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Crash Investigations for Active Safety – Meeting New Demands on Investigation Methodology

Abstract

Active safety systems are aimed at accident prevention, hence the knowledge required for their development is different from that required for passive safety systems aimed at injury prevention. Particularly, knowledge about accident causation is required. When looking at existing accident causation data, it is argued it fails to explain in sufficient detail how and why the accidents occur. Therefore, there is a need for detailed micro-level descriptions of accident causation mechanisms, and also of methodologies suitable for creating such descriptions. One study addressing these needs is the Swedish project FICA (Factors Influencing the Causation of Accidents and Incidents), where an accident investigation methodology suitable for active safety is developed, and in-depth accident investigations following this methodology are carried out on-scene in the area of Gothenburg by a multidisciplinary team. A preliminary aggregated analysis of different cases shows that the methodology developed is adequate for pointing out common contributing factors and devising principal countermeasures.

Introduction

Vehicle safety has increased significantly during the last decades due to development of vehicle structures and highly efficient passive safety systems. However, as these systems are aimed towards injury prevention, other technologies need to be introduced to reduce the total number of collisions, preferably through preventing the accidents from occurring at all. This reduction is expected to come through active safety systems.

Data from accident investigations are frequently used as a base for the development and/or evaluation of safety features. As active safety systems are aimed at accident prevention, the knowledge base required for their development is different from what is needed to develop passive systems aimed at injury prevention. While passive safety research is focused on injury mechanisms, active safety research needs to be focused on knowledge about contributing causal factors, and be formed in such a way that effective countermeasures can be developed based on the causes found.

That new methodologies are needed for accident investigation can be clearly discerned by looking at what is generally available in current accident causation analysis. Here, causes of accidents are mostly described on a coarse macro-level, through factors such as weather and road conditions, drug abuse and driver inexperience. Although these parameters are easy to collect from police reports and easy to manage statistically, they are not detailed enough for creating guidelines for active safety systems.

This last observation is especially true when it comes to knowledge about human behaviour. In analyses of traffic accidents it is often argued that the human factor, or driver errors, is responsible or involved in 90-95% of accidents [1-3]. However, accident analyses rarely explain why the human factor is involved, and it would be dubious to make direct use of these findings for the design and implementation of accident countermeasures [4]. Instead there is a need for micro-level descriptions of accident causation mechanisms, with sufficient detailed accounts of how and why accidents occur. Otherwise, efficient development of active safety systems that can detect and respond to situations associated with accident risk is hard to accomplish. Active safety therefore demands different data collection procedures for accident investigations, compared to passive safety.

FICA – Project Description

The Swedish project FICA (Factors Influencing the Causation of Accidents Incidences and) is a project aimed at developing data collection procedures that are adequate for active safety research. The project has three objectives. The first is to develop a methodology that can be used for active safety accident investigations. The second is to use this methodology to identify factors, expressed in the domains driver-vehicle-environment, that contribute to the occurance of typical vehicle-to-vehicle accidents. The third objective is to develop guidelines or principles for how the next generation of automotive safety systems should be designed, based on the factors identified. The third objective is primarily not aimed at providing technological support in the pre-crash phase, but to prevent the pre-crash phase from occurring at all. If you eliminate risk, you eliminate accidents.

Important Demands when Developing Accident Investigation Procedures

To achieve the objectives of FICA, two things are required: (1) detailed transcriptions of the courses of different accidents; (2) a systematic way of sorting out the threads of the accident event and finding the factors behind it. The first objective is relatively straightforward, and the procedures for doing this work will be described below. The second objective, however, needs some discussion and clarification.

In order to avoid an accident analysis to be based on individual judgement, it is necessary to have a way to systematically sort out the threads of an accident event and the factors behind it. Therefore, an accident model and an accident analysis method are two essential ingredients in every kind of accident analysis. An accident model is a theoretical framework for the accident analysis. Its purpose is to describe how a set of causes and conditions may lead to an accident, and to explain what the concepts of the model mean. An accident analysis method is a set of definitions and procedures, which the investigators follow in order to carry out every analysis in the same way. Having an accident model and an accident analysis method is very important when conducting in-depth accident causation investigations, because the model and method selected will determine which data are to be collected, in what form the results are to be presented and how they can be used [5].

