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A support tool for identifying evaluation issues of road safety measures

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Abstract

The introduction of new technologies in traffic produces a range of unknown deviations in the desired traffic process. These developments require additional ex-ante assessment procedures for measures which will be implemented in the traffic system. In this paper, the HAZOP methodology is applied to road traffic measures to provide scenarios based upon predicted deviations and problems with new, mainly in-vehicle technologies. To make HAZOP applicable for road safety purposes analysis of the expectations of road users is added to the traditional approach. In this paper, some results are shown for speed reduction measures. The dependency of the results on the membership of the HAZOP team and especially the question if a mixture of expertise is required are also discussed.

Keywords: Road safety; Ex ante evaluation; New technologies; Policy making

1. Introduction

The HAZOP technique has long been used in the chemical industry for assessing designs In recent years its area of application has increasingly been extended to other industries and technologies. In the Safety Science Group in Delft these applications have included road maintenance work, tunnel building and more recently driving [e.g. 1, 2]. This paper describes the approach taken in the last area and the results which have been achieved in assessing the potential safety effect and effectiveness of both conventional road features, such as speed humps, and new technologies, such as intelligent speed adaptation (ISA).

This study forms part of a larger doctoral research into the proactive assessment of intended and unintended effects on safety of proposed new technology (both in-car and roadside).

2. Need for proactive safety assessment in traffic

The use of ICT (Information and Communication Technology) based technology in vehicles has been increasing since the 1980s [e g., 3]. Whereas the first applications were mainly based on providing various sources of information to drivers (e.g. RDC-TMC for regional traffic information and navigation systems), nowadays systems are on the market that are able to influence driving tasks directly. An example is adaptive cruise control (ACC), a system designed to keep a minimum headway to a vehicle in front. Although car manufactures sell these systems as so-called ‘comfort extensions’ functional safety problems might occur when using these systems. Furthermore the systems might influence one’s driving behaviour and through this the safety of the traffic system as a whole. Jagtman et al. [4] discussed the current knowledge on safety effects of ACC-like systems. They showed a gap in the types of effects that were incorporated in safety studies of these systems. The ex-ante studies performed covered safety problems relating to the desired process that was defined for a system (e.g. keeping a safe headway), but often did not deal with safety problems resulting from deviations from the desired process, such as malfunctioning of the system or driver adaptation.

Recently, Carsten and Nilsson [5] have argued that a generic safety assessment for driver warning and vehicle control systems is lacking. They concluded that a standardised safety performance test will not be feasible and that a process-oriented approach is necessary. Part of this

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approach is the definition of possible test scenarios. In order to assess the safety of driving support systems these scenarios should at least contain the normal and desired process and plausible deviations from this process. The scope of possible deviations should be known before defining the scenarios containing deviations. The complexity resulting from the implementation of all kinds of new technology increases the need for a method to identify the test scenarios. This paper addresses that need.

Elliott and Owen [6] described similar problems during the design of new chemical plants. They tried to provide a systematic approach to think about not only the process and its predictable deviations but also to try to take into account unknown deviations [7]. The ideas of Elliot and Owen were modified by Lawley [8] into the HAZOP method known today. The need to adopt such methods in the field of road traffic increases with the introduction of (complex) technologies that may affect the possibilities of the road users to adapt their behaviour to the situation they find themselves in. In the next section the traditional HAZOP is explained, and in the subsequent sections the research questions and the way in which the HAZOP was adapted for traffic use.

3. The traditional hazop approach

The method developed by Lawley [8] is designed to search for every conceivable process deviation and look backwards at possible causes and forwards at possible consequences His reason for developing the method was the assumption that most problems are missed because of the system's complexity rather than because of a lack of knowledge on the part of the design team. The main objective is to define safety (hazards) and operability problems. A secondary objective is to evaluate the possible consequences, which is done in a semi-quantitative manner. The approach is based on stimulating creativity and imagination through a structured brainstorm, in order to think of all possible manners in which hazards and operability problems can occur [9]. This is done in a systematic way by a team of specialists with different training and experience in order to reduce the chances of missing any hazard and operability problems. In order to perform the method systematically a matrix with *process parameters* (e.g. temperature and flow) and *guide words* (e.g. no, high and reverse) is used. A combination of a process parameter and a guide word (e.g. no flow) forms a potential deviation. For each deviation (cell of the matrix) the HAZOP team discusses the following questions [7,9]:

1. Could the deviation occur?
2. If so, how could it arise?
3. What are the consequences of the deviation?
4. Are the consequences hazardous or do they prevent efficient operation?
5. If so, can we prevent the deviation (or protect against the consequences) by changing the design or method of operation?
6. If so, does the size of the hazard or problem (that is, the severity of the consequences multiplied by the probability of occurrence) justify the extra expense?

4. Research questions

Extending the use of the HAZOP approach to the field of road traffic requires attention to be paid to the particular characteristics of traffic systems compared to the process industry and the needs for which the technique will be applied The first issue is concerned with the adaptations that were necessary to apply the methodology to road traffic operations. These included decisions about the representation to be used, the experts to be involved and the parameters and guidewords to be chosen. The usability of the adapted procedure in predicting the full range of deviations in a traffic system was assessed in the research. The adaptations are discussed in Sections 5 and 6.

