

**How Can Car2X-Communication
Improve Road Safety**
A Statistical Based Selection and Discussion of
Feasible Scenarios

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Abstract

A lot of applications have been sketched in the area of Car2X-Communication. Safety aspects are often mentioned among others as a motivation for Car2X-Communication systems. We present a statistical based selection of feasible applications with the goal of increasing safety. Therefore the official statistical information of the year 2007 has been considered.

Additionally we will present some consequences for the introduction of Car2X-Communication systems including infrastructure.

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1 Introduction

Car2X-Communication is a field of research with high interest and considerable potential for improving road safety. Because of that, there are several organizations like the C2C-CC [1] and projects like SIM-TD [2], AKTIV [3, 4], Cognitive Automobiles [5, 6] or SAFESPOT [7] devoted to this research direction. Topics of these projects are real life tests, increasing traffic safety and traffic flow, the introduction of cooperative traffic systems and more.

A lot of different applications have been defined. Due to [8] they can be categorized by:

- safety applications
- transport efficiency applications
- infotainment applications

In [9] it has been stated that a significant reduction of killed persons by road accidents is a declared European goal. Therefore, we focus in our research project on applications increasing road safety.

In this paper, we show feasible scenarios with potential for increasing road safety by introducing Car2X-Communication. These scenarios are selected by high crash rates or a high amount of fatalities. Furthermore, we discuss solutions in which a communication system based on Car2X-Communication can achieve a reduction of accidents.

The German Federal Statistical Office publicizes statistical information [10] concerning the road crashes on german roads annually. We use this statistics for our considerations because of the high quality, completeness and the actuality. For this paper, the publication based on the year 2007 is used because the report for 2008 is not yet available. Some of these statistics are combined with the latest results of the german traffic census of 2005 [11] for considerations of the different road usage.

To identify the scenarios with high crash rates we have taken accident victims and fatalities into account. Accident victims are those

persons who are injured or killed as consequence of a crash. So, fatalities are a subset of accident victims.

The remainder of the paper is organized as follows: In Section 2 different scenarios are presented by statistics and are discussed in the context of Car2X-Communication. Related work is mentioned in Section 3. The papers conclusion and our future work are provided in Section 4. Finally the acknowledgment is given in Section 5.

2 Feasible Scenarios for Car2X

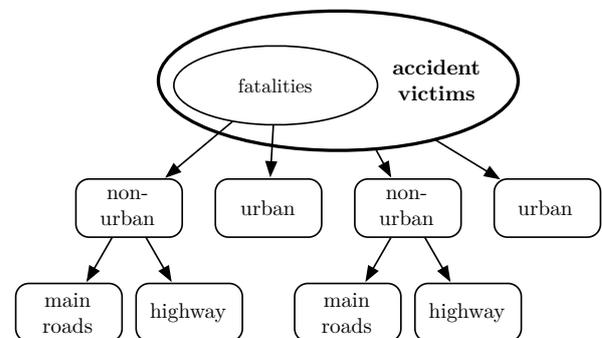


Figure 1: Tree with Categories

Figure 1 shows the fundamental separation of the major categories for crash scenarios which are used in this document. All presented statistical information in this paper is based on that tree to make the conclusions comparable.

We used a comparison between killed persons and the total amount of accident victims because this allows us to figure out where the scenarios with high crash rates are located. Furthermore, an evaluation of the relevance of those scenarios for road safety is possible.

2.1 General Survey

In this section we give a general survey of the statistics on road accidents. Even this leads to first relevant information for Car2X-Communication.

2.1.1 Statistics

To get an first idea where accidents happen and which of those accidents are really dangerous we present an abstraction of [10]. Table 1 shows a comparison between the major categories. The raw values (1st column) of that table are qualitatively depicted in Figure 2. In Table 2 the percentage shares of fatalities in the total amount of accident victims is presented.

	amount (raw values)	urban/ non-urban	with/ without HW	all leaves
fatalities	4949	100%		100%
urban roads	1335	27%		27%
non-urban	3614	73%	100%	
main roads	3012		83%	61%
highway	602		17%	12%
victims	436368	100%		100%
urban roads	278307	64%		64%
non-urban	158061	36%	100%	
main roads	126119		80%	29%
highway	31942		20%	7%

Table 1: Comparison between Categories

The first column 'amount' of Table 1 includes the raw values for each leaf of the tree presented in Figure 1. For example there were 436 368 people injured or killed by road accidents in 2007 in Germany. 4949 of them were fatalities.