FICA Accident Model

The accident model of the FICA project (see figure 1), is based on the principles of Cognitive Systems Engineering (CSE) [6]. It refers to a contemporary accident model [7], which is framed in a Man-Technology-Organization (MTO) perspective. It involves latent failure conditions [8-10], and a distinction between sharp end and blunt end factors. Briefly, a traffic accident or incident is caused by the failure of the Joint-Driver-Vehicle-System (JDVS) at a certain point in time and space (a sharp end failure). However, the analysis of the causes behind the event must include also factors at the blunt end, that is factors that can be remote in space and time and yet contribute to the course of the event. Consequences of a blunt end failure (such as an improperly fastened tyre) remain in the system as latent conditions if they are not corrected, and can contribute to an accident scenario (the tyre comes loose during an evasive manoeuvre, for example).

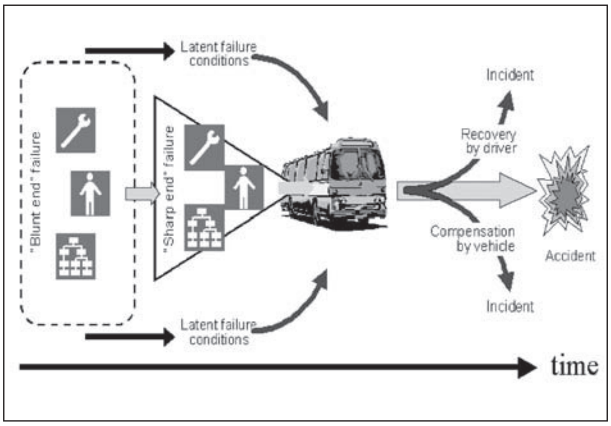

Fig. 1: Preliminary accident model of FICA

FICA Accident Analysis Method – DREAM

The analysis of the accident data is carried out using a method called Driving Reliability and Error Analysis Method (DREAM) [11]. DREAM is developed within the FICA project and is an adaptation to the traffic safety domain of the more generic Cognitive Reliability and Error Analysis Method (CREAM) [12]. Analysing an accident with DREAM takes place in two steps. First, an evaluation of the context from an MTO-perspective for the event is made. This evaluation is done by assigning values in a table to a set of so-called Common Performance Conditions (CPCs). Each CPC represents the state of a contextual variable affecting the general performance of the JDVS (Joint-Driver-Vehicle System) in a traffic situation.

Second, a detailed analysis of the accident scenario is made, with the context description as support.

This analysis is carried out using the DREAM classification scheme. On the highest level the scheme distinguishes between the effects that are present in a situation, and the causes of those effects. The effects are classified as belonging to different phenotypes, where the phenotypes represent possible ways for a dysfunctional behaviour to manifest itself in the dimensions of time, space and energy. The causes of the effects are called genotypes. Every genotype is a factor which can be used to describe what has brought about, or can bring about, the effects.

Causes typically cannot be observed, but must be inferred by reasoning. In addition to listing possible factors that can cause dysfunctional behaviour, the DREAM classification scheme therefore also describes the links between them. The links can be said to represent existing knowledge about how different factors (causes and consequences) can interact with each other. The purpose of a DREAM analysis is to find a probable connection among these factors; a connection that can explain the observed consequences or the event phenotype.

One important advantage of the DREAM methodology is that the results of the individual cases analysis can be aggregated in order to discover causation patterns among different groupings of accidents. How this works will be demonstrated below.

Accident Investigations in FICA

Identification of Typical Accidents for In-Depth Investigations

Accident types can be classified in many ways. In this project, the classification used by the Swedish National Road Administration (SNRA) was adopted. The reason for this is that the accident investigations are conducted in Sweden, and therefore it is easier to compare with statistics based on Swedish accident categorisations. Besides the SNRA database [13], several accident data sources were surveyed and two extra data files were selected because of their high validity and compatibility with the SNRA classifications. One is the Statistics of Road Traffic Accidents in Europe and North America Accident Data File [14]. The other is the European Accident Causation Survey (EACS) [15].