Secondly, we pay special attention to the dependency of the HAZOP results on the composition of the HAZOP team. The question is whether a traffic HAZOP can be performed by a team consisting only of policy makers or only of traffic participants, as opposed to a team with a mixture of expertise, including designers, as the traditional method requires. If the homogenous groups of policy makers or traffic participants are found to be able to use the method just as successfully, it means that it can be used by policy makers alone for ex-ante assessment. To assess this the results of different groups are compared to analyse to what extent the identification of problems and the interpretation of these depend on the expertise and experience of the HAZOP team. This second issue will be addressed by means of both a quantitative and a qualitative analysis. The quantitative analysis assess whether the different groups come up with the same number of deviations and the same distribution of the deviations across the different system levels at which deviations can occur (see also Section 6). For example, policy makers might be expected to have little expert knowledge on the technology of new road safety measures which include ICT technologies, whereas designers of these systems will know a lot. Does the latter group therefore identify far more deviations for these new technologies, than the two groups without this expertise (see Section 7.1)?

The qualitative analysis compares whether the groups discussed the same subjects. Is a homogeneous group of policy makers able to identify the same issues as a group with a mixture of expertise, including designers? The expectation is that the mixed team will come up with a larger variety of issues (Section 7.2).

Finally we analyse whether the composition of the HAZOP team is of importance for estimating the frequency and severity of the deviations. This analysis compares the distributions of judgements in each team, based on their own list of deviations identified during their brainstorm session (Section 7.3).

5. Hazop for traffic purposes

The fields in which HAZOP studies have been used (e.g., chemical process engineering, food process engineering, nuclear power and programmable electronic systems, [9,10]) have in common the investigation of a process that is delimited both in space and in the number of different operations. The road traffic system has much in common, but differs in some ways:

- It deals with a larger number of people who moreover do not all have similar experiences or expectations in participating in the traffic process.
- The number of participants and the variety in these participants (car drivers, pedestrians, etc.) within the traffic process is variable in time and in space/location.
- Within the traffic process individual participants cannot be assumed to have the same goals as each other or as the authorities.

As a result of these differences the tasks of different participants are harder to describe in a generic process description. However, as the HAZOP approach seems to show great promise for the identification of test scenarios for ICT-based new technologies in traffic, this research explores the possibilities of adapting this approach to traffic processes.

5.1. Traffic process

The desired traffic process discussed in a HAZOP is defined as the regulators' goals specified for the location under study As these goals comprise both achieving a sufficient capacity, depending on the function of the network under study (for instance through-flow for a motorway or access in residential areas) and minimising the number and/or severity of traffic accidents, a HAZOP in traffic can study both the operability of the system and the hazards in it, as is the case with the original field of application [10]. Environmental impacts resulting from the traffic process could be studied in a similar way, but are not further discussed here.

A general description of the desired traffic process is defined as [11]: *Offering a particular capacity in a defined area under conditions of minimum loss*. The process is worked out in detail based upon formal rules set by the regulator, which are derived from specific goals such as priority for a specific traffic stream or for specific road users (e.g. vulnerable road users), speed reduction during specific time slots (e.g. day time, lunch break) and use of time windows for good distribution (allowing no heavy traffic outside these windows).

5.2. Representation and visualisation of the traffic process

In order to carry out a HAZOP a physical or logical representation is needed of the traffic system and its intended operation The traffic process under study is characterised by means of the physical layout, including information on the surroundings. The area information includes possible special destinations in the neighbourhood of the study object, such as: hospitals, schools, playing fields, shops, housing, offices, and industries. This information might be of importance for the events (including incident or accident events) that could occur. The road (safety) measures included in the HAZOP are represented using standard descriptions from handbooks, where available [e.g. 12, 13], or using the information available from pilot studies for the measures which use new technologies. The description provided to the experts in the HAZOP team should, apart from the location description, contain characteristics of the vehicles and the road users.

A number of the traffic elements are autonomous entities having their own goals. This is the case for all users and their vehicles in the system. As a result these entities do not move through the system in a predefined manner. To cope with the dynamic and continuously changing character of these system elements the representation of the traffic system used during the brainstorm consisted not only of a fixed visualisation of the network and its fixed elements (e.g. road and traffic signs) but also of free objects that represent the road users and if applicable their vehicles. For this purpose the elements of the traffic system were visualised by means of LEGO™ to have a dynamic representation of the traffic system available. The dynamic representation was intended to allow the HAZOP team to build all sorts of traffic situations in order to show the other experts, by moving the element in the situation, the deviations and possible causes of these. Fig. 1 gives an impression of two situations that were developed during a HAZOP brainstorm.