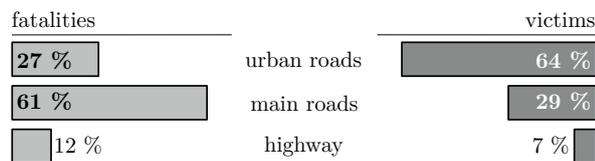


Figure 2: Qualitative Comparison between Categories

The second column of Table 1 includes the values for urban and non-urban roads. As it could be expected, the values show a change of relevance between fatalities and accident victims. On urban roads the rate of accident victims is higher than on non-urban roads. How-

ever, the rate of fatalities on urban roads is less than on non-urban roads.

The third column of Table 1 compares main roads (non-urban roads without highways) with highways (in tables sometimes abbreviated to 'HW'). As result this column points out that highways are less dangerous than main roads. Both aspects (fatalities and victims) show that with nearly the same distribution. Main roads and highways are in that point directly comparable because on both road types approximately the same traffic volume take place which is shown later in this section (Table 3 and Figure 3).

The most interesting values of Table 1 are presented in the last column which includes the values for all leaves (also depicted in Figure 2). Highways are once more in the lower range. Only 12% of the fatalities and only 7% of the accidents with victims happen on highways. Beside this, urban roads and main roads switch roughly their values by changing the point of view from fatalities to accident victims. The change of relevance by the urban/non-urban comparison (2nd column) is therefore almost independent of highways.

Table 2 shows the percentage share of fatalities in the total amount of accident victims (see column 1 of Table 1). Despite the fact that most accidents with victims take place on urban roads, those roads take by far the least share of fatalities. On the second place highways can be found. On highways there are by far the least shares of fatalities and accident victims in their respective total amounts but the high traveling speed cause accidents with a higher mortality rate than on urban roads. The highest share of fatalities in accident victims take main roads. The reason for that could be seen by the values Table 2 is calculated from. On main roads the raw value for accident victims is in the middle (lower than on urban roads) but the raw value for fatalities is the greatest one (greater than on urban roads).

To characterize the situation on non-urban roads more in detail, the results from the german traffic census from 2005 [11] can be used to take the different road usage into account.

	$\frac{\text{fatalities}}{\text{victims}} \cdot 100\%$
total	1.13%
urban roads	0.48%
non-urban	2.29%
main roads	2.39%
highway	1.88%

Table 2: Comparison between Killed and Total

This traffic census is updated every five years. In Table 3 and Figure 3 the road length and the annual mileage is presented. One of the results of [11] is that 53.0% of the non-urban traffic takes place on highways which only have a part of 11.9% in the non-urban road net. Interesting is that especially on highways occur only 17% of the non-urban accidents with fatalities and only 20% of the non-urban accident with victims.

	road length		annual mileage	
	in 10^3 km		in 10^9 km	
highway	12.3	11.9%	213.3	53.0%
main roads	90.9	88.1%	189.5	47.0%
	103.2	100%	402.8	100%

Table 3: Comparison between road length and annual mileage



Figure 3: Qualitative Comparison between road length and annual mileage

2.1.2 Relevance for Car2X

Based on the accident statistics [10] and on the traffic census [11], the highest influence for increasing road safety could be reached by improving the situation on main roads. Main

roads show the highest rate of fatalities and the amount of accident victims is also quite high. Taking into account that only 47% of the non-urban traffic takes place on main roads, the fact that the amount of fatalities is five times higher than on highways is significant. For the introduction of a Car2X-Communication system, it is therefore important that the full functionality of the system is guaranteed especially on main roads. Useful systems for main roads could be Cooperative Collision Warning, Electronic Brake Lights, Glare Reduction, Cooperative Adaptive Cruise Control and more as described in [1].

Nearly the same importance take urban roads. On urban roads occur about two thirds of all accidents with victims. As to be expected, the lower travel speed is the reason for the lower mortality rate of this accidents. A suitable system for increasing safety in this cases could be a intersection assistance, e.g. the PREVENT subproject INTERSAFE [12] was working on.