To decide typicality, several sorting criteria can be used. These include frequency, fatalities, injuries, and various indexes, such as Disability Adjusted Life Years (DALY). Because the purpose of FICA is to identify the factors that lead to accidents, using consequence-related criteria is misleading. Two accidents can have the same causes but very different consequences, depending on how or where they happen (falling asleep at high speed as compared to low speed). Therefore, the frequency criterion was chosen as a definition of typicality, and evaluated in a car-to-car perspective, since the development of countermeasures in FICA will be directed at in-vehicle technologies. Using this criterion on the data from the three files, two typical accident types were identified; ‘single vehicle’ accidents and intersection accidents (crossing/turning) (Figure 2).

Accident Investigation Procedure

The multidisciplinary accident investigation team consists of investigators with expertise in driver behaviour as well as vehicle design and vehicle dynamics. When necessary, expertise on infrastructure can be included through cooperation

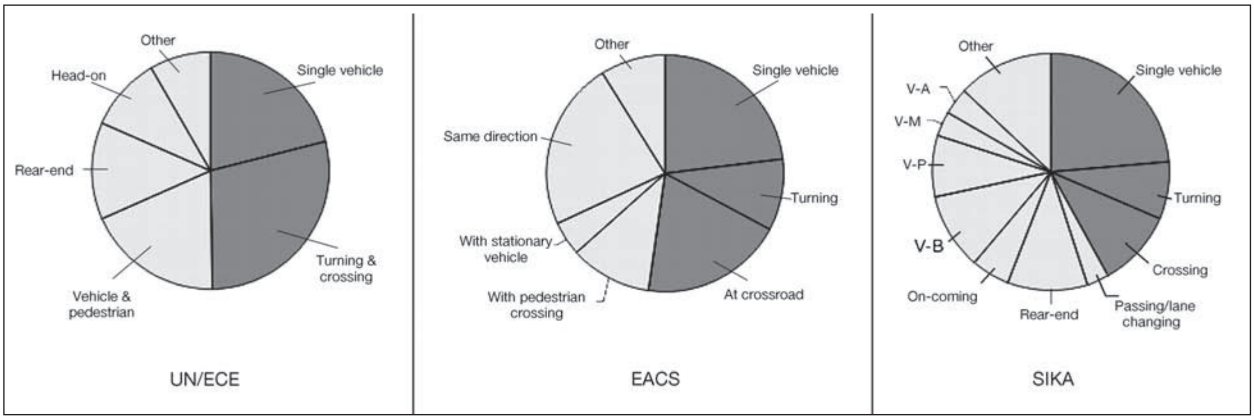

Fig. 2: Proportion of single vehicle and intersection accidents in three databases [13-15]

with local traffic authorities and the Swedish National Road Administration.

Accident alarms are automatically sent to the investigation team from the regional emergency central as an XML-file distributed by email (also to a mobile phone). The XML-file arrives within one or two minutes of someone calling the Swedish emergency number (112) and reporting a traffic accident. Accident alarms are received from the whole region of Västra Götaland in the south-west part of Sweden. However, for on-scene investigations to take place, the area is for practical reasons limited to a 30 minutes drive (corresponding to about 30km radius) from Gothenburg City Centre. Alarms are received twenty-four hours a day, but the team restricts investigations to Monday through Friday during normal working hours (08.00-17.00).

The average time for arriving at the accident scene is 15-30 minutes. Since the team does not include rescue service personnel, it cannot drive faster than normal speed limits. Because the XML-file in most cases includes GPS-coordinates for the accident, the accident scene is usually easily navigated to. The team experience is that the GPS-service both decreases the time to reach the accident scene and the stress felt while driving to the scene.

On the scene, the team establishes contact with rescue services and police, and then tries to create a description of the accident site and context as close to the course of events as possible. This includes getting the vehicle rest positions and deformations for later technical reconstruction, as well as identifying the point of impact, tire tracks and debris. The positions of the evidence are put on a sketch for a later scale-to-scale digital sketch. A digital camera is used for further documentation of the scene and vehicle state. A digital video camera is also used to film the driver's view driving up to the point of the accident.

Drivers remaining at the scene are interviewed about their experience of the accident. The interviews are audio recorded for later review. If the driver is no longer on the scene, an in-depth follow-up interview is made as soon as possible after the accident. The interview follows a protocol set up to correspond to the accident analysis method, and is performed in an informal, conversation like way, to make the driver feel comfortable and avoid hesitance [16].