5.3. Basic assumption in the Traffic HAZOP

The basic assumption for the Traffic HAZOP is that a safe traffic process (for a particular location) is established when all traffic participants involved have both sufficiently similar expectations about how to resolve the situations in that traffic process, and the means to effectuate that behaviour 'Sufficiently similar' means that expectations do not have to be exactly identical but that they should at least not conflict with each other. The complexity of expectations has been shown for different junction settings by Heijer and Wiersma [14]. All measures implemented in

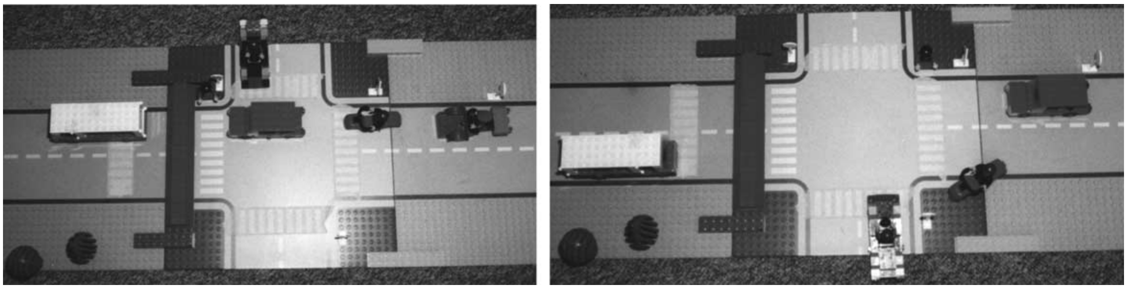

Fig. 1. Examples of traffic situations built during a HAZOP brainstorm.

the traffic system, either in-vehicle, in the infrastructure or in regulation, could influence these expectations. For instance, a driver with a detection system for other traffic (of which ACC is a preliminary system) will possibly put less effort into observing the other traffic and overlook a pedestrian near a pedestrian crossing. Moreover, this modified behaviour of the drivers or vehicles with such ICT-based systems could also interact with the expectations of other road users without these systems. An example could be the pedestrian on a pedestrian crossing expecting the driver to have an automatic system to notice him/her and hence to give priority.

In order to cope with the differences as described above, discussion of the traffic participants' expectations was added to the first three steps of the HAZOP approach as discussed in Section 3. The discussion of expectations involved:

1. Discuss whether or not the road users' expectations are likely to be sufficiently similar. A positive conclusion here indicates that the traffic system and the measure(s) have the potential of realising safe traffic situations.
2. Conclude whether the users' expectations fit the desired process at the location as defined by the regulator. If the conclusion for the second part is negative, the designers of the traffic network should reconsider the layout of the situation including the road safety measure(s). Preferably, the policy makers should decide to use measures that will bring the expectations of the users and the intentions of the regulator closer together.

Apart from the discussion on the expectations resulting from the case study location, the HAZOP team were encouraged to go into the possibilities of learning from experiences at this location for building expectations at other locations involving the same road safety measures.

5.4. Traffic parameters and guidewords

For the application of the HAZOP methodology parameters and relevant guidewords have to be chosen for the specific field under study [15] Safety problems in traffic result from deviations caused by a single road user as well as from deviations caused by situations in which several road users are involved. Consequently, we included traffic parameters both for single users (marked with 'a' in Table 1) and parameters for traffic situation with multiple users involved (marked with 'b'). A detailed explanation of these parameters and guide words can be found in Jagtman [11].

6. Example: speed reduction in built-up areas

The HAZOP methodology has been applied to study the use of speed humps in a built-up area with a speed limit of 30 km/h. The 30 km-zone is located in the neighbourhood

Table 1
Traffic HAZOP matrix (a single traffic participants; b: traffic situation)

	no(ne)	(too) high	(too) low	wrong	fail of	part of	unknown	unexpected
speed (a)				■	■	■		
direction (a)	■	■	■		■	■		
location (a)	■	■	■		■	■		
focus (a)		■	■				■	
attention (a)	■	■		■		■	■	■
travel time (a)	■		■	■	■	■		
speed difference (b)				■	■	■		
distance (b)	■				■	■		
road users (b)	■	■	■		■	■		
number of road users (b)	■		■	■	■			
violations (b)	■		■	■	■	■		■
flow rate (b)	■	■		■		■	■	
expectation (a)	This cell is discussed at the end of the HAZOP							

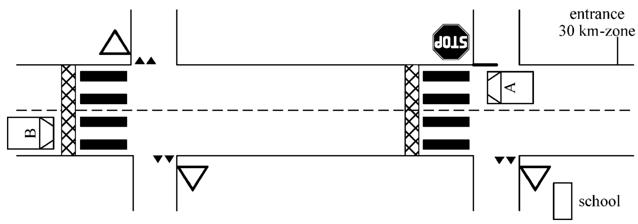

Fig. 2. Visualisation of location and the infrastructure measure (speed humps).

of a school. The location under study was rebuilt in 2001 to improve the priority given to pedestrians on the pedestrian crossing. This priority was emphasised as part of the desired traffic process. In general the process is defined as 'adherence to the formal rules' by all participants. At this location these rules include: 'give priority to pedestrians on the pedestrian crossing', 'give priority to traffic on the main road' and 'do not block the junctions'. Notice that these rules may lead to conflicts and problems. For instance, drivers from the 'A' direction in Fig. 2 first cross the junction having priority, then have to stop for pedestrians, if present, during which they block the junction, and finally they have to cross the speed hump.

