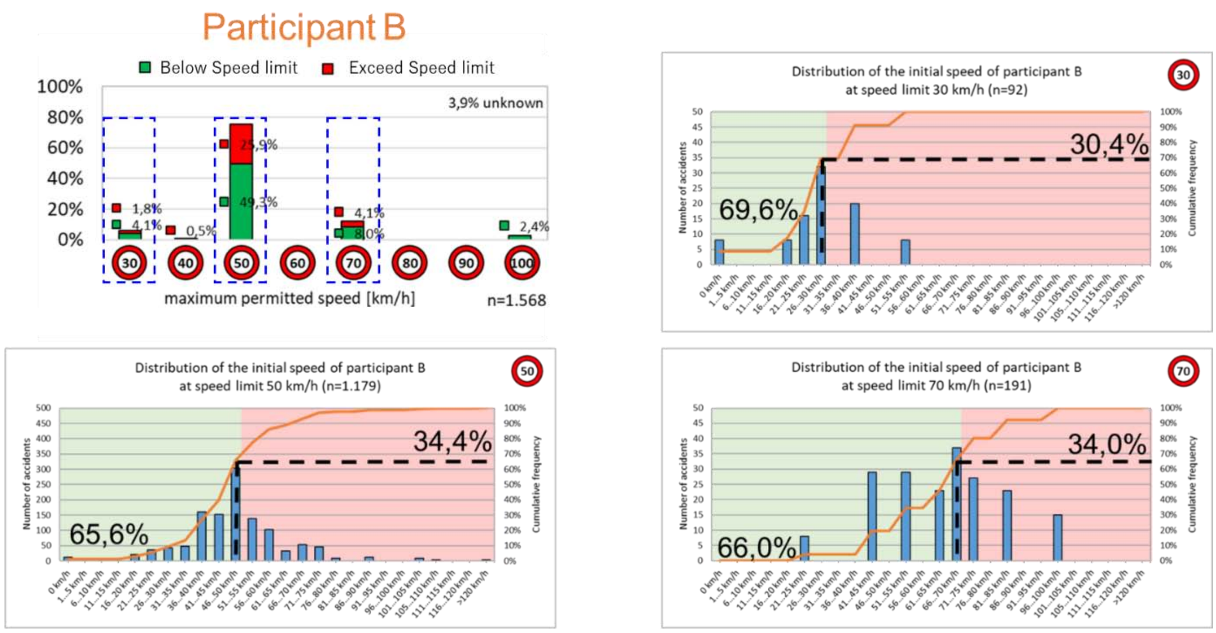


Figure 57: Speed distribution by participant B (211)

6.1.10 j) Speed before the accident and at the time of collision

Figure 58 shows the initial speed of each participant. It is clear from the figure that participant B going straight has higher average speed than participant A who is in the turning process.

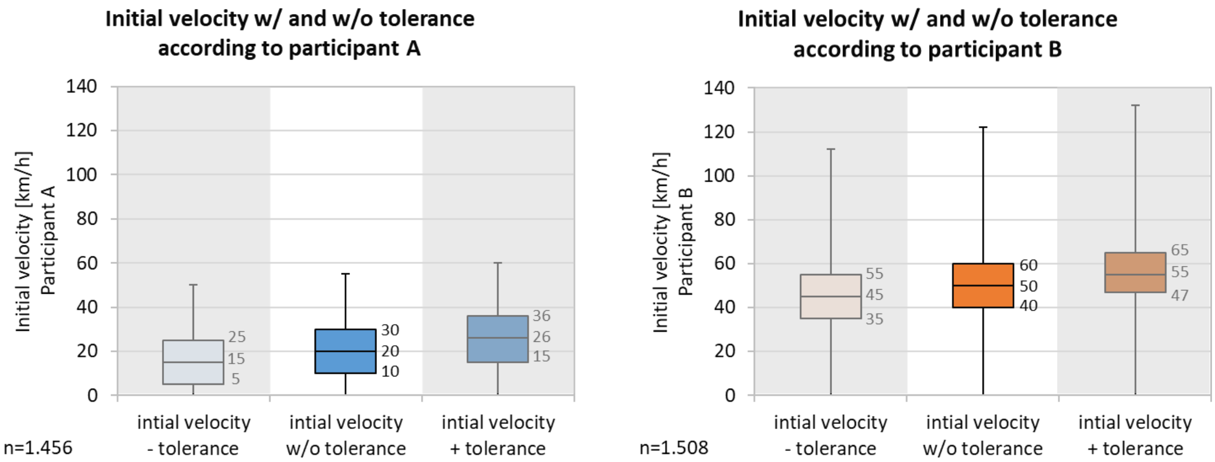


Figure 58: Initial speed of participants (211)

Figure 59 shows the colliding speed of each participant. Comparing the initial speed of participant A in Figure 59 and the collision speed in Figure 58, participant A is found to approach the turning point and slowing down to take the turning process, while participant B seems to collide without significant speed reduction, which may be due to less braking or no reaction time to the situation.

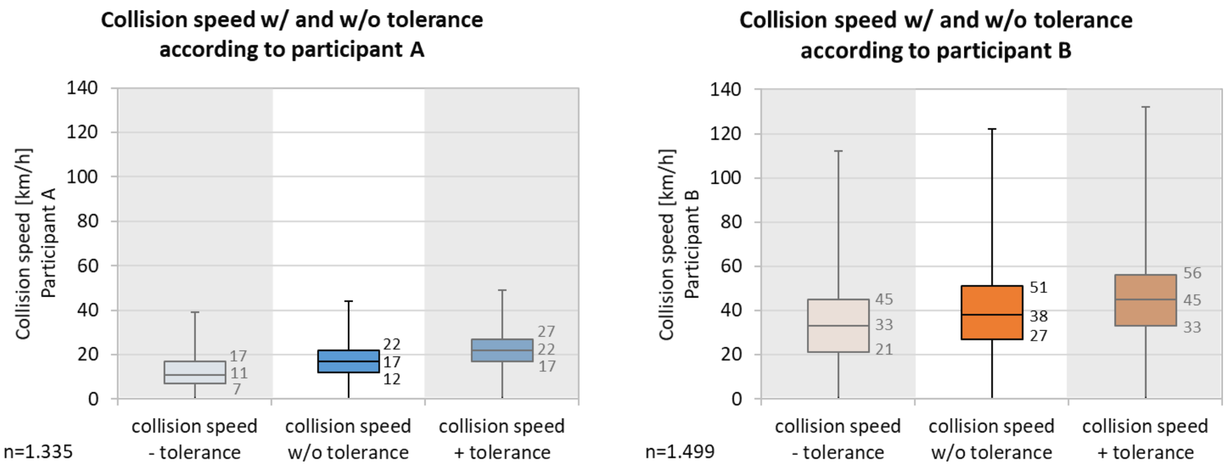


Figure 59: Collision speed of participants (211)

6.1.11 k) View obstruction

Figure 60 and Figure 61 show existence of view obstructions and the types of obstruction respectively. It can be seen that around 80% of the cases had no view obstructions and the rest with non-permanent obstruction, e.g., moving and parked cars.

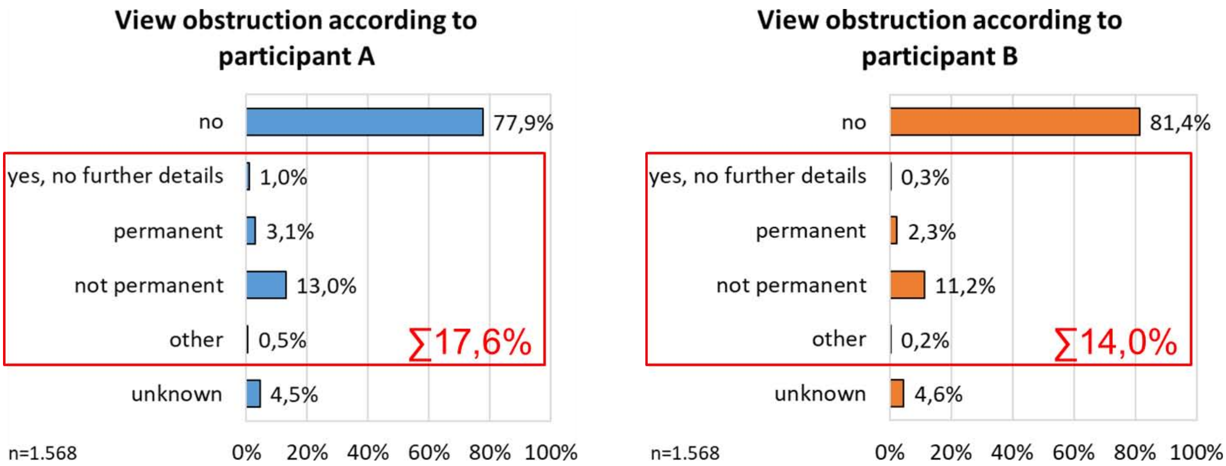


Figure 60: View obstructions (211)