Preliminary Analysis

After the scene investigation, a preliminary accident analysis is conducted using the collected material. In this preliminary analysis, some initial theories about the accident circumstances are drawn up. Also, the need for follow-up data collection is discussed, where additional data concerning the driver, vehicle and accident site can be collected to clarify the accident circumstances. Information about the involved vehicles is retrieved from the Swedish national vehicle registry which the team has access to on-line.

Technical Reconstruction

If the quality of the information collected from the accident scene is high enough to sufficiently describe the vehicles rest positions, identified point of impact, tire tracks and debris, a simulation in PC-Crash [17] is made. This simulation results in a scene-based and kinematical reconstruction which can be used to either confirm or reject some hypothesis regarding e.g. impact velocities and emergency manoeuvres up to a few seconds before impact. In some cases a damage based reconstruction is made using AI Damage [18] and correlated measurement protocols for measuring the vehicles deformations.

Final Analysis

Once a month there is an in-depth study meeting where collected cases are discussed together with experienced accident investigators from Volvo Cars, Volvo Trucks, and Saab Automobile. In these meetings, the task of the delegates is to comment on the preliminary case analysis performed by the team. After thoroughly discussing the cases and forming a final analysis, cases are filed and stored.

Examples of Individual Case Analysis and Aggregated Factors Analysis

In the following, an example from the FICA in-depth studies is shown, as well as an example of what can be achieved through aggregating the analysis results, which is possible using the DREAM method.

Individual Example Case

Type of accident:	intersection accident
Time, month:	10:10, August

Light conditions: Sunny. Because of the sun angle and nearby buildings, the Peugeot lane was in deep shadow, while the Toyota lane was in bright sunshine. The sun angle was 45 degrees up and 45 degrees to the left from the Toyota driver's field of view.

Traffic environment: Urban intersection, both vehicles travelling on primary road

Road surface condition: dry

Speed limit: 50km/h

Vehicles involved: Peugeot 206, 2001, in good condition
Toyota Corolla, 1999, in good condition

On an urban street, a Toyota (T) with a 58 year old male driver approached a crossing (see figure 3). The driver had the radio on and was driving in moderate speed (40-50km/h). He works as a construction site supervisor, and was out to pick up some blueprints at the copy centre next to the car park. He was just about to turn left onto the side street when a road-work to the right caught his attention. He had the indicator turned on but did not stop since he had not seen any approaching vehicle. He afterwards estimated his approaching speed to be 20-30km/h.

From the opposite direction, a 23 year old male driver in a Peugeot (P) approached, heading straight. The driver had his car stereo on quite loud and was driving fast, 60-65km/h according to his own estimation. The young man was in a hurry since he had just been home (1km away) to pick up some study material which he had forgotten for a student project meeting at the college 300m further down the road from the intersection.

The young driver noticed the Toyota but did not see its indicators, and was surprised when the Toyota suddenly turned right in front of him. He thought that he just had time to put his feet on the brakes right before the impact. At the impact he felt as if the car was lifted up in the air and that the brakes lost their efficiency after the impact.

The Toyota spun around 270 degrees and came to rest with the front wheels against the sidewalk. The Peugeot continued with a slight angle to the right and came to rest after 23m right in front of the car park wall (see figure 4). Both vehicles had airbags on driver and passenger side which deployed in the collision. The Toyota driver wore a seat-belt, but suffered a rib fracture on the lower right side due to an impact against the Toyota's mid console. The young man in the Peugeot was not wearing a seat-belt at impact. The only damage he suffered however was small cuts on his forehead, from hitting the laminated windscreen.

Using PC-crash to reconstruct and simulate the crash, the speeds prior to impact were calculated to be around 70km/h for the Peugeot and 17km/h for the Toyota. These velocities are supported from a damage based reconstruction using Ai Damage