Besides the current layout, the use of Intelligent Speed Adaptation (ISA) at the same location instead of the speed hump was analysed. ISA, as it is now in development, consists of vehicle-based technology that assists motorised vehicles in adhering to the local speed limit. The assistance can be provided in various manners, such as information on a display, auditive warning signals and physical feedback. We studied an ISA application called the 'active gas pedal' in which the driver experiences a counter force through the gas pedal at the moment the vehicle exceeds the local speed limit. GPS positioning and a digital map are used to determine the local speed limit. The driver is able to overrule the assistance by kicking down on the gas pedal [see for further details on the system: 16].

6.1. Results

Three HAZOP sessions were carried out in which the two alternatives were discussed A selection of the meaningful cells for the HAZOP matrix was made by eliminating the non-feasible cells (the blank cells in Table 1). Each session resulted between about 140 and 210 useful deviations of which a selection will be presented in this paper. An extended review of the results of the HAZOP performed by the traffic participants can be found in Jagtman and Heijer [17].

We will show the results in a framework with four levels of safety problems in traffic. The basis for this framework was set by Carsten et al. [18] and Morello [19] to evaluate the use of new in-vehicle technologies. They both distinguished a functional level, a driver level and a traffic level at which effects on safety in traffic systems might occur. The traffic safety level is divided into the interaction between a group of road users, who meet at the same location at the same time and the traffic flow as a whole. The four levels are defined as follows [3,4,18,19]:

- Functional Safety Level: covers safety problems that result from the hardware and software design of the measure, in particular the technical reliability, probability of system failures and the potential of it getting into a dangerous or unexpected mode.
- Driver Safety Level: focuses on the interaction between the user and the measure under study. This level covers the appropriateness of the design, possible distraction of the user and adequate support in performing a safe trip.
- Safety of Interactions: focuses on the interaction of drivers and of the measure under study with their close environment, including other road users, vehicles and the infrastructure.
- Traffic Safety Level: covers the effects of the measure under study on safe operation of the traffic system. This level incorporates macro safety effects on the whole network.

6.1.1. Speed humps

A selection of deviations, problems and conflicts for the implementation with speed humps resulting from the HAZOP sessions is shown in Table 2.

6.1.2. Intelligent speed adaptation ISA

In Table 3 a selection of the results for the ISA system is shown. The percentage of cars equipped with the ISA system was not fixed for the discussion. If specific deviations result only in mixed traffic, in which ISA and non-ISA cars meet each other, or in a fully equipped flow, this is made clear in the table. Note that the deviations in Table 2 which are not directly concerned the speed humps were identified as also applicable to ISA.

6.2. Expectations of road users

In addition to the traditional HAZOP, the expectations of the different road users were discussed As all road users do not act according to one pattern, the teams discussed likely behaviours and the expectations that would lead to this behaviour. The results are summarised in this section.

6.2.1. Speed hump

The following expectations were expressed. The motorised traffic approaching from direction A will be focussed on the speed hump and might not observe other traffic, including pedestrians, as a result. They could block the side roads while waiting for a pedestrian to cross, or continue without giving priority to the pedestrian, in order not to block the intersection. Pedestrians will assert their priority less for traffic from direction A than from direction B,

Table 2
Deviations, conflicts and problems for speed hump implementation

Functional Safety
Vehicle breakdown caused by engine, lack of fuel, flat tyre;
Driving with too high speed caused by wrong estimation of speed required to smoothly pass the speed hump;
Driver Behaviour and Safety
Misjudgement of situation or road signs;
Slowing down for pedestrian, but paying no attention to other road users;
Distraction by events in the vehicle (children, mobile phones, radio);
Short cuts: crossing main road diagonally, short cut while turning left. This increases when road users are in a hurry (for instances if they are almost late for school);
Speed up between speed humps;
Pedestrians not crossing at pedestrian crossing;
Impatient with waiting and as a result taking priority;
Driving slowly and/or carefully because the location is unknown to drivers or they are inexperienced;
Complexity of the situation leads to performance of sequential, partial solutions;
Mainly focus on the speed hump ahead instead of on possible other road users;
Safety of Interactions
Groups of pedestrians/cyclists take priority;
Blocking part of the road and/or the junction (removal lorries, delivery vans, cars who stop to pick someone up);
Speed up to get to pedestrian crossing before pedestrian does;
Rear-end shunts caused by short headways and sudden braking by vehicle in front;
Pedestrians expect to get priority when they cross at the pedestrian crossing;
Vehicles stop across junction to give pedestrians the possibility to cross the road at the pedestrian crossing;
Motor vehicles on the main road will not give priority to pedestrians in order not to block the side roads;
Traffic Safety
Speed hump increases travel time for emergency vehicles;
Change of public transport routes because of discomfort caused by the speed hump for driver and (standing) passengers;
Traffic from side road cannot cross or enter main road because of blocking of the junction in congested circumstances;