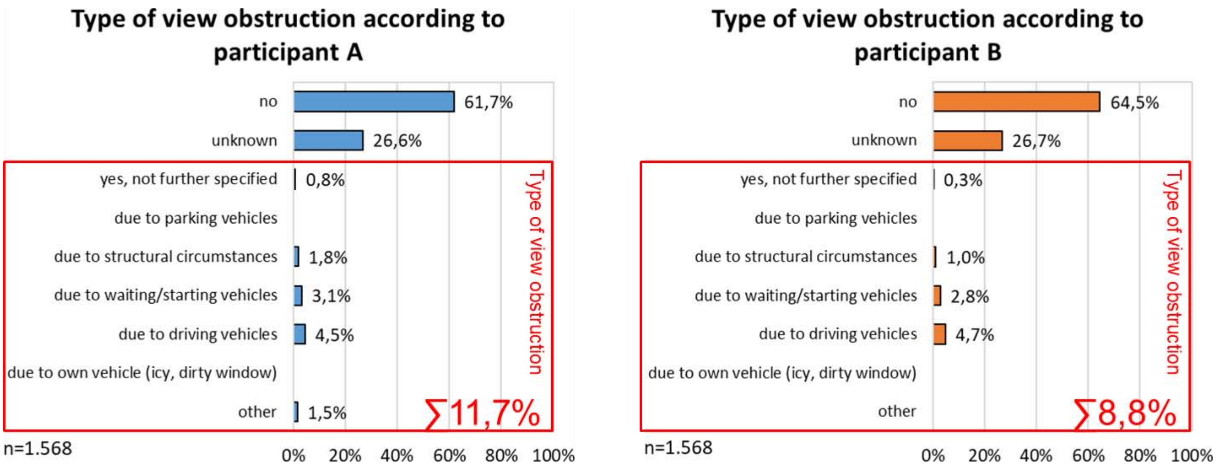


Figure 61: Type of view obstruction (211)

6.1.12 l) Used lane when encountering an accident

Figure 62 and Figure 63 shows which lane the participants took when encountering an accident. For participant A, the majority of left turn was taken at a single lane and a double lane with dedicated left turning lane. For participant B, the majority was with a single lane, followed by a dedicated lane to go straight or a straight + turning right lane.

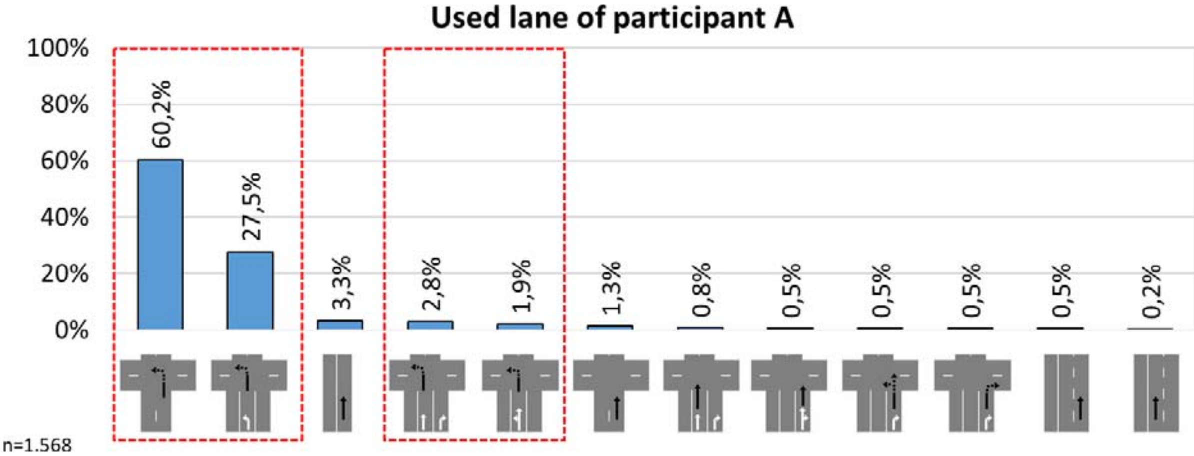


Figure 62: Used lane at an accident, participant A (211)

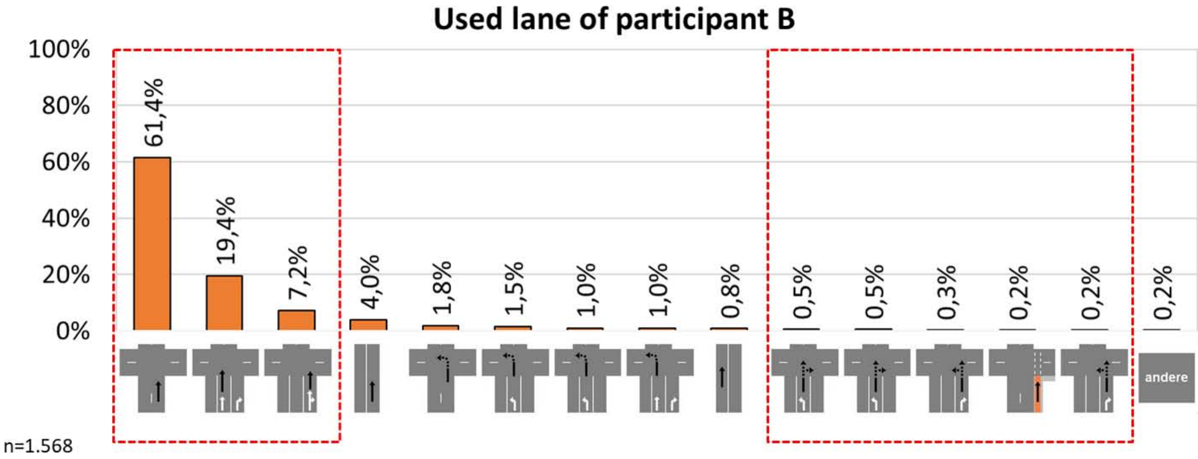


Figure 63: Used lane at an accident, participant B (211)

6.1.13 m) Road surface

Figure 64Figure 22 shows which kind of road surface it was when encountering an accident. The majority of left turn accident scenario participants were driving at a conventional asphalt road.

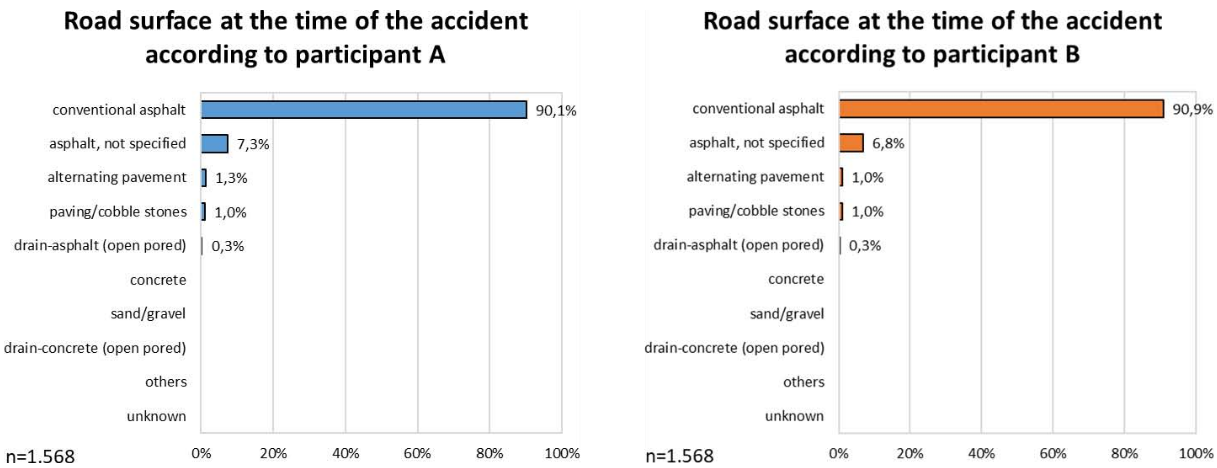


Figure 64: Road surface (211)

6.1.14 n) Precipitation at the time of the accident

Figure 65 shows precipitation at the time of the accident. From the figure, it can be observed that in most accidents it was not raining.

