Fridulv Sagberg
TØI report 912/2007

Institute of Transport Economics
Norwegian Centre for Transport Research

A methodological study of the Driving Reliability and Error Analysis Method (DREAM)

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Summary:
The Driving Reliability and Error Analysis Method (DREAM) was used for further analyses of possible causes of 15 fatal road accidents that had been investigated by the Norwegian Public Roads Administration. It is concluded that DREAM is a useful supplement to currently used investigation methods for a thorough analysis of the precrash phase of road accidents. A complete analysis of road accidents requires that the DREAM be used in combination with methods for barrier analysis and for analyses of factors in the crash and postcrash phases, which may influence the severity of an accident. An important advantage of DREAM is the use of taxonomy of predefined general causal factors, which enables easy aggregation of results and comparisons across transport modes. Some modifications of the taxonomy were suggested on the basis of the analyses.

Tittel: En metodologisk studie av ulykkesgransking med "Driving Reliability and Error Analysis Method (DREAM)"

Forfatter(e): *Fridulv Sagberg*

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Sammendrag:
"Driving Reliability and Error Analysis Method" (DREAM) ble benyttet for videre analyser av mulige årsaker til 15 dødsulykker i veitrafikken, som hadde vært undersøkt av Statens vegvesens ulykkesanalysegrupper. Det ble konkludert med at DREAM er et nyttig supplement til de metoder som brukes i dag, spesielt med tanke på en grundigere analyse av "precrash"-fasen ved ulykkene. I en fullstendig analyse av veitrafikkulykker er det nødvendig å kombinere DREAM med metoder for analyse av barrierer og for analyse av faktorer i "crash"- og "postcrash"-fasene som kan påvirke konsekvensene av ulykken. En viktig egenskap ved DREAM er bruk av et klassifiseringssystem med forhåndsdefinerte generelle årsakskategorier, som gjør det enkelt å aggregere resultater og foreta sammenligninger på tvers av transportgrener. Noen modifikasjoner av klassifiseringssystemet ble foreslått på grunnlag av analysene.

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Preface

This report is part of the project “Errors, information processing, barriers, and accident risk in the operation and control of different means of transport”, which has been carried out within the RISIT programme (”Risk and Safety in the Transport Sector”) of the Research Council of Norway. A main objective of the project has been to try out and to adapt a methodology for identifying and analysing erroneous actions and their causes, which can be applied across transport modes. In the first phase of the project it was decided, on the basis of a review of previous work, to focus on methods based on the Cognitive Reliability and Error Analysis Method (CREAM). This method, developed by Erik Hollnagel at the Institute for Energy Technology, Halden, Norway, in the mid 1990’s, is based on an MTO (Man-Technology-Organisation) approach to analysing incidents and accidents. It was decided to carry out case studies within both rail and road transport. In this report we present the road traffic case studies, which consisted of analysing fatal road accidents with DREAM (Driving Reliability and Error Analysis Method), which is an adaptation of CREAM to the analysis of driver behaviour. The railway case studies are presented in a separate report.

During the project we have appreciated very much the opportunity to discuss our work with Professor Erik Hollnagel (presently at École des Mines des Paris, Sophia Antipolis, France), who originally constructed CREAM, and with Researcher Mikael Ljung Aust at Chalmers University of Technology, Göteborg, Sweden, who adapted the method for road traffic by constructing DREAM.

We thank the following persons in the five region offices of Norwegian Public Roads Administration, who have contributed to the project by providing material from their in-depth accident investigations: Eivind Kvambe, Elisabeth Longva, Hans Olav Hellesøe, Bård Øien, and Per Magne Solvoll.

At TØI, Chief Research Psychologist Fridulv Sagberg has managed the project, and he has also authored this report. Research Psychologist Inger Synnøve Moan has carried out parts of the DREAM analyses and has also contributed to the suggested further development of the methodology. Chief Research Officer Torkel Bjørnskau has been responsible for quality assurance, and Trude Rømming has edited and prepared the report for printing.