Table 3
Deviations, conflicts and problems for speed hump implementation

Functional Safety
Feedback of the ISA system;
Wrong speed limit used by the ISA system caused by a positioning error;
Wrong speed limit used by the ISA system caused by old maps, temporary limits at road construction sites;
Difference in location of speed limit boundary between the road signs and the feedback of the ISA system;
Two ISA vehicles both driving on the main road may suffer from calibration problems resulting in different boundary for the vehicles and possibly slightly different speed limits;
Driver Behaviour and Safety
Relying on ISA for keeping to the speed limit although a lower speed might be required for the actual situation (extreme: use of ISA as cruise control);
Immediate speeding up when getting into a zone with higher speed limit/unexpected fast accelerating by ISA vehicle caused by pressing down the gas pedal totally;
Not noticing the 30 km/h sign and suddenly experiencing the counter force by the ISA system;
Drivers experiencing ISA for the first time mainly pay attention to the new system;
ISA users forget to change gear after the speed limit is passed;
Check the ISA system by (more than normally) observing the speed on the speedometer;
Trust in the ISA system resulting in less checking of the speedometer;
Irritation at the ISA system if the speed limit is inappropriate or incomprehensible (e.g. night time);
Kick-down of the ISA system provides a way of release for the irritation at the system, without immediate speeding by the vehicle;
Non-ISA drivers will probably drive faster because there are no speed humps at this location;
Safety of Interactions
Expecting vehicles to slow down when entering the lower speed zone may lead to problems if a vehicle without ISA is approaching (high number of ISA vehicles in the traffic flow);
Trusting the ISA system to slow the vehicle down when entering a lower speed limit zone could result in problems if a leading vehicle starts braking before the zone boundary;
Non-ISA users, pedestrians and cyclists will anticipate on (smaller) gaps to cross or enter the main road;
Mopeds, which are not equipped with ISA, will overtake the ISA vehicles in the 30 km zone;
Irritation of non-ISA users because the ISA users drive slowly in the 30 km zone;
Traffic Safety
Too high speeds of ISA vehicles at the pedestrian crossing caused by wrong/awkward boundary set in the ISA system;
Compensate for unexpected delays by driving at or beyond the speed limit in areas where ISA is not activated/supported;
ISA may result in less acceleration and deceleration and as a result show a smoother traffic stream (perhaps even provide a greater capacity);

because the speed hump is located wrongly for traffic in this direction and offers them no protection from speeding traffic.

Vehicles from the opposite direction (B) have to slow down for the speed humps before crossing the pedestrian crossing and the junction. Since they will already have reduced their speed for the humps they will be more likely to give priority to the traffic from the side road than will vehicles from direction A, even though the traffic on the main road has priority. This may be reinforced by the side traffic that will be inclined to accept smaller gaps before entering the main road. In this case the pedestrians' resolve to assert their priority will be strengthened by the presence of the speed humps.

Cyclists will not change their behaviour as a result of the speed humps. In the case of dense traffic on the main road pedestrians will use the special crossing more intensely than in low traffic intensity. On the other hand groups of road users, such as a group of pupils from the school, may act as a single powerful entity and take (and get) priority at the crossing location or even elsewhere around the intersection.

When driving at another location with speed humps drivers will have learned from earlier experiences to cross the hump slowly because higher speeds might be uncomfortable. After experiencing the hump once, the road user knows how to pass it the next time. Further use will hardly affect their focus on vulnerable road users.

6.2.2. ISA (all motorised traffic equipped)

For this alternative the following expectations were mentioned. When all vehicles are equipped with the ISA system the behaviour of all drivers of motorised vehicles will be more uniform and there will be no distinction between directions A and B on the main road (speed humps no longer required when ISA is used). The traffic on the main road will move steadily with a speed of about the maximum allowed speed (30 km/h). As a result of this low speed the pedestrians and the side traffic will probably neglect the priority set at the intersection and cross or join the traffic stream when they think is appropriate. Moreover the pedestrian crossing may be seen as pointless and the pedestrians may cross anywhere.

Mopeds, depending on the feasibility to install ISA in such motorised bicycles, may cause problems. If these are not equipped with Intelligent Speed Adaptors they will most likely drive faster than the motorised traffic stream that is equipped.

6.2.3. ISA (mixed traffic allowed)

In this situation different expectations were expressed. Depending on the traffic intensity, clusters of vehicles may form behind one or more ISA-equipped vehicles. If the traffic intensity is low and drivers without ISA are irritated by the system, they may start overtaking the slower vehicles.

In the case of clusters of vehicles, the ease of crossing the street or entering the main stream will increase. If, however, the number of overtaking manoeuvres increases, this will increase the risk to pedestrians, cyclists and (motorised) traffic from the side roads. Road users may have difficulty estimating speed outside a range of expected speeds. Especially when the use of ISA becomes more common, exceptional speeds (of vehicles without ISA) will become less and less expected.

The benefits of ISA and speed limits needs to be understood by the road users in order for them not to be irritated by these kind of systems, for example in quiet hours such as at night. This problem will increase in mixed traffic situations in which not every motorised vehicle is equipped.

Finally the use of ISA requires both users and other traffic to learn. The system will not only have an effect locally but elsewhere in a network. Road users may experience the assistance of the system and/or meet vehicles that are equipped with the system at different points in the network and will need to learn how to recognise which regime is applicable.

6.2.4. In summary

Building expectations upon the behaviour of the other road users in the case of speed humps is problematic, because the options are variable. Will the vehicles on the main road slow down or stop to give priority to pedestrians and, for direction A, where will they stop? What is the behaviour of the side traffic? Will they take priority where the traffic on the main road stops? We measured the behaviour of the main road traffic in our study by video observation and showed that, in this last respect, it is independent of the situation. Hence, it is hard for pedestrians and side traffic to estimate if and where these vehicles will slow down [20]. These findings confirm that the current design of the intersection is badly chosen.