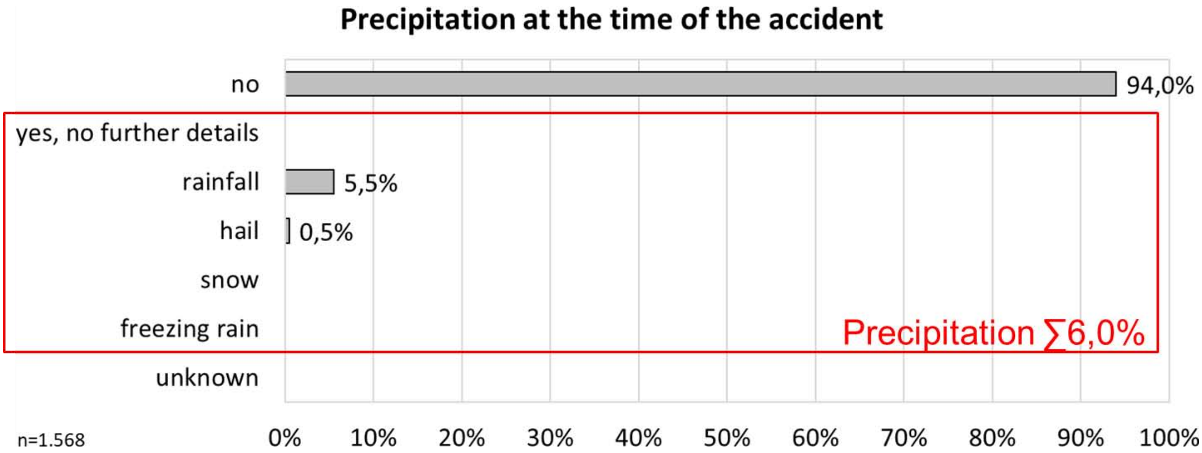


Figure 65: Precipitation (211)

6.1.15 o) Road condition: dry / wet / snow, etc.

Figure 66 shows the road condition at the time of the accident. From this figure and also from Figure 65, indicating that in most cases there was no precipitation, it is found that in most accidents it was with a dry road surface.

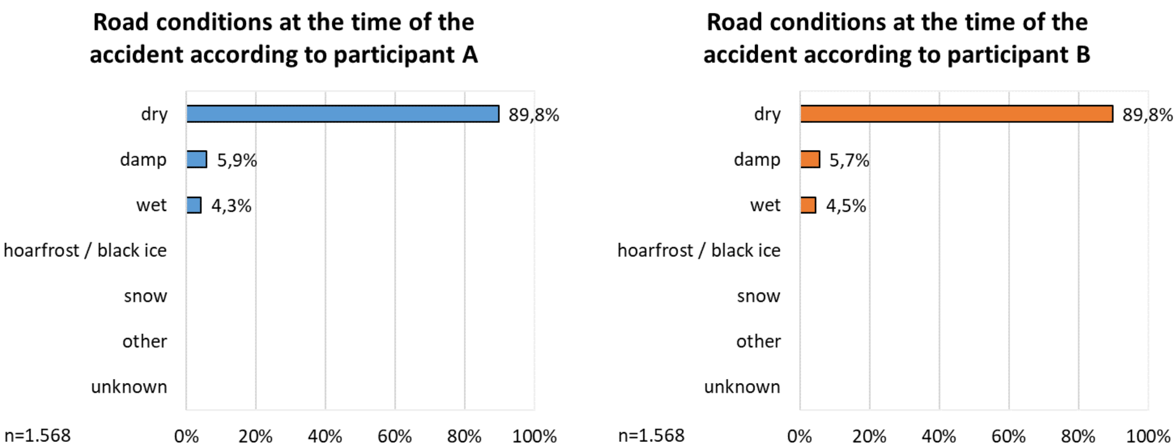


Figure 66: Road condition (211)

6.1.16 p) Cloudiness at the time of the accident

Figure 67 shows cloudiness at the time of the accident. Every forth accident showed no clouds and few clouds in about 35% of accidents.

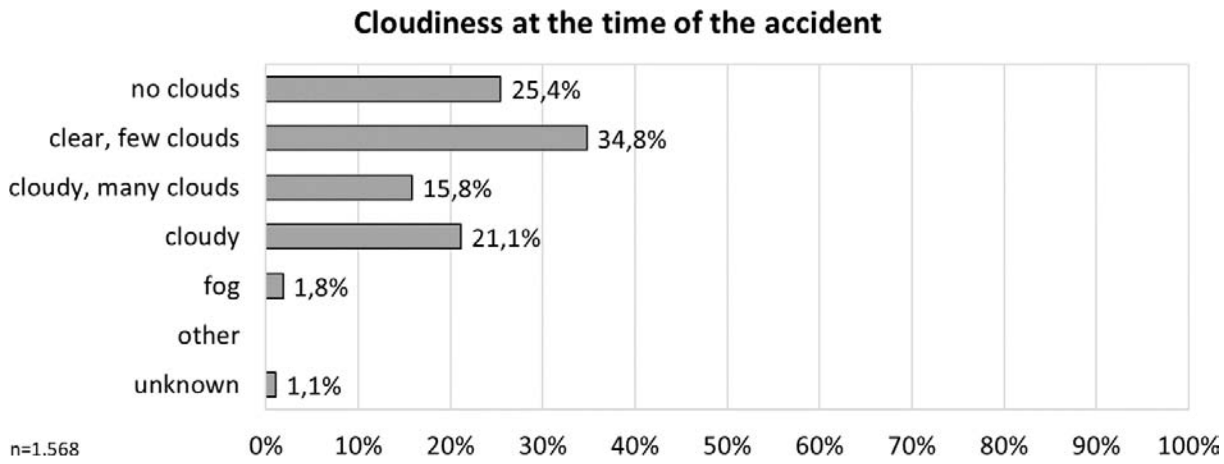


Figure 67: Cloudiness (211)

6.1.17 q) Interview result: visibility / audibility limitation

Figure 68 shows the participant interview results about visibility and audibility limitations. As from the figure, participant A reports more limitation in visibility or audibility than participant B. This may indicate more challenge with participant A in judging the decision for manoeuvring.

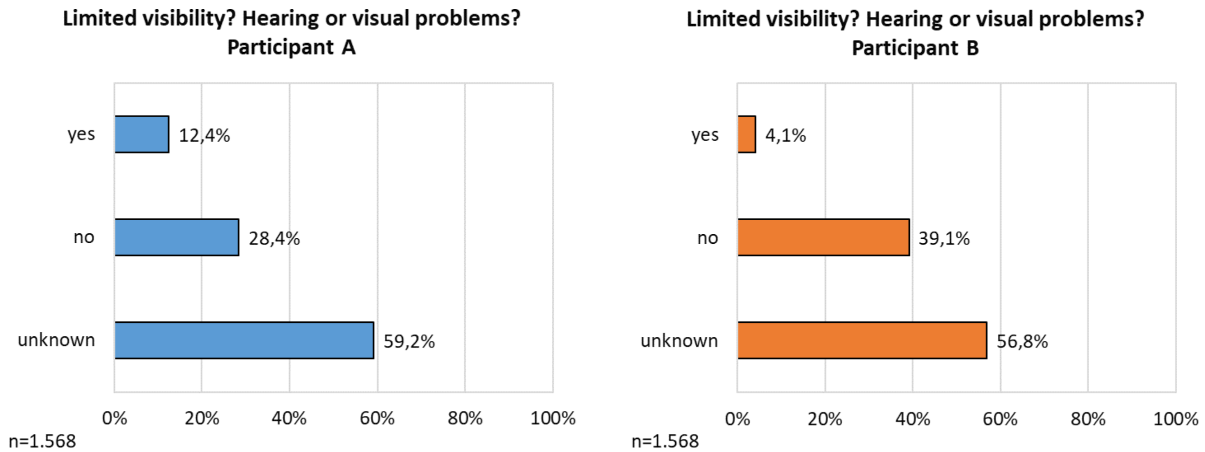


Figure 68: Interview - visibility limitation (211)

6.1.18 r) Interview result: overlooked / distracted, etc.

Figure 69 shows the participant interview results whether they overlooked important information or if they were distracted. As from the figure, participant A reports more overlooking or distraction compared to participant B.
Figure 70 shows further insight into the influencing factors of participant A who answered that they overlooked or were distracted. For the factors asked, such as stress, fatigue etc., over 70% of participants A answered that there was no influence. This may indicate that in most cases, participant A's overlooking or being distracted simply comes from human error.