As previously mentioned highways take only a low share in accidents which could also be seen easily in Figure 2. Because of the high velocity a high share in accidents ends up with fatalities. This is significant to any realization of the Car2X-Communication, because a suitable system should also be able to cope with high vehicle speed. Furthermore, the system should handle time critical messages in appropriate time. To deal with all such requirements, the PHY- and the MAC-layer (OSI Reference Model for network stacks [13]) have to be developed accordingly [14, 15].

2.2 Characteristics of Crashes

Another point of view for the definition of feasible scenarios to improve road safety provides the breakdown of the different crash types. In this section we split up the different crash types more in detail.

2.2.1 Statistics

The fatality rates derived from this drill-down reflects the different types of roads very well. So it is sufficient, only taking fatalities into account. An abstraction of the accident statistics [10] is presented in Table 4 and Table 5.

	urban	non-urban	
		wo. HW	highway
crash between cars			
start, stop, standing	2.8%	0.6%	3.0%
ahead or waiting (rear end crash)	1.6%	2.6%	35%
besides with same direction	2.9%	1.8%	8.0%
opposite direction	8.2%	33%	3.0%
turn or junction	20%	14%	0.5%
others			
run-off-road (road departure)	18%	39%	40%
accidents w. pedestrian	36%	5.6%	3.3%
impact with obstacle	0.5%	0.5%	1.3%
other	11%	3.0%	6.8%
	100%	100%	100%

Table 4: Distribution of Crash Types

In Table 4 the distribution of crash types on the special road types is given. E.g. 20% of the accidents on urban roads happen in turns or junctions. The crash types presented in Table 4 emphasize some important cases which are highlighted. Such cases are for urban roads 'turn or junction', 'run-off-road' and 'accidents with pedestrian' which sum up to 74%. On main roads there are the cases 'opposite direction' and 'run-off-road' which sum up to 72% and for highways there are 'ahead or waiting' and 'run-off-road' relevant which sum up to 75%. It could be seen that the row 'run-off-road' is relevant on every road type.

In Table 5 are crash characteristics and specifics given. These attributes are secondary conditions and can therefore not be summed up to 100%. As for the crash types in Table 4 there are also some outstanding cases

	urban	non-urban	
		wo. HW	highway
characteristics			
intersection	16%	6.9%	
T-junction	17%	12%	2.3%
estate entrance	6.4%	1.7%	
steep upwards	4.1%	6.7%	7.3%
steep downwards	8.2%	13%	8.5%
turn	16%	40%	18%
specifics			
grade crossing	4.6%	0.8%	
crosswalk	1.6%		
crosswalk at traffic lights	5.6%	0.2%	
bus stop	3.2%	0.5%	
working areas	0.9%	0.4%	3.8%

Table 5: Distribution of Crash Characteristics and Specifics

highlighted. These cases are for urban roads 'intersection', 'T-junction' and 'turn'. For main roads the high rated cases are 'T-junction', 'steep downward' and 'turn'. Highways show only for 'turn' a significant value in respect of crash specifics. The case 'turn' is emphasized on every road type and takes therefore a special role.

2.2.2 Relevance for Car2X

The distribution of accidents depends on the road type as shown in Section 2.2.1 for fatalities by crash types, characteristics and specifics. Because of that a Car2X-Communication system could improve its performance if it dynamically adapts to the road type the car is driving on. So, the complexity of the whole system could be reduced to two or three major crash types depending on the road type with an at least 72% coverage of all accidents with fatalities. The crash type 'run-off-road' and crash characteristic 'turn' show on every road type an increased significance. This leads to the fact that a Car2X-Communication system for increasing road safety needs also some basic functionalities like beaconing, forward collision warning, hazardous location notification

or post crash warning [1]. However, it could be an advantage to use a different parameterization for the applications depending on the road type. With such a situation based adjustment the system could improve the over-all performance of the safety applications.

To improve the situation on urban roads is a hard challenge for Car2X-Communication. Because of radio obstacles (e.g. buildings) in cities, a two-dimensional routing is required [16, 17]. Furthermore, pedestrians and intersections are especially in cities relevant which can be seen in Table 4 and Table 5. Those situations could not only be satisfied with Car2X-Communication. However, Car2X could play an important role in systems which combine the special abilities of different techniques. For example, on intersections with traffic lights the Car2X system could exchange information about the switching timing [1, 18] between cars and traffic lights. Furthermore, a traffic light communication system could support the routing for emergency vehicles or detect hazardous situations with involved cars which are not yet equipped with a Car2X system. To protect pedestrians, cars or infrastructure elements which detects a hazardous situation between a person and another car with its own environment sensors (e.g. cameras, radar, lidar, ...) could warn at least the involved car or the surrounding environment.