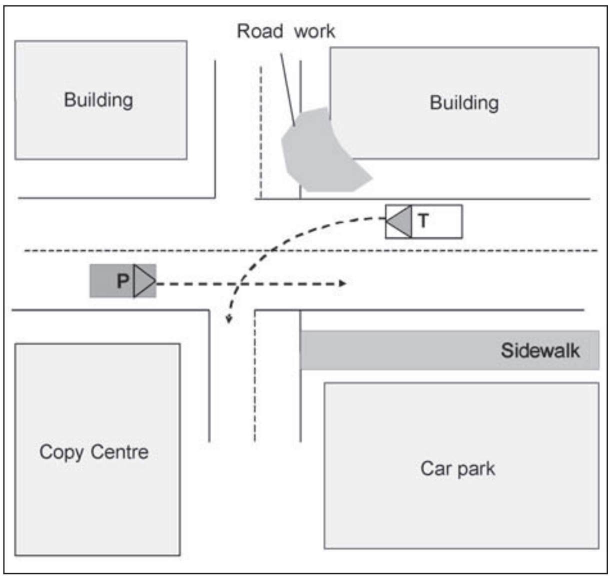

Fig. 3: Vehicle movements prior to collision

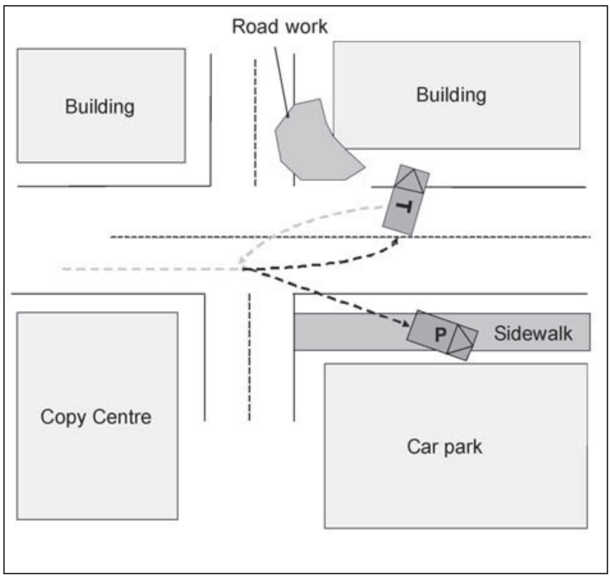

Fig. 4: Vehicle rest positions after collision

and the damage measurement protocols prescribed for this method.

The final analysis result from this accident is documented in a DREAM-diagram where the contributing factors and their links are depicted. The diagrams should be read from left to right, where the rightmost box represents the phenotype (the error state immediately prior to the collision). The DREAM-diagrams for the example case are shown in the figures 5 and 6.