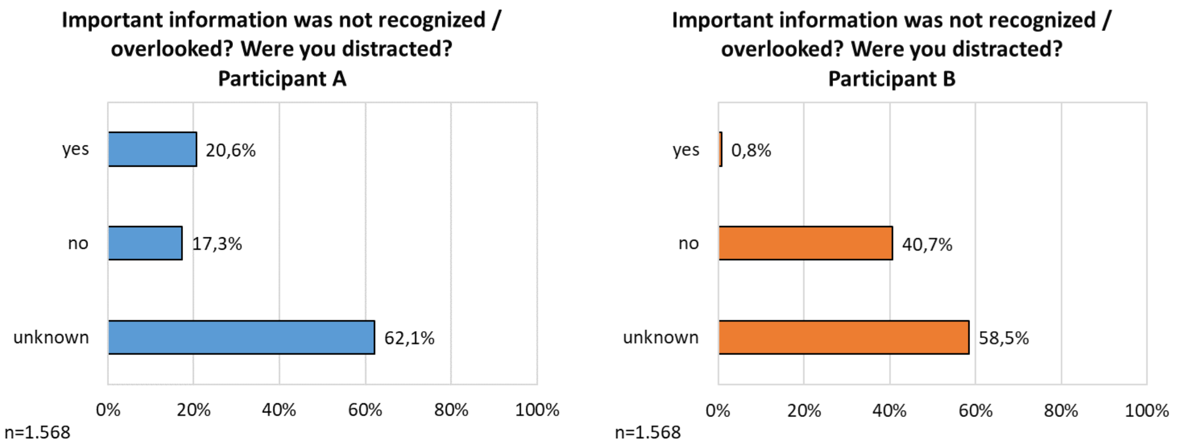


Figure 69: Interview - overlooked / distracted (211)

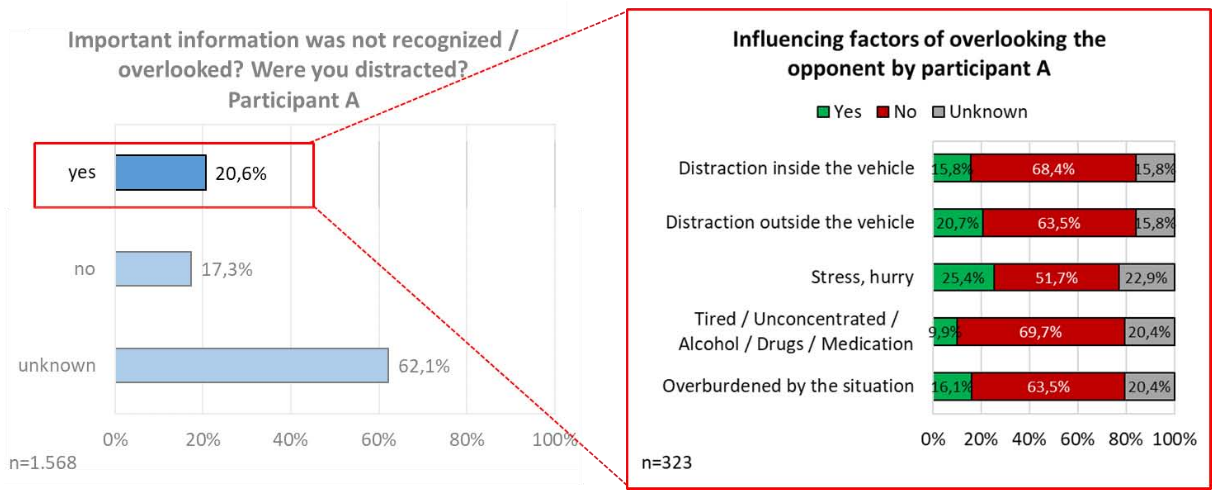


Figure 70: Interview - Influencing factor for overlooking (211)

6.1.19 s) Interview result: misjudgement

Figure 71 shows the participant interview results whether they misjudged the situation or not. For participant A, out of those who answered "yes" or "no", (so taking out the unknown cases), 70% (= 24.8/(10.4+24.8)x100) of the participants report they have not misjudged the situation. For participant B, this rate iss higher, at 93% (= 38.4/(2.8+38.4)x100). It was reported that most of the participants B felt innocent and had assessed the situation correctly.

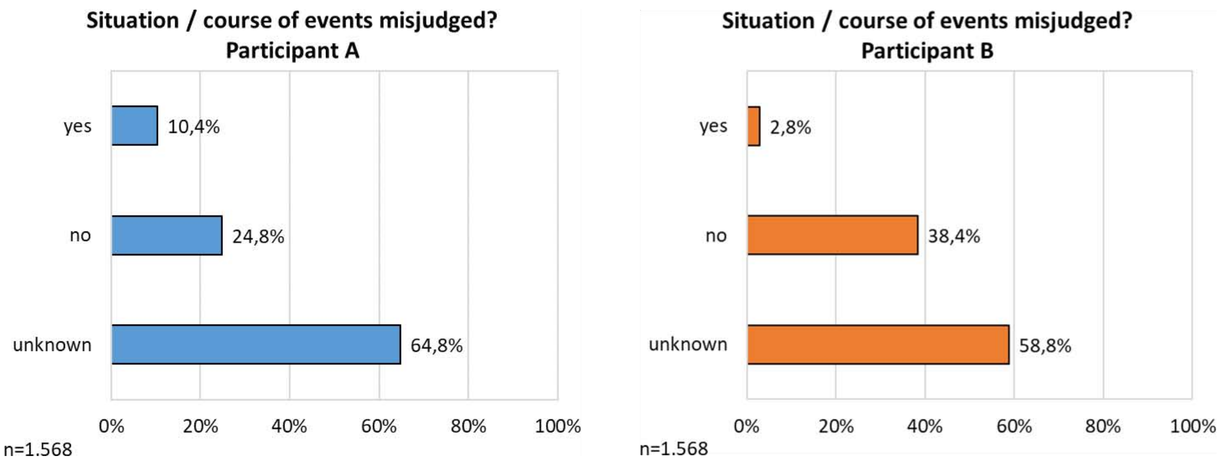


Figure 71: Interview - Misjudgement (211)

6.1.20 t) Interview result: accident-avoidance possibility by other action

Figure 72 shows the participant interview results whether the accident was possible to be avoided by other reaction / action. Comparing the number of participants answering "yes" to "no", for both participant A and B, the ratio of "no" is much higher meaning that the accident was not possible to be avoided with other actions taken.

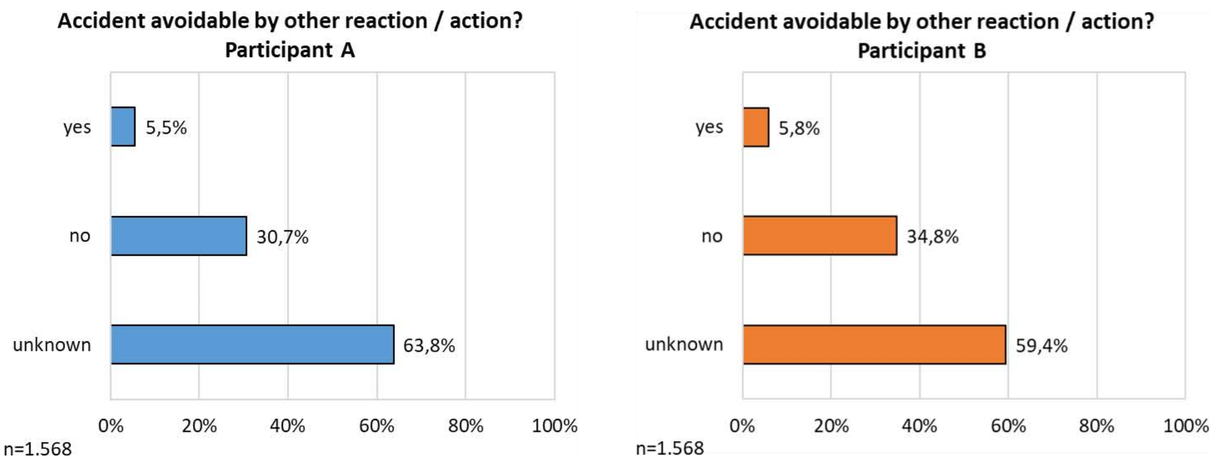


Figure 72: Interview - Accident avoidance possibility (211)

6.1.21 u) Interview result: mistakes in executing the avoidance action

Figure 73 shows the participant interview results about difficulties / mistakes in taking the planned action. Comparing the number of participants answering "yes" to "no", for both participant A and B, the ratio of "no" is much higher meaning that the planned action was not difficult or mistaken to execute. If comparing the "yes" ratio of participant A to participant B, participant B shows a slightly higher number which means that the planned action, e.g., braking or steering was slightly more often difficult or mistakenly executed.

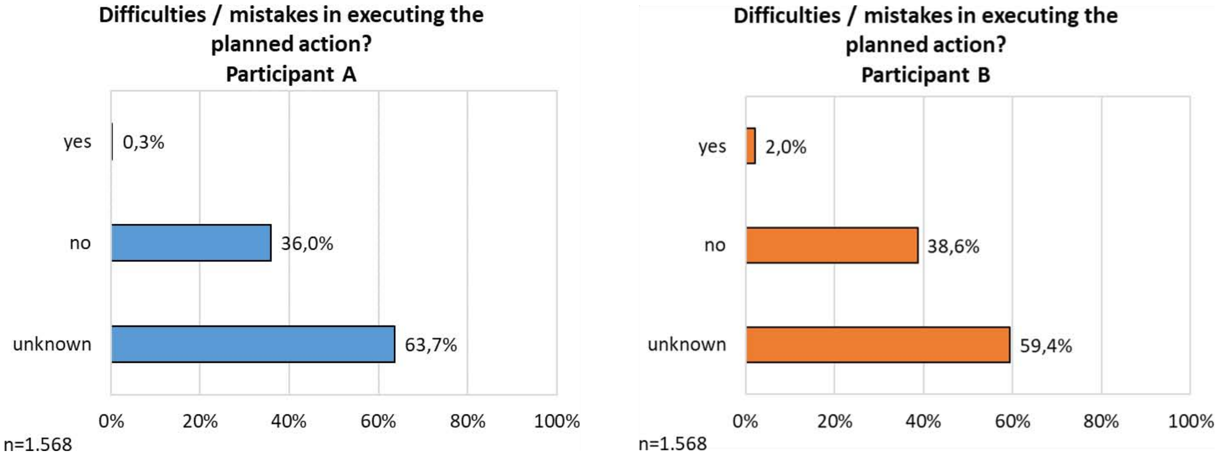


Figure 73: Interview - Mistakes in avoidance action (211)

6.1.22 v) Interview result: influence from vehicle technology

Figure 74 shows the participant interview results about influence of the vehicle technology. This query is asking whether the participants had difficulty in operating a certain function provided by the vehicle or were distracted by the function on the vehicle. There were no participants A nor participants B answering "yes".