On non-urban roads the crash types differ for main roads and highways but they have in common that the increased values results from crashes with cars driving ahead or coming from opposite direction. So, a system which observes and interprets the traffic in front of the car should be able to detect and so to prevent some crashes or at least weaken the impacts of a crash. Once more, a Car2X-Communication system on its own could not achieve a satisfying system. But in combination with environment sensors of cars and the infrastructure these situations with increased crash values could be addressed [19].

2.3 Driving Mistakes

In this section we take driving mistakes into account because those are part in the reasons of almost all crashes. A future Car2X-Communication system has to address this also.

2.3.1 Statistics

Driving mistakes are among the main reasons for crashes in [10]. For accidents with victims there were 351 186 drivers faults and for accidents with fatalities there were 5 730 drivers faults counted. Taking into account that there were in total 436 368 accident victims and 4 949 fatalities, as presented in Table 1, the importance of addressing driving mistakes is clearly shown. The numbers for drivers faults which cause victims or fatalities and the total amounts for victims or fatalities differ because they are not correlated (e.g. the fault of one driver could cause one, two or more death or two drivers faults could cause only one death).

The german crash statistics [10] splits the information about driver faults in several dimensions. In this paper we selected the values for the reasons which cause fatalities which are presented in Table 6. Some cases like cargo securing and others have been omitted and some others have been combined for clarity. The case 'way of driving' is a combination of speed, distance, side by side driving and lane change. The case 'traffic coordination' is a combination of right of way, turn off and reverse driving.

The two columns including the distribution of drivers faults in Table 6 refer to the amount of the addressable cases. Every case shows a more or less relevant share in the total amount so none could be omitted. The most important case is 'way of driving' followed by 'traffic coordination'. The case 'wrong road usage' is mostly important on non-urban roads in contrast to the case 'behavior towards pedestrian' which is mostly important on urban roads.

	amount		distribution	
	urban	non-urban	urban	non-urban
wrong road usage	58	516	6.0%	18%
way of driving	367	1561	38%	54%
overtaking	34	344	3.5%	12%
traffic coordination	294	440	31%	15%
behavior towards pedestrian	208	54	22%	1.9%
	961	2915	100%	100%

Table 6: Fatalities as Sequence of Misbehavior

2.3.2 Relevance for Car2X

Unfortunately, all the above mentioned major cases differ too much to cope with them with a single and simple system. Because of that there has to be a combination of systems. Such combined systems should change its behavior depending on the situation.

In the following, some approaches to cover the major cases are discussed. The 'usage of wrong roads' could be addressed by a navigation system including a road map in combination with a higher localization accuracy [20]. The higher localization accuracy could be achieved with a Car2X-Communication based collaboration. The benefits of that are the accurate detection of the road lane the car is driving in or the positioning on an intersection. The case 'way of driving' could not be inhibited but reduced by beaconing (periodic sending) the position, driving direction and vehicle type to other vehicles. With those information a system trying to interpret the driving situation could be significantly improved. The case 'overtaking' might be addressable with a collaborative system between cars which is also a possibility for the cases 'traffic coordination' and 'behavior towards pedestrian'. Such a collaborative system could include a curve speed warning, pre-crash sensing, cooperative forward collision warning or lane-change warning [1, 21].

2.4 Time of Day

The fatality rates and the traffic density differ over the time of day. So, a comparison between both points of view will provide some interesting facts a Car2X-Communication system will be confronted with.