Oslo, December 2007
Institute of Transport Economics

Lasse Fridstrøm
Managing Director

Torkel Bjørnskau
Chief Research Political Scientist

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Summary:

A methodological study of the Driving Reliability and Error Analysis Method (DREAM)

This study is part of a project about risk-related errors in transport, which has been carried out within the research programme "Risk and safety in the transport sector" (RISIT), organised by the Research Council of Norway. One purpose of the project is to develop tools for analysing dangerous incidents across transport modes, emphasising classification and explanation both of errors that could lead to accidents and of factors influencing the probability of such errors.

This report summarises our experience in the use of the Driving Reliability and Error Analysis Method (DREAM) for the secondary analysis of primary data from road accident investigations. These investigations were performed by the permanent accident investigation teams of the Norwegian Public Roads Administration (NPRA), and the material was made available for the DREAM analyses. DREAM is based on the same methodological and theoretical approach as the more generic method CREAM ("Cognitive Reliability and Error Analysis Method"), developed during the mid 1990's by Erik Hollnagel at the Institute of Energy Technology in Halden, Norway.

The use of DREAM on road accidents has shown that the method functions well for identifying factors that influence the course of events during the pre-crash phase of an accident, and that it adds to the results of primary investigations knowledge and hypotheses regarding causal mechanisms of accidents. Since the method involves classifying actions and causes according to predefined categories, it provides a basis for the aggregation of results from a large number of accidents. Such aggregated data can provide knowledge about the frequency of various risk factors and enable comparisons across different crash types, transport modes or sectors.

The study also resulted in suggestions for improvement of the analysis method.

Background

Although CREAM was originally developed to analyse safety-critical incidents in nuclear power plants, it is generic in the sense that it uses causal categories that are largely independent of the type of socio-technical system analysed. CREAM is based on an MTO perspective (Man-Technology-Organisation), and includes a taxonomy for causal categories covering the three elements M, T, and O, as well as a method for identifying relationships both among the categories and between causal factors and action categories ("error modes"). The method begins by

characterising that action which is most directly connected to the critical event (a critical event here is an accident or a near-miss incident). This action characteristic is the "error mode" or, using a biological analogy, the *phenotype,* (which denotes the observable characteristics), as opposed to a *genotype*, which is the more or less covert cause of a phenotype. For a given incident, a general phenotype is selected from a list of nine different classes. This list is supposed to cover all possible physical relationships between objects, which may characterise an action: timing, duration, sequence, object, force, direction, speed, distance, volume. The error modes are further specifications of the general phenotypes, as e.g. "too short distance", "too high speed", or "wrong direction".

In the analysis, a given genotype is always an *antecedent* to a phenotype or to a different genotype. At the same time it may be a *consequent* of other genotypes. The taxonomy specifies the possible connections backward from a consequent to an antecedent, which in turn is the consequent of one or more other antecedents. In this way, and according to the rules for the analysis a network of (assumed) causal relationships is constructed.

Another important element in CREAM is the specification of "Common Performance Conditions (CPC)", which comprise the objective circumstances of the accident, such as work environment, time of day, work organisation or information, as well as an assessment of their possible favourable or unfavourable influence on the process in which the incident took place.

Other variants of CREAM have been developed for special applications or domains, where domain-specific causal categories have been added to the general categories (genotypes) of CREAM. DREAM is an example of such a modification for the road traffic domain, where some categories were added to cover factors related to vehicle and road system. Since CREAM is the core of all these approaches, the term "CREAM-based methods" will be used here when we are considering general aspects of the method.

Data basis

The data for this study are reports and documents from the in-depth analyses of fatal accidents, done by NPRA investigation teams. For the present study material from 15 accidents was selected. We chose accidents with a high level of complexity, i.e. where the chain of causal events was not clear, on the assumption that they would be more suitable for assessing the potential of DREAM to provide new knowledge. An additional selection criterion was driver age, so that most of the selected accidents involved young drivers. Those accidents were chosen because young drivers are over-involved in crashes, and it is therefore particularly important to get more knowledge about accident causation for this group.

Method

Because use of CREAM-based methods allows for some degree of subjectivity on part of the analyst, a small number of accidents were first analysed independently by two persons. The analyses were then compared and discussed, and some inconsistencies were identified and corrected, so that a common understanding was achieved. The remaining accidents were then analysed by only a single analyst.

On the basis of the experience with the analyses, some modifications of the taxonomy were made, and all the analyses were reviewed and revised in accordance with the modified taxonomy.