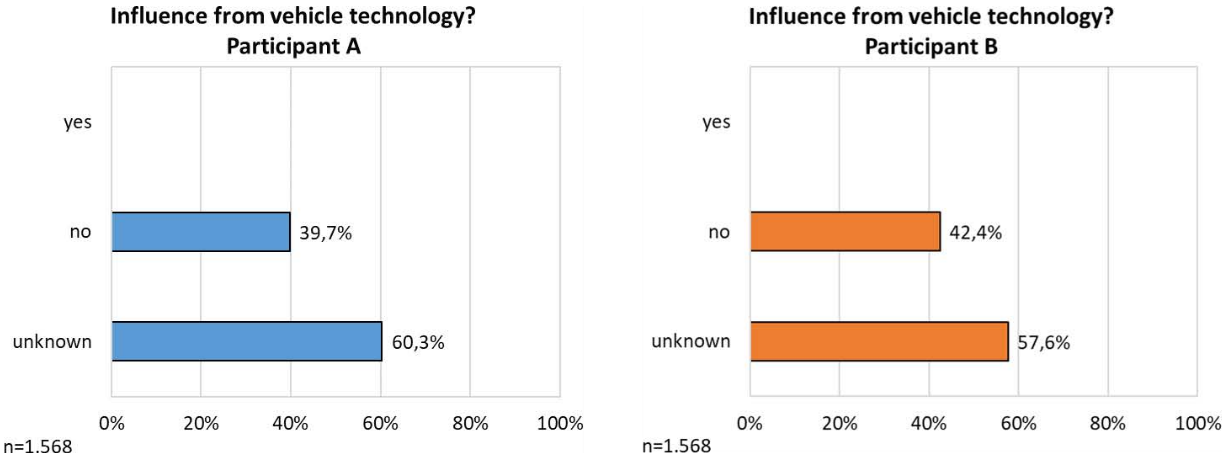


Figure 74: Interview - Influence from vehicle technology (211)

6.1.23 w) Interview result: influence of road condition

Figure 75 shows the participant interview results about influence of road condition. The ratio of participants answering "no" for both participant A and B are much higher than those answering "yes", meaning that there was little influence of road conditions such as a slippery road leading to an accident.

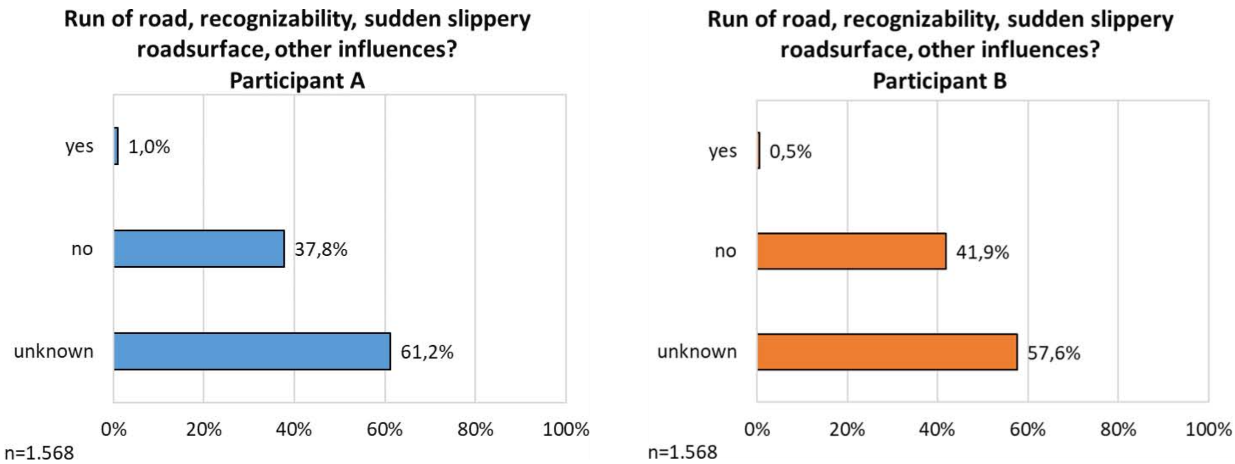


Figure 75: Interview - Influence of road condition (211)

6.2 Module 2

Database for the study of Module 2 is changed from the GIDAS data base to the simulation database GIDAS-PCM, which contains more detailed information for each time step and each participant (e.g., trajectories and manoeuvres of the participants). An overview of both databases is shown in Figure 76.

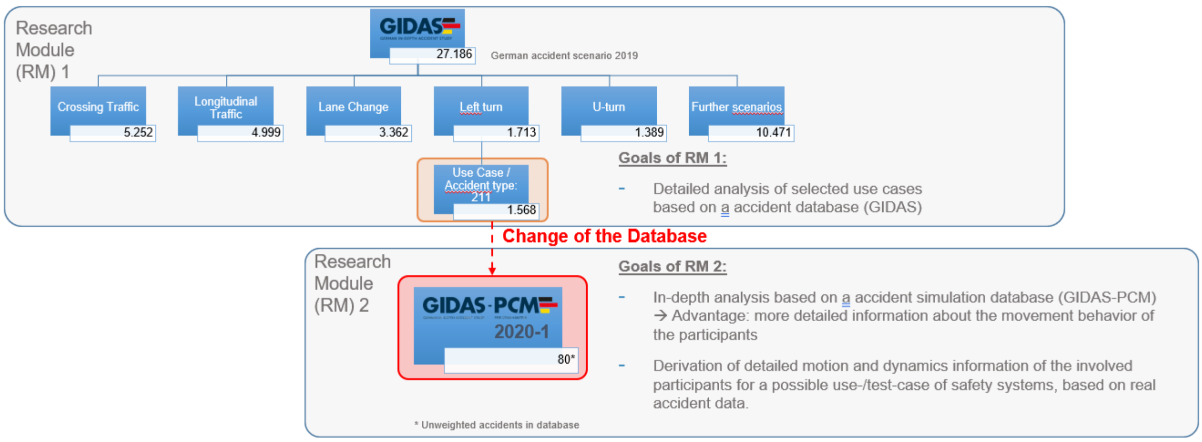


Figure 76: Overview of database used for Module 2 study (211)

For left turn accident type 211, analysis is performed for the 6.2% cases as shown in Figure 1 in which PTW is the victim, i.e., participant B and participant A is a passenger car as shown in Figure 77.

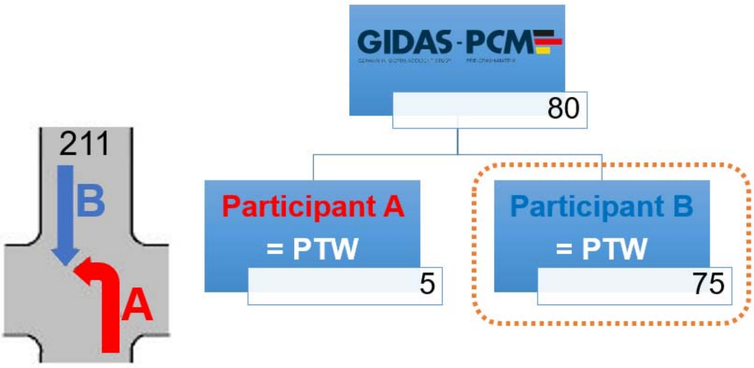


Figure 77: Assignment of the participants (211)

6.2.1 a) Trajectory of the traffic participants

For 75 accidents in GIDAS-PCM for left turn accident 211, the collision point for participant B was aligned to one point and each participant's trajectories were arranged to its position accordingly. Figure 78 shows its results and from this data, the median value is derived and is shown in Figure 79.