2.4.1 Statistics

Table 7 and Table 8 show the distribution of the fatalities over the time of day. Table 7 has a higher resolution of time and is depicted in Figure 4. Table 8 includes additional information about the traffic density (also depicted in Figure 6) consisting of average values of road sections which are equipped with counting devices. Data recordings for the traffic density are only completely available on state roads (germ.: Bundesstraßen) and highways [11].

time	amount	distribution
0 - 1:59	213	4.30%
2 - 3:59	183	3.70%
4 - 5:59	298	6.02%
6 - 7:59	412	8.32%
8 - 9:59	331	6.69%
10 - 11:59	439	8.87%
12 - 13:59	484	9.78%
14 - 15:59	652	13.17%
16 - 17:59	700	14.14%
18 - 19:59	536	10.83%
20 - 21:59	373	7.54%
22 - 23:59	328	6.63%
	4949	100%

Table 7: Distribution of Fatalities over Time [10]

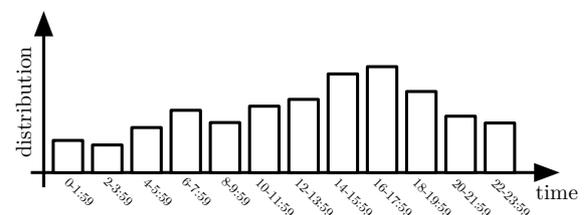


Figure 4: Fatalities over Time

In Table 7 and Figure 4 it could be seen that the fatality rate increases from 2 am to

6 pm and decreases afterwards. There is only one little peak between 6:00 - 8:00 am which probably is caused by the rush-hour traffic. The comparison in Table 8 figures out that the distributions for fatalities and traffic density are not correlated. For example, during night time the fatality rates on highways are higher (18.4 % in amount) than in the evenings (9.6 % in amount) or by day (10.8 % in amount). Despite, the traffic density is at night much lower than in the evenings or by day. Furthermore, Figure 5 shows a normalization of the fatalities columns of Table 8 to one hour (values divided by the length of the time interval). This figure shows only a small decrease of fatalities per hour over time of day which not decreases like the traffic density (see Table 8 and Figure 6). Highways cause even an increase of fatalities at night despite an decrease.

time	fatalities		traffic density Ø in vehicle/h	
	amount	HW	state road	HW
6 - 17:59	3018	327	694	2994
18 - 21:59	909	87	462	2216
22 - 5:59	1022	188	117	664
	4949	602		

Table 8: Fatalities and Traffic Density over Time [10, 11]

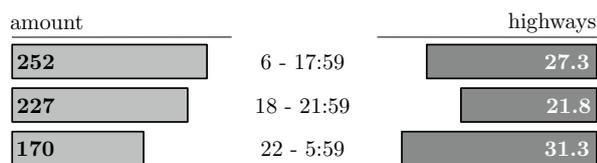


Figure 5: Normalized Fatalities per Year over Time

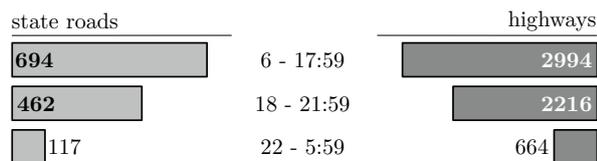


Figure 6: Traffic Density over Time

2.4.2 Relevance for Car2X

The non-correlation between fatality rates and traffic density is an important information for the design of upcoming Car2X-Communication systems. This fact shows that it is necessary for a Car2X system to cope with an arbitrary number of communication partners. So, e.g. these systems have to work during nighttime with a small number of cars in the surrounding and during rush-hours too. Also, if there will be a high market penetration in future there will be situations with no or just a few communication partners.

2.5 Age of Car

In this section we present statistical information about the distribution of the age of the cars involved in accidents. Such information is important to identify the ramp-up time which is necessary for a new technology to show results.

2.5.1 Statistics

Table 9 includes the age of the passenger cars whose drivers mainly caused the accident [10]. The information is presented for the accident victims and the fatalities. We use this information about the main originators and passenger cars because of the lack of information about the involved vehicles. So the numbers are not directly comparable to the others in that paper. However, we include these numbers because they will contribute relevant information for Car2X-Communication systems. Additionally, it should be considered that the rows have different time intervals. Figure 7 shows a qualitative comparison between the distributions whereas the area of each bar equates to the corresponding value according to the time interval.

In Figure 7, nearly an equipartition is reflected, especially for accident victims. The distributions for the fatalities shows a little increase over time with one peak between 8 and 10 years. Both distributions exhibits lower values for the first year.