Estimation of the speed of ISA equipped vehicles is easier. Where ISA is used, the possibility to estimate other road users' behaviour will depend on whether or not all motorised traffic is equipped and whether or not ISA vehicles can be distinguished from non-equipped vehicles. The speed behaviour in general in the Swedish pilot studies with ISA [16] showed a lower average speed and a reduction in the spread of speeds. On 30-km roads in local networks the Swedish study found speed reductions in mixed traffic of 0.3–0.9 km/h.

7. The effects of the composition of the hazop team

Lawley [8] stated that the team performing a HAZOP should be carefully chosen to provide sufficient knowledge and experience to lead to adequate results Though the team should be small enough to be efficient, it should contain sufficient spread of skills and disciplines to cover all aspects of the process under study. As described in Section 4, we wished to assess whether such a mix of HAZOP team members was essential, or whether the HAZOP was just as successful with a more limited and homogeneous group. The HAZOP methodology was therefore applied with three teams of four up to six people with different mixes of expertise and experience. The first team consisted of students, who could be considered as simple traffic participants, the second team consisted of local and regional policy makers and the last of participants with a mixture of expertise, drawn from institutions in the Netherlands involved in design, development and research into new technologies. The expertise of the latter team included human factors, vehicle-approval, traffic, automotive and infrastructure engineering. The similarities and differences in the kinds of deviations that were identified in the workshops are described in this section.

None of the participants had any knowledge of the HAZOP methodology beforehand, except for the leader of the workshops, but this did not present any problems. Lawley [8] and Kletz [9] indicate that it is not necessary for all participants to be familiar with the method.

7.1. Differences in types of deviations noted

The three HAZOP sessions generated a variety of deviations Table 4 shows the division of the total number of problems identified during each workshop over the safety levels. The participants were asked in the ISA case only to indicate problems for ISA which were additional to those which would occur with the humps. They indicated that 87–94% of the deviations in respect of the speed humps were also applicable to the ISA implementation.

Testing the results shows that there are quantitative differences. Clearly designers identify more deviations than traffic participants, with policy makers in between. However, the proportion of deviations found at each level and between speed humps and ISA differs much less. For ISA there are no significant differences ($\chi^2=3.78$, $P=0.71$, df = 6). For speed humps the difference is significant ($\chi^2=15.15$, $P=0.019$, df = 6), accounting for largely by the difference between the traffic participants and the other two groups. The last two groups had between 70–75% of their deviations covering the driver safety (DS) and safety of interaction (SoI) levels. In all three HAZOP sessions and for both speed reducing measures, the largest category of deviations was that relating to the level of the individual driver (DS). This varied from 39% of the total number of deviations for the traffic participants up to 49% for the policy makers.

Table 4
Number of deviations identified per safety level during the HAZOP sessions

Safety level	FS	DS	SoI	TS	$\sum$
Traffic participants					
Hump	14	38	24	21	97
ISA	12	18	9	9	48
Total	26	56	33	30	145
Policy makers					
Hump	3	52	36	15	106
ISA	11	28	9	10	58
Total	14	80	45	25	164
Designers					
Hump	14	74	40	17	145
ISA	16	27	9	19	71
Total	30	101	49	36	216

It is interesting that the number of deviations addressing specifically the implementation of ISA was about 1/3 of the total number of deviations in each of the sessions ($\chi^2=0.29$, $P=0.86$, df = 2). We had expected that the team of designers, who consisted of researchers acquainted with ISA, would have identified more deviations than the other teams who hardly had any knowledge of ISA. That did not happen. Quantitatively, the results are therefore not so different, particularly between policy makers and designers. All groups produced a good spread of results across the different levels and traffic measures.

7.2. Subjects of deviations noted

More important than quantitative differences are the qualitative ones Do policy makers identify all the subjects of deviations which come out of the other two groups? We hypothesised that policy makers should be able to identify the same issues as designers at least in the areas most connected with their own tasks, namely ‘infrastructure and ISA’ and ‘violations’. One subject, ‘road users behaviour’ is particularly linked to the knowledge of the designers. For this subject it was expected that the designers, a mixed team, would come up with a larger variety of issues. We expected the road users to identify the least variety in issues.

Infrastructure and ISA

It is the task of the policy makers to decide about the design and maintenance of the infrastructure and measures used to regulate traffic using that infrastructure. The team with policy makers came up with the following problems for the ISA case:

- Changes of speed limits made by the regulator have to be changed in the digital maps as well
- Awkward definition of boundaries could result in inappropriate speeds of the ISA-vehicles especially at the zebra location
- Temporary speed limits such as at road construction sites are often not accompanied by temporary regulations; the fixed digital maps used by ISA would not know about those temporarily changed limits
- Incorrect local speed limit in ISA caused by either incorrect data in the digital maps or a GPS positioning failure causing the wrong limit to be selected from the digital maps
- Not noticing the 30 km sign and therefore unexpectedly experiencing the ISA counter force
- Suddenly accelerating when entering a zone with higher speed limit regime.