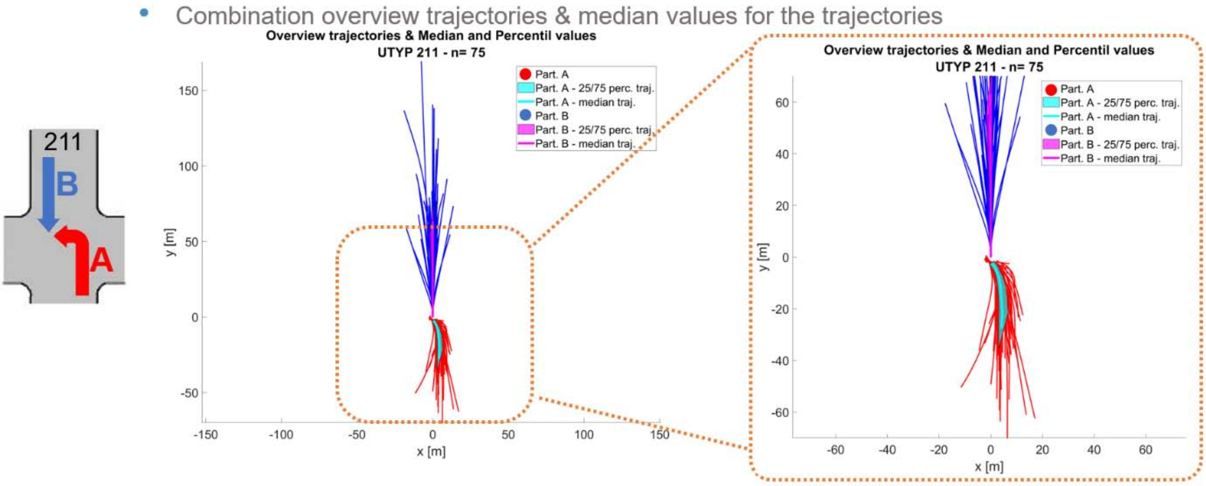


Figure 78: Trajectories of crossing traffic accident (211)

(The trajectories do not cross each other, because they display the centre of gravity trajectory.)

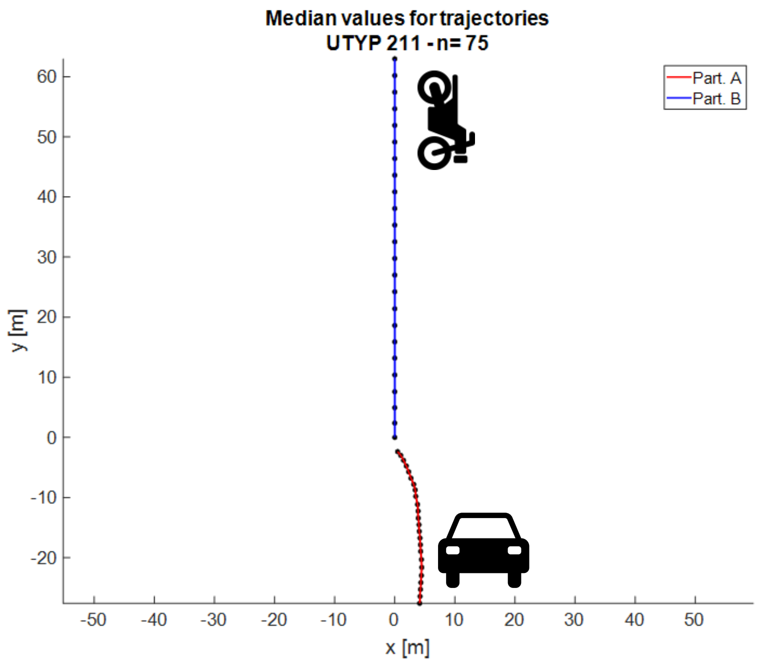


Figure 79: Median values for trajectories (211)

6.2.2 b) Manoeuvres

To understand what actions the participants were performing at each point in time, the dynamics data of the participants were analysed and mapped into a manoeuvre catalogue. The manoeuvre catalogue is shown in Table 1 and the criteria of the vehicle movement in Table 2 were commonly used for left turn accident 211 as well.

Figure 80 shows the top 5 of the last two MIDs before a collision for participant A.
The most frequent manoeuvre was MID 1 followed by MID 8 which counts for 39%. In this manoeuvre, participant A constantly moves towards the left turning point and left turns with constant speed which could be considered as participant A either did not recognise the oncoming participant B or recognised the oncoming participant B but was not able to take any avoidance action. The second and third frequent manoeuvre was MID 8 followed by MID 10 and MID 10 followed by MID 3 which counts for total of 25%. In these manoeuvres, participant A slows down at the left turning point which can be considered that the vehicle operator has recognised that participant B is oncoming, but mis-judged its timing to turn and collided.

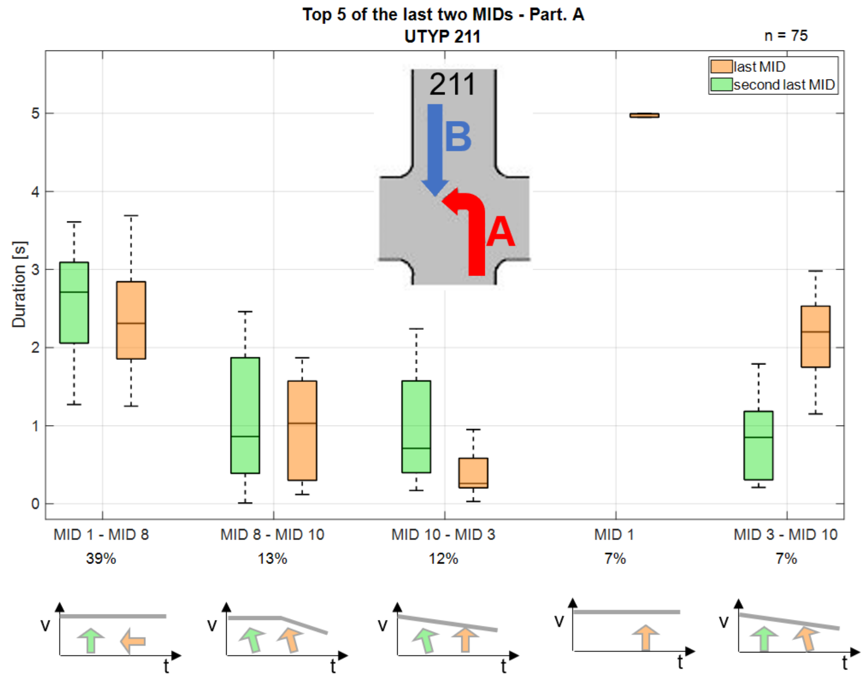


Figure 80: Top 5 of the last two MIDs for participant A (211)

Figure 81 shows the top 5 of the last two MIDs before a collision for participant B. As participant B is moving straight through, the vehicle is at a constant speed in the beginning and as in MID 1 followed by MID 3 which counts for 51%, the rider recognises participant A at a certain point and starts to decelerate. MID 1 only or MID 1 before a collision would mean that the participant B did not have time to react to participant A moving or was too late to recognise participant A moving towards participant B. MID 14 followed by MID 16 and MID 8 followed by MID 10 shows some avoidance reaction by either changing its direction to the right or left while slowing down.

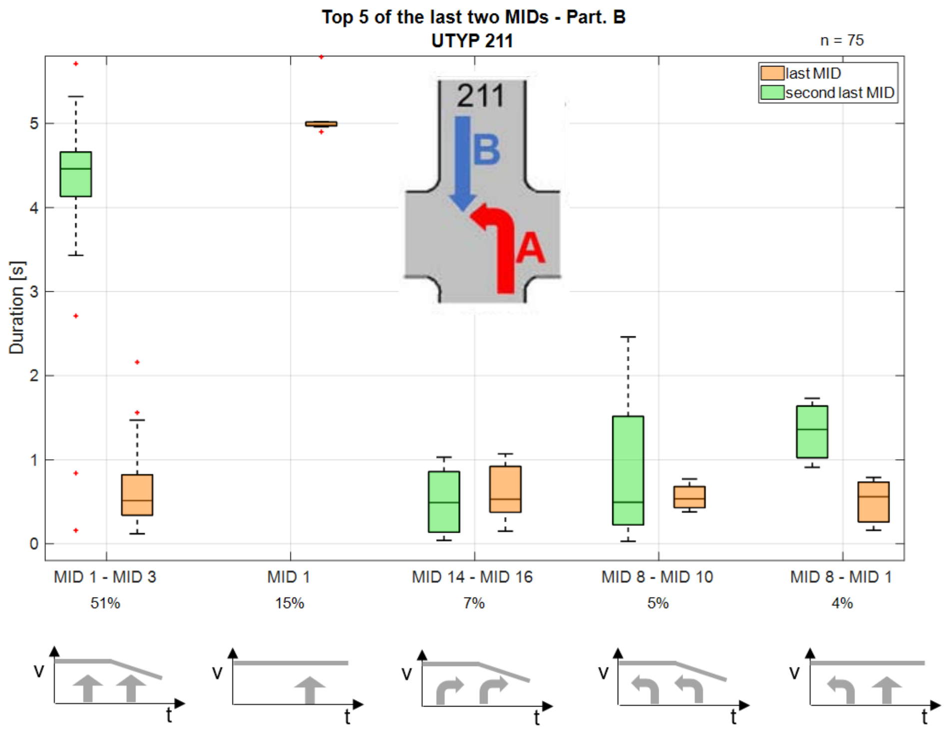
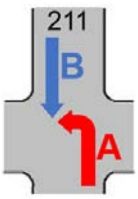
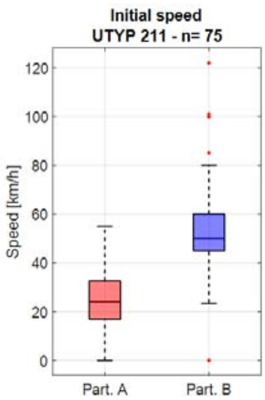