Age of Car in years	victims	fatalities
< 1	9240	74
1 - 2	18575	128
2 - 3	17582	131
3 - 4	16325	133
4 - 5	16504	141
5 - 6	16752	161
6 - 8	35048	329
8 - 10	41513	474
10 - 12	37980	382
> 12	77630	956
unknown	24205	219
	311354	3128

Table 9: Victims and Fatalities over Age of Car

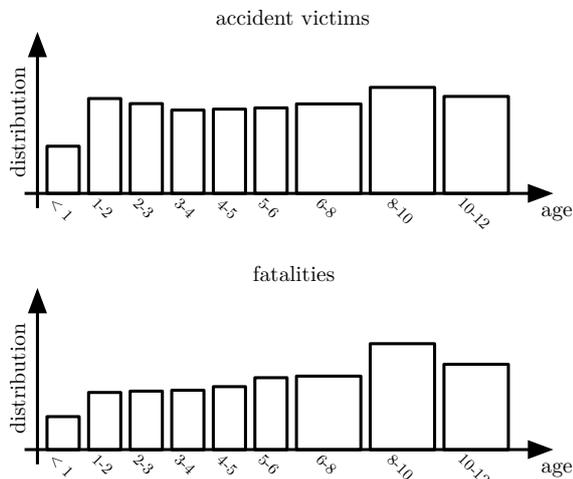


Figure 7: Distribution of Age of Cars

2.5.2 Relevance for Car2X

The market introduction of a Car2X-Communication system will show effects on the crash statistics very slowly. There are two main reasons for that. At first, the market introduction will be a slow process which will take several years. In [1] it is shown that a market penetration of 50% would take 6 years. This calculation is based on the assumption that each new car would be equipped with a Car2X system. This example is not realistic but at least the upper bound of the time for an feasible market penetration could be estimated. At second, the accidents

are caused by cars at any age which is shown in Section 2.5.1. So, there will be hazardous situations and accidents for a long time between newer and older cars which are equipped with and without Car2X-Communication systems. These two reasons in combination will slow down the impact of Car2X-Communication systems on the crash rates.

Therefore, the most important point for the design of a realistic Car2X-Communication system is a long term compatibility. It is absolutely necessary that the first equipped cars provide benefits for the customer without a high market penetration. In addition, such cars must be capable to operate with future versions of the network.

3 Related Work

A lot of research is done or validated on highway scenarios [22, 23]. This work is important because on highways occur high traffic densities (see Table 3). Therefore, it must be ensured that Car2X-Communication systems work well in such scenarios. But for safety research the potentials of highways are limited as we have shown.

In [24] the german accident occurrence is presented. This document shows an historical analysis of the german and european accidents. Furthermore, the accident statistics are discussed in the context of the different federal states, place, month, reason, traffic contribution and some special groups of persons. However, this document shows only a general analysis of the accident numbers and is therefore not related to Car2X-Communication.

4 Conclusion and Future Work

In this paper we analyzed several statistical information and combined these to determine feasible scenarios for improving road safety by an introduction of a Car2X-Communication system.

The most important result is that accidents with victims and fatalities show the lowest rates on highways. Because of that, highways are not so important for the development of safety applications. On main roads and in cities occur more accidents which should therefore be addressed by safety applications.

By reviewing the distributions of the crash types, characteristics and specifics of the different road types, we detected differences which should be considered:

- The crash type 'run-off-road' and the crash characteristic 'turn' are relevant for any road type.
- Urban roads show additional relevance for intersections and accidents with pedestrians.
- Non-urban roads without highways show additional relevance for crashes with cars driving in the opposite direction, T-junctions and on road segments which are steep downwards.
- Highways show additional relevance for crashes with waiting cars or cars driving ahead.
- Driving mistakes are part in the reasons in almost all accidents.
- The time of day of accidents and traffic densities are not correlated.

To cope with these points a Car2X-Communication system needs some basic functionalities, some special road depending functionalities and must be able to handle high and low traffic densities.

The last point serves the identification of ramp-time for market introduction. The distribution of the accidents over the cars ages is quite balanced. So, effects for road safety will take a long time. The slow market introduction and the occurring of accidents by low traffic densities show the necessity for applications and systems which work without direct or many communication partners.

In our future work, we intent to:

1. expand the statistical analysis to european scope to check whether the results are comparable,
2. conduct technical feasibility studies to identify applications and communication strategies with the biggest impact on road safety and
3. put one of those feasible applications or communication strategies into practice.

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