The results of the DREAM analyses were compared to the available causal analyses in the reports from the NPRA accident investigation teams. Pros and cons were compared between DREAM and the methods used by the investigation teams – primarily "Sequentially Timed and Events Plotting" (STEP) and "Why-Because-Analysis" (WBA).

Results and implications

Identified causal factors

In the 15 accidents analysed, the most frequent phenotype was "wrong direction", reflecting the fact that many of the accidents involved vehicles that ran off the road or moved into the opposite lane and collided with an oncoming vehicle. The most frequent immediate causal factors (genotypes) were "observation missed", "information failure", "false diagnosis", and "performance variability". The most frequent antecedents to these genotypes were (ranked by frequency of occurrence): sight obstruction, inattention, inadequate road design or maintenance, inadequate skill, influence by substance, psychological stress, error in mental model, fatigue, and distraction. The finding that inadequate skill is among the most frequent factors is clearly related to the high proportion of young drivers in the sample.

Assessment of DREAM

In most cases there was a reasonable correspondence between possible causal factors identified by DREAM and the primary analysis. There were, however, a few cases where the DREAM analysis resulted in new hypotheses about accident causes.

An important difference between DREAM and the primary analysis is that DREAM uses predefined causal categories, whereas both STEP and WBA describe events in terms of causal factors defined *ad hoc*. This means that results from DREAM analyses can be aggregated so that frequencies of causal factors can be compared, for instance, between different domains. Such aggregation is not possible when categories are specific for each incident. In other words, the use of specific categories enables a more detailed description of each incident, but it is uncertain whether this will result in more knowledge about accident causation in general.

One possible drawback of those causal analysis methods which, like DREAM, are based on single incidents, is that there is uncertainty associated with some of the identified factors. The results of the analysis may thus give the impression that all factors are equally important. A possible way to partly overcome this problem, is to include a qualification of each factor in terms of a simple probability statement, i.e. to try and differentiate between “possible”, “probable”, and “certain” factors. An important tool that can help make such judgements is the specification of “Common Performance Conditions” that is carried out in advance of the causal analysis.

A limitation of DREAM as a total approach to accident investigation, is that the method can be used to analyse the course of events only up to the point of loss of control; for road traffic accident this means only the pre-crash phase, while the other methods mentioned here also include description of the crash and post-crash phases.

Another limitation is that DREAM is not suitable for analysing the importance of preventative measures, or “barriers”, that could have prevented the incident or reduced its consequences. On the other hand, the knowledge about causal factors obtained using DREAM may in turn have implications for barriers for reducing the risk of similar accidents.

Even though the present assessment is based on experience with DREAM, the similarity to CREAM is so close that the conclusions here can be assumed to be valid for CREAM-based methods in general.

Implications for analyses of road accidents

Against the background of the advantages and limitations discussed above, it is concluded that DREAM would be very useful as one out of three main elements in a total road accident analysis approach. The main function of DREAM would be to analyse the background factors contributing to the occurrence of dangerous situations. The second element should be a method for timeline plotting of all relevant actions and events occurring before, during and after an accident, that could have contributed either to the occurrence of the accident or to its consequences. STEP, which is commonly used by investigation teams, seems to be suitable for this purpose. The third element should be a method for identifying possible barriers that can be assumed to prevent similar accidents or reduce their consequences.

In many cases it was difficult to carry out the DREAM analysis as thoroughly as we would have liked, because information was either missing or of poor quality. This observation raises questions about the procedures that the NPRA investigation teams use to collect accident data. The use of a relatively structured approach like DREAM demands high quality data, and its use should lead to suggestions about the way data collected in the first place could be improved. To achieve a more comprehensive test of a DREAM-based approach to road accident investigation it would be useful to use DREAM as an integrated part of the primary data collection, in which the method of analysis could influence which data are collected.

Finally, a practical limitation to consider is that the CREAM-based methods require a good understanding of the underlying theoretical model(s) and cognitive concepts used in the taxonomy. On the other hand, clear definitions of the concepts, supported by good examples, should make it possible to use the methods without very comprehensive training beyond the basic knowledge of the domain of the particular analysis.

Sammendrag:

En metodologisk studie av ulykkesgransking med "Driving Reliability and Error Analysis Method (DREAM)"

Denne undersøkelsen er del av et prosjekt om feilhandlinger i transport, som har