Figure 81: Top 5 of the last two MIDs for participant B (211)

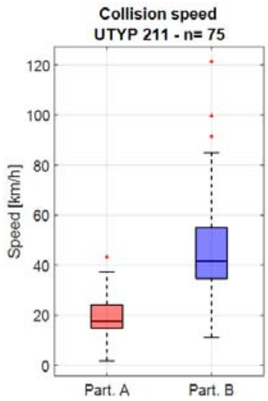
6.2.3 c) Speeds

The initial speed and collision speed of each participant is shown in Figure 82. As a median value, participant A is at 24km/h and participant B is at 50km/h. Collision speed for participant A as the median value is constant at 18km/h and for participant B with some slowing down at 42km/h.





Initial speed	Data Part. A [km/h]	Data Part. B [km/h]
Maximum	55	122
Upper Whisker	55	80
75th percentile	33	60
Median	24	50
25th percentile	17	45
Lower Whisker	0	23
Minimum	0	0



Collision speed	Data Part. A [km/h]	Data Part. B [km/h]
Maximum	43	121
Upper Whisker	37	85
75th percentile	24	55
Median	18	42
25th percentile	15	35
Lower Whisker	2	11
Minimum	2	11

Figure 82: Initial and collision speed of participants (211)

Figure 83 shows the median values of trajectories with speed information indicated. All the information mentioned so far are inputted together for understanding the whole picture of median scenario for left turn accident 211.

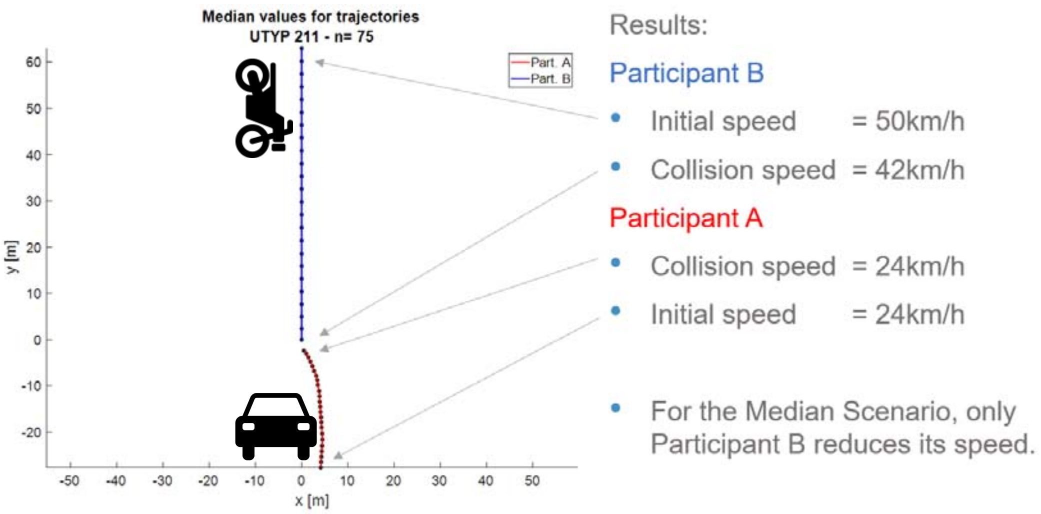
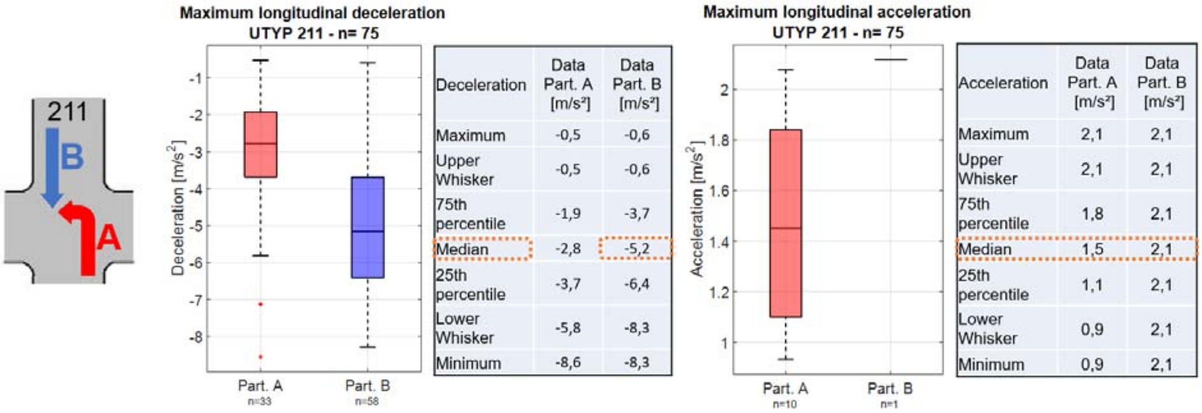


Figure 83: Results of median values for trajectories and speeds (211)

6.2.4 d) Decelerations / accelerations

Figure 84 shows the analysis results of each participant's maximum deceleration and acceleration value. For the median scenario, participant A decelerate with $-2.8m/s^2$, and participant B decelerate with $-5.6m/s^2$ before the collision.



Deceleration	Data Part. A [m/s²]	Data Part. B [m/s²]
Maximum	-0,5	-0,6
Upper Whisker	-0,5	-0,6
75th percentile	-1,9	-3,7
Median	-2,8	-5,2
25th percentile	-3,7	-6,4
Lower Whisker	-5,8	-8,3
Minimum	-8,6	-8,3

Acceleration	Data Part. A [m/s²]	Data Part. B [m/s²]
Maximum	2,1	2,1
Upper Whisker	2,1	2,1
75th percentile	1,8	2,1
Median	1,5	2,1
25th percentile	1,1	2,1
Lower Whisker	0,9	2,1
Minimum	0,9	2,1

Figure 84: Deceleration / Acceleration analysis results (211)

Figure 85 shows the overview of median scenario of left turn accident 211 with all the information so far derived.

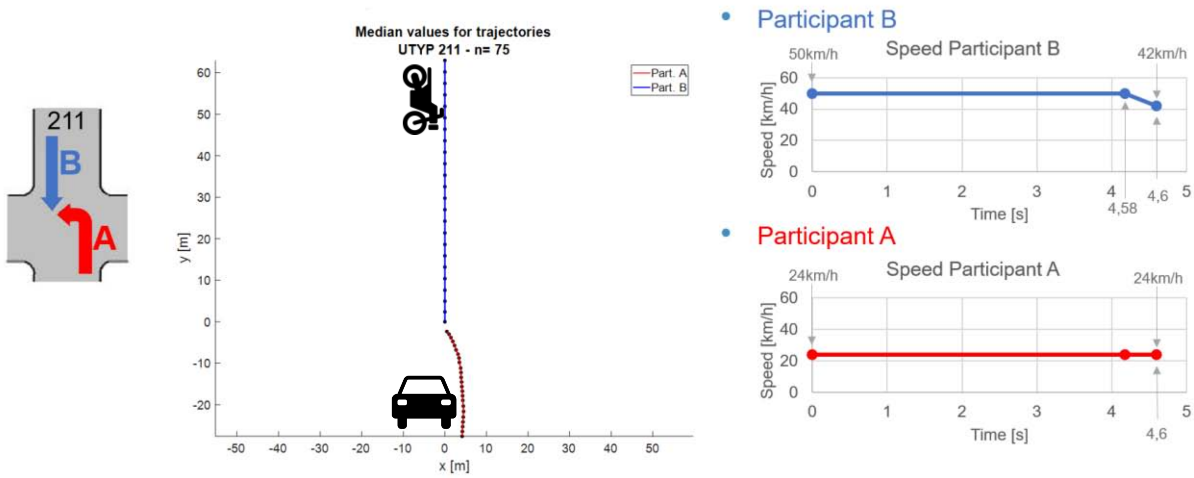


Figure 85: Overview of median scenario of left turn accident 211 with trajectory, speed and deceleration / acceleration information

6.2.5 e) TTC model

Time to collision (TTC) is an important safety indicator as sufficient TTC will provide time for the vehicle operator to recognise the danger ahead and will make room for reaction time. Figure 86 shows the basic TTC calculation model used in this analysis. A tube for each traffic participant is extended as linear straight motion with the current speed values and determines whether the two participants enter the critical conflict zone at the same time. If so, TTC is provided as a division of distance by relative speed.