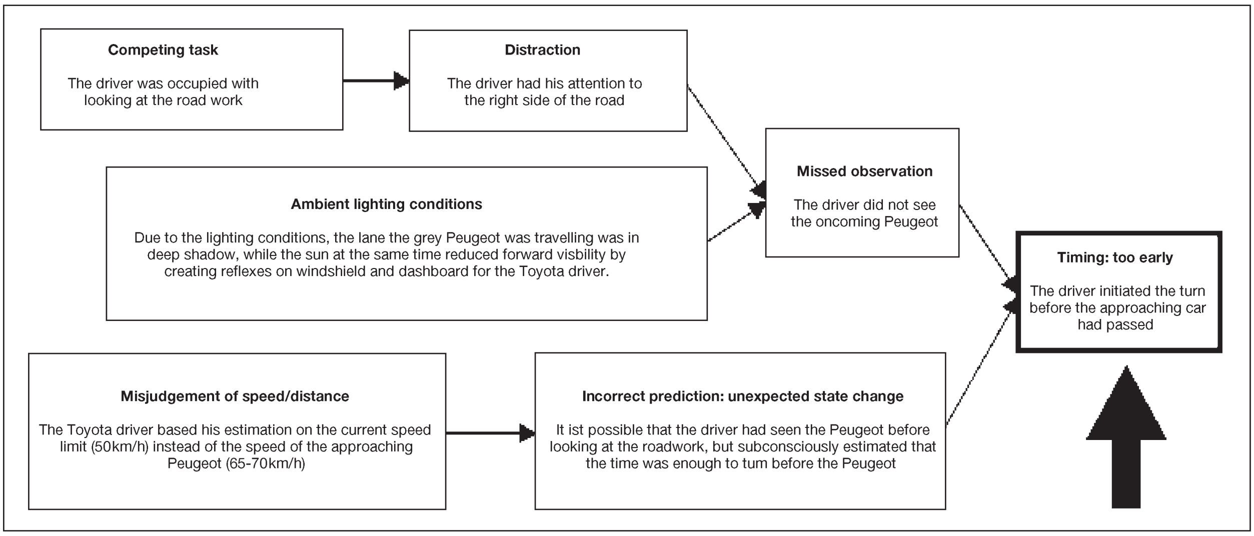

Fig. 5: DREAM analysis for the Toyota

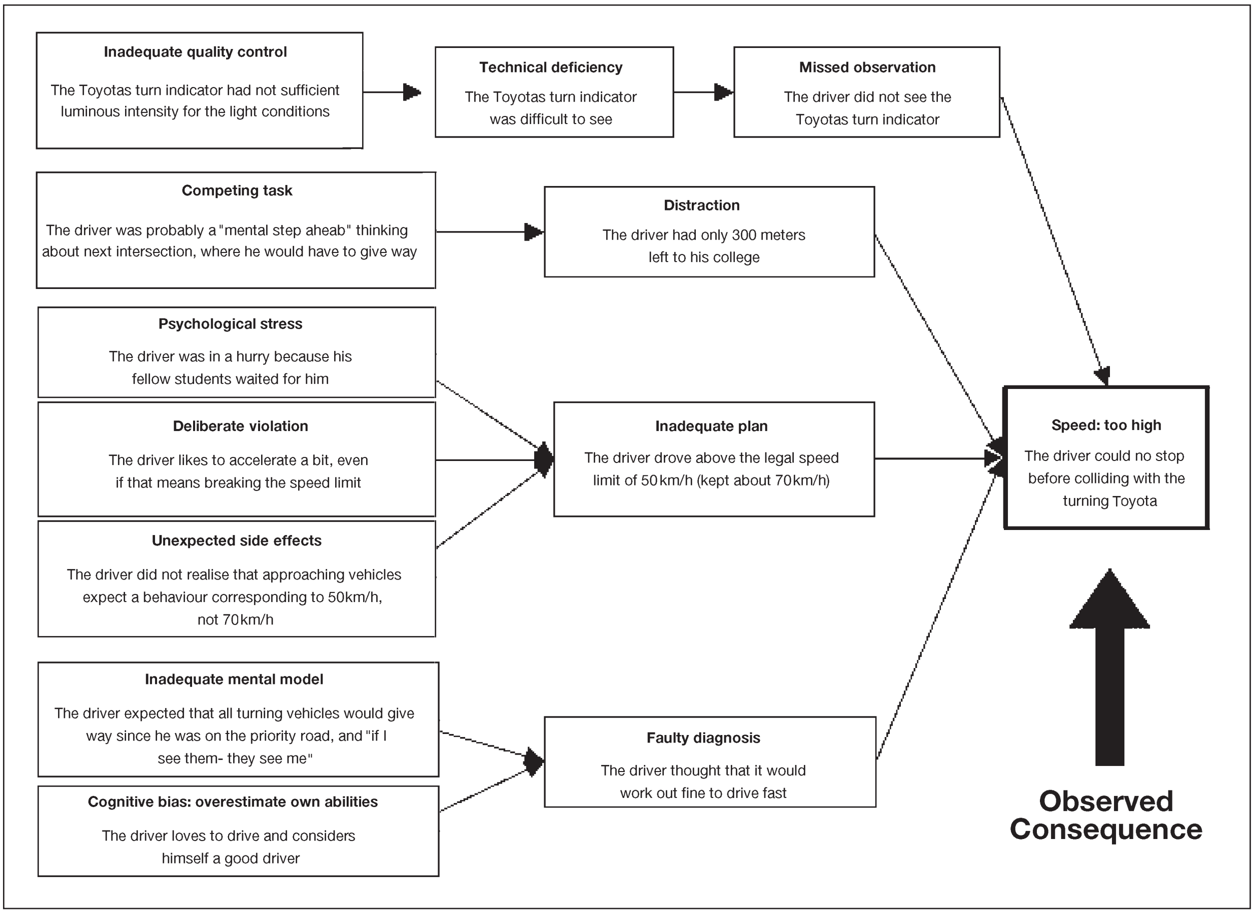

Fig. 6: DREAM analysis for the Peugeot

Example from Aggregated Factors-Analysis

As mentioned above, the DREAM-analysis method makes it possible to make an aggregate analysis of groups of accidents by superpositioning the causal links from the classification scheme. This is a useful tool when looking for patterns in accident causation. In the example provided below, five intersection cases (including the one described above) were selected based on vehicle movements prior to the accident (see figure 7).