All of these problems were identified also by the other two groups, except for the last problem which the designers did not identify. However, they did go into related deviations, such as ISA drivers driving outside the ISA area, but think they will still get ISA support when the speed limit changes. The group of designers did go into more detail on the possible causes of the second and fourth issues above, drawing on the result of past ISA pilot studies, but both other groups did identify these deviations.

The analysis of this subject supports the hypothesis that policy makers are able to derive the same type of issues as designers. Moreover, in contrast to our hypothesis, the group of traffic participants also identified the same issues.

7.2.1. Road users' behaviour

All HAZOP participants are traffic participants in addition to their possible professional involvement in road traffic. Up front we expected all groups to come up with a common core of deviations in relation to road users' behaviour. This was indeed the case; the commonly occurring 'problems' like short cuts, crossing at other locations than the pedestrian crossing, impatience and irritation at slow drivers were mentioned during all workshops.

With respect to ISA, which is not yet implemented, we expected the extra knowledge of the designers to lead to a greater number of deviations identified. The designers identified the following issues:

- ISA user does not have to check the speedometer, the user may, however, check it in order to monitor the correct operation
- Appropriate choice of borders for speed limits can increase the awareness of ISA users that at this location attention is required
- If the ISA system is not implemented in the entire traffic system this will create uncertainties among the users about where they supported and where not
- ISA does not allow the driver easily to accelerate to solve conflicts or to quickly overtake another road user

The first and second issue were covered in all HAZOPs. The team of policy makers also covered the last issue. When handling the issue of not having to check the speedometer any more, there were discussions in all groups about whether this reduction in the driving task would add to road safety or would perhaps decrease the attention given by the ISA user to the driving task. The issues of ISA not being installed in the entire traffic system was only addressed by the designers.

However, the other two HAZOP session did result in a number of additional possible problems covering the behaviour of the user of a new technology which the designers did not mention. Both groups indicated that the user of a new technology may show off with the new feature. This could be combined with mainly focussing on the new system instead of the road situation. Both groups also identified the issue of possibly driving in the wrong gear, because the user forgets to change gear as a result of paying less attention to the speed of the vehicle. The traffic participants also suggested that having a safe ISA system may encourage car usage, whilst the policy makers identified the issue of road users who normally use an ISA equipped vehicle and then get into a vehicle without this speed reducing measure.

The conclusion is that all groups identify a common core of issues under this heading, and all identified issues not seen by one or both of the other groups. However, it is not the designers who consistently identify more issues, as predicted by our hypothesis.

7.2.2. Violations in traffic

Local road authorities and policy makers set up a traffic system in which a certain behaviour or operating process is desired. This process may, however, be consciously violated. During all three HAZOPs the groups came up with what could be called the 'classic' violations such as speeding, not giving priority, taking short cuts and crossing the street diagonally. Less common violations, that may specifically happen near a school, such as the one in the example and which were mentioned in all HAZOPs, were cycling on the pavement or against traffic at the edge of the road where the school is located. In addition the following thee problems were discussed by the team of policy makers. These can be considered as 'violation' of the operating process as intended by the local road authorities:

- Vehicles from direction A stop at the junction to let pedestrians cross at the zebra and block the road for traffic approaching from the side streets
- Irritation with the ISA measure might lead the user to try to tune it or turn it off when it is obligatory
- Mopeds without ISA may speed in a situation in which all other vehicles have ISA

The traffic participants and the designers also covered the first and second issue. The traffic participants discussed a particularly extreme form of this which could fully block the junction with traffic from all directions and lead to deadlock situations (see the motorised traffic in the example build in Fig. 1). The final issue of the mopeds was also addressed by the group of designers. They were also the only group to discuss the question of the emergency services, who should be able to drive without ISA in all cases even if ISA were to become obligatory. For this topic the policy makers identified the same diversity of issues as the designers and one more issue than the group of road users. However, this differences is not really great.

The paragraphs above show how little the groups differ in detail on three subjects as examples. A broader analysis showed that over 75% of the potential problems have been identified by all three groups. Less than 5% of the deviations

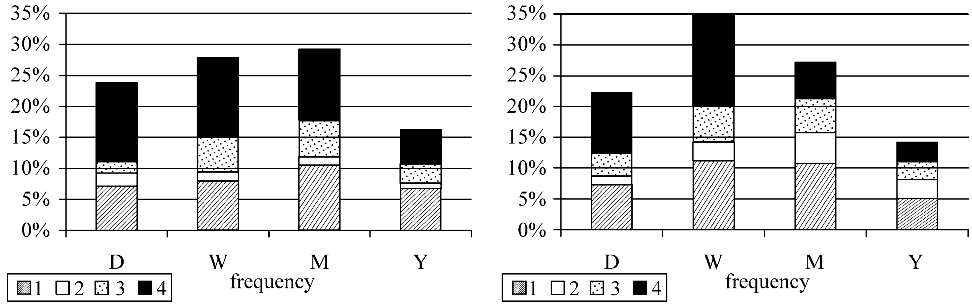

Fig. 3. Estimations of frequencies and severities for speed humps (left: policy makers, right: designers).

were addressed only by one group. Most of these were deviations referring to the ISA alternative. However, these additional deviations were not all seen by the same group. In other words, designers were not able to identify more deviation types in general. They did get into more details about the functionality of the active gas pedal. However, the other two groups who had no or limited experience with ISA were able to identify possible problems that the designers did not see, such as showing off, paying less attention to traffic situation while trying out the new feature and forgetting to change gears. The large difference between the absolute number of deviations identified by the designers (216 deviations) compared to the policy makers and the traffic participants (164 and 145 deviations) is thus not found in a wider variety of deviations. It is just that the designers split the issues up more and give more detail and explanation of deviations and their causes. The group of traffic participants were able to point out that some sort of problem would arise, but were often not able to elaborate on the problem. The team of policy makers could explain the context of certain problems especially those relating to the decision making processes.