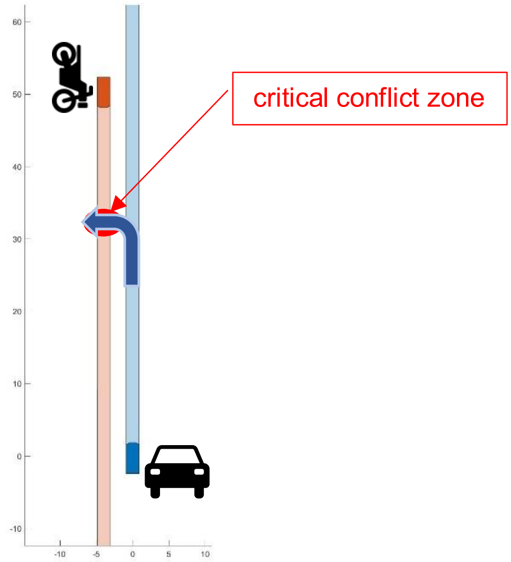


Figure 86: TTC calculation model

Figure 87 shows the TTC calculation result in a heat map for left turn accident 211. The graph shows relatively linear rise from the point of collision and high density in the area of severely critical. However, in the area TTC > 1.6s, it becomes low density which indicates that it is difficult to provide TTC before 1.6s. This is due to the fact with left turn accidents that before participant A starts its action to turn left, it is going in parallel with participant B and the extended tube never crosses, resulting in not making any conflict zone.

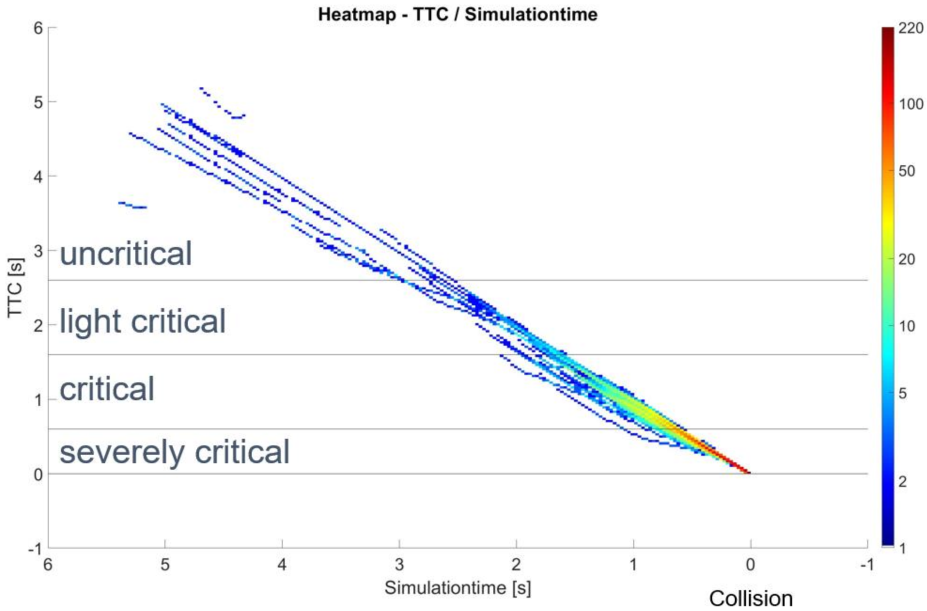


Figure 87: TTC calculation result for left turn accident 211

Figure 88 shows cumulative case numbers of TTC and where it crosses the 50% line. It reads from the figure that 50% of the TTC for left turn accident 211 can only be achieved at 1.5 seconds before the collision. This implies that with 50% of the left turn 211 accidents, the vehicle operator can only be informed 1.5 seconds before the collision.

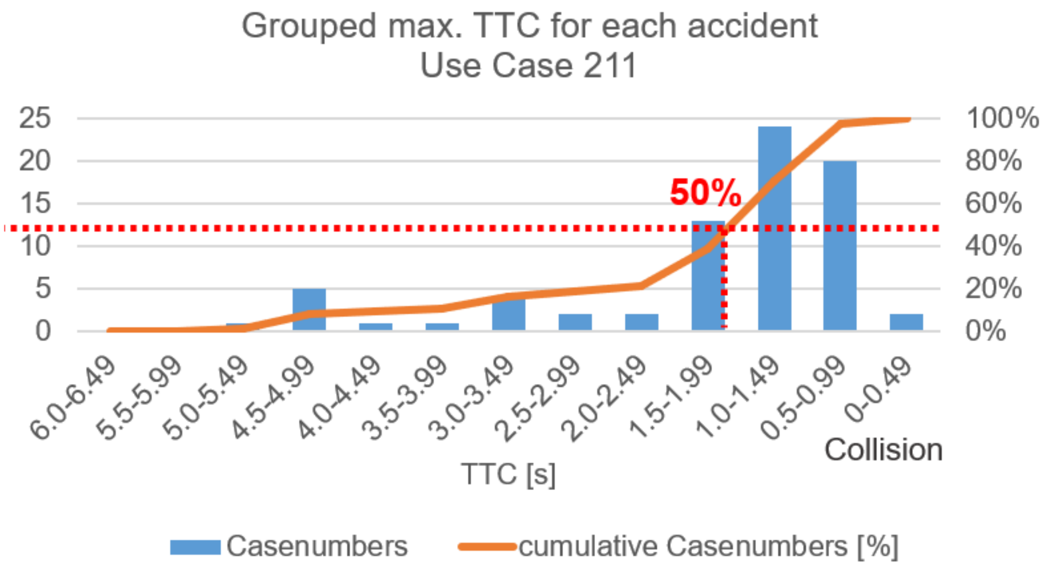


Figure 88: Cumulative case numbers of TTC for each accident (211)

7. Conclusion

CMC analysed crossing traffic accident type 302 and left turn accident type 211 in detail based on the GIDAS database and GIDAS-PCM. These databases provide insights into a great number of aspects of each reported accident; for example road conditions, speed, visibility, trajectories, actions of the participants etc. In analysis Module1, a total of 23 potential influencing factors were investigated and reported, including the ones that eventually did not appear to have an important contribution to the accident. In analysis Module2, an additional 5 investigations were conducted to understand the accident situation more clearly.

From the analysis, an important outcome is that no explicit view obstruction existed in the majority of cases, but still participant A (mainly cars/ trucks) overlooked participant B (mainly PTWs) or misjudged the situation. It is assumed that the situation has led to a collision due to a missed opportunity or late timing to take avoiding action at the correct time. This implies that there is a need for technology support to inform participant A of the existence of oncoming participant B.

In addition, the study of TTC shows that the earliest possibility to notify a vehicle driver/ rider is 4.5 seconds (Median) before the collision in case of crossing traffic accident type 302, while it is 1.5 seconds (Median) in case of left turn accident type 211 as shown in Figure 89.

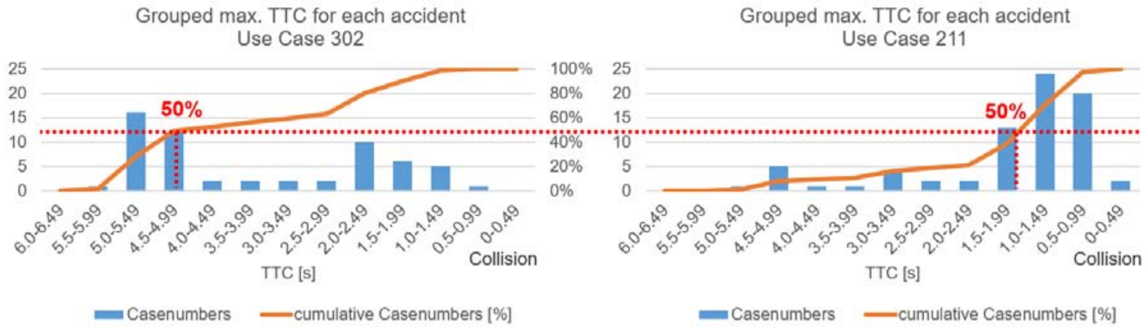


Figure 89: Comparison of cumulative TTC case numbers for 302 and 211

A further challenge remains concerning the appropriate timing to inform the vehicle operator of the danger ahead. To provide notifications with sufficient time margin before a collision, a different TTC calculation method, which detects the risk earlier, needs to be applied. This time margin, however, should be optimised to avoid excessive false positives and does not simply mean the longer the better.

Abbreviations

CMC	Connected Motorcycle Consortium
GIDAS	German In-Depth Accident Study
PCM	Pre-Crash-Matrix
MID	Maneuver IDentifier
PTW	Powered Two-Wheeler
TTC	Time To Collision