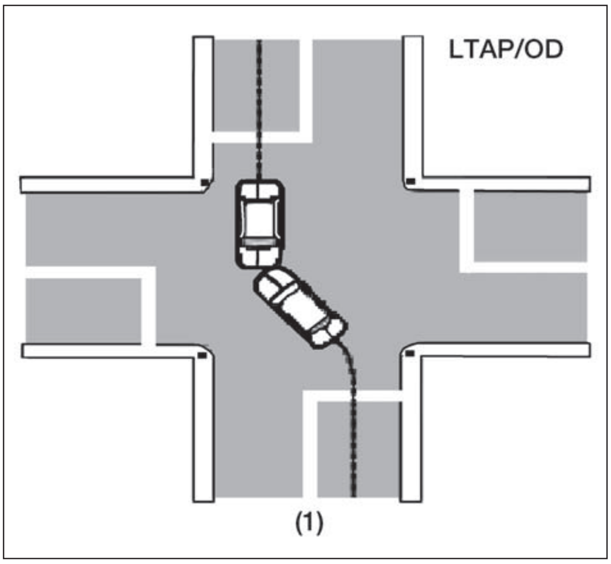

Fig. 7: Vehicle turns left across the path of oncoming vehicle from opposite direction

In the aggregated analysis (see figure 8) the individual analyses for each of the left turning drivers have been aggregated in such a way that the frequency of the causal links is illustrated by arrow thickness.

Analysing this figure, several patterns in the contributing factors emerge, distributing themselves over the whole spectra of possible MTO-factors (Man-Technology-Organisation) available for the analysis. Beginning with the M-factors, three of the drivers were distracted by a competing task, and two of the drivers made incorrect predictions about the speed of the approaching vehicle. Next, in the T-factor area, there is one case where the design of the vehicle contributed to reduced forward visibility (the glare-factor above). Last, several O-factors have contributed. For example, three of the drivers have not had enough information available, due to inadequate traffic environment design.

A note of caution is of course in place when doing the aggregated analysis. It needs to be remembered that the results and conclusions from the accident investigations are case investigations. The possibility to make generalized conclusions from these cases is therefore limited, at least until the number of cases reaches statistical significance. What also has to be taken into consideration is the hours for which the accident