7.3. Estimating the importance of the deviations

The final step in the Traffic HAZOP, which was only asked of the teams of policy makers and designers, was to ask them the frequency of occurrence of the deviations identified during their HAZOP session, and the severity that could reasonably result if the deviation occurs The experts were given four categories to estimate the frequency: from a few times per year (Y), about monthly (M), weekly (W) up to at least daily (D) and four categories to estimate the severity: from ‘leads only to a disturbance of the intended process’ (1), ‘leads to an incident without damage’ (2), ‘leads to an accident’ (3), up to ‘leads to an injury accident’ (4). The distributions of these estimations per road safety measure are compared in Figs. 3 and 4.

The frequency distributions are not significantly different between the two groups ($\chi^2=6.2$, $P=0.10$, df=3). All other distributions were found to be significantly different for the two groups. The expected frequencies of occurrence of deviations relating to the ISA alternative shows a very different distribution, in which the designers are far more pessimistic than the policy makers. For the estimations of severities the designers are also a little more pessimistic than the policy makers in case of ISA. However, in the case of the speed humps the designers consider that the severities will be somewhat lower than the policy makers. Both groups score a generally lower severity level for ISA compared to the speed humps.

7.4. Conclusions on team composition

The general conclusion of the studies with different teams is that the composition of the team does not seem to be an important deciding factor for detecting deviations and defining conflicts and problems when applying a HAZOP in road traffic At most special knowledge may be necessary, for the interpretation of the results or providing details about the causes of the deviations. The composition of the team does seem to influence the ranking of the deviations. More studies would be needed to understand why this is so.

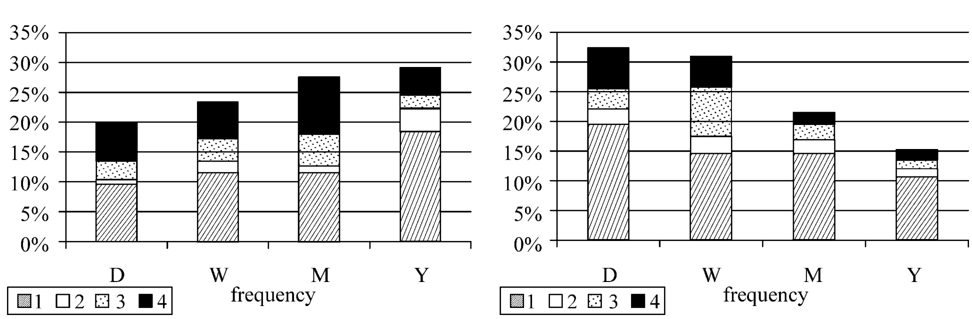

Fig. 4. Estimations of frequencies and severities ISA (left: policy makers, right: designers).

8. Conclusions

This paper describes the adaptations made to the HAZOP methodology to apply it to traffic processes To cope with the divergent goals of road users, that moreover may conflict with each other and with the desired process set by the regulator, the discussion of expectations of all road users was added to the standard HAZOP procedure.

Application of the Traffic HAZOP was shown for two speed-reducing measures in the neighbourhood of a school. The HAZOP was carried out three times. This resulted in a large number of possible deviations being identified for this location. The discussion of the expectations of the road users at the study location showed that the current speed hump implementation does not assist in building compatible expectations. A video observation confirmed this conclusion. The effect of the ISA new technology and the expectations of road users in relating to it was shown to depend on whether all vehicles are equipped with the system, whether ISA vehicles can be distinguished from the other traffic and on the acceptation of the system itself.

The deviations relating to the behaviour of individual road users and to the interactions between road users were the most frequently identified in all groups covering about 75% of the problems in the sessions with the policy makers and the designers and over 60% in the session of the traffic participants.

Although the three groups have differences in experience regarding the design and operation of local and regional road networks (speed hump alternative) and ICT based technologies in traffic (ISA alternative) they came up with very similar deviations. Only 5% of the deviations were identified by only one of the teams and no team was consistently more productive. This means that the traffic HAZOP should be able to be used by a homogeneous group such as the group of policy makers alone at least for identifying problems, though specific knowledge may be required to elaborate on the safety issues and explain why these problems may arise. Since the estimations of frequencies and severities were found to be dependent on the composition of the team, it requires further prospective research to establish which of the expert opinions are closer to reality, in terms of how often deviations actually occur and how serious the consequences are. This is necessary in order to have confidence in the traffic HAZOP as approach for ranking the priority of the deviations identified.

The cases studied show that the HAZOP methodology can be used very effectively to study traffic processes, especially for identification of a wide range of potential safety issues. The participants found the structured approach of HAZOP particularly useful when thinking of infrastructure design for safety.

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