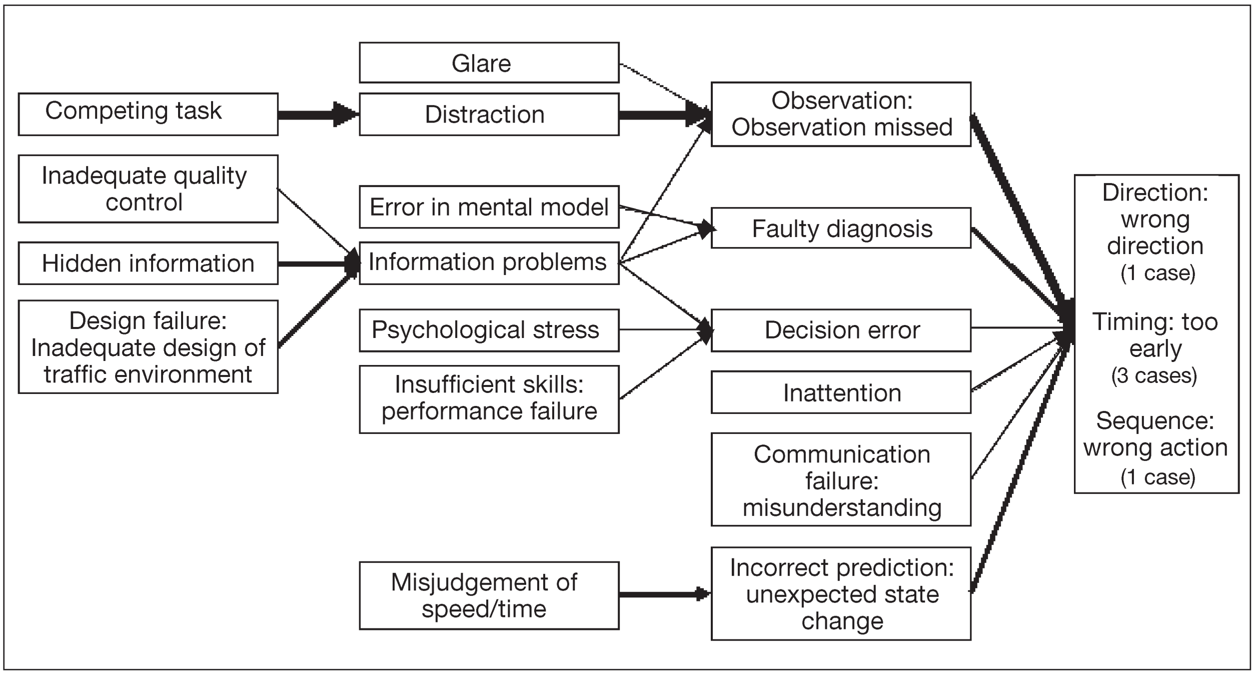

Fig. 8: Aggregate DREAM analysis for left turning driver in five intersection collisions. (To make it readable, only the headlines and not the detailed descriptions in each box is included. The conclusions below however, are based on the full material)

investigations are scheduled (Monday to Friday, 8.00-17.00), which might give a bias towards accidents typically occuring in this time interval.

Discussion and Conclusions

As an accident investigation method, in-depth case investigations can be argued to be crucial for accident causation studies, since it is necessary to get a micro-level causation description of events in order to develop efficient countermeasures. Comparing accident analysis methodologies for active and passive safety, it can be said that the analysis of the pre-crash phase through technical reconstruction from kinematics might, if data quality is sufficient, explain how an accident occurred from a physical point of view, which is very useful for the reconstruction of injury causation mechanisms.

A technical reconstruction however is not satisfactory when analyzing why or how an accident occurred from a psychological point of view, which is crucial when investigating accidents in order to develop and evaluate countermeasures for accident prevention. Also kinematical reconstructions can only explain the accident event physically milliseconds, or seconds prior to the accident. This time scope is very limited and can be used only for conclusions regarding an emergency phase just before a crash.

However, it can be argued that the challenge for accident prevention measures is to prevent an emergency situation from occurring at all. Hence, the circumstances which may have contributed to the accident must be considered when analysing accidents for prevention measures. Also, it is necessary to find the causation factors which are involved in the majority of accidents, and not concentrate countermeasures on a factor which is unique to only one accident [19].

The methodology developed in the FICA project shows promising results in this regard. It provides a tool for consistent and detailed accident analysis, and by aggregating the results of each analysis in the way exemplified above, questions of why, how and how often can be answered in sufficient detail to identify principal solutions that address the identified contributing factors. For example, the fact that several drivers were distracted by a competing task shows that one appropriate countermeasure would be to redirect driver attention to a vehicle approaching at collision speed and course, especially when the approach is unexpectedly fast (the approaching driver drives faster than the legal limit).

In-depth accident studies on scene are acknowledged as being resource demanding, and sometimes it is argued that in-depth accident investigations should be conducted after-the-fact instead. However, the team's experience is that the time used for reaching the accident site and conducting an on-scene investigation is less than the time needed for tracing all the necessary information after-the-fact. This is partly due to the efficient on-line alarm system, which gives the team immediate and accurate accident information.

Future Work

While doing the in-depth studies, it has become apparent that both the accident model and accident analysis method of FICA need partial revisions. Certain concepts and interactions in the model need to be clarified further, and in the method, certain factors and links should be added in the DREAM categories, mostly within the organisational and traffic environment areas. This is in line with expectations. It is believed that with continued work, the in-depth studies and the more theoretical parts will iteratively continue to refine each other, resulting in a methodology that is well adapted to the active safety domain in the end. The improvements to model and method give a better tool to conduct the studies, which in their turn suggest alterations and improvements in the model and method.

Work on achieving the third objective of FICA (to develop guidelines or principles for how the next generation of automotive safety systems should be designed) will start in the beginning of 2005, when the in-depth data collection phase has finished. The collected cases will be thoroughly analysed according to the principles described above, and form the base for this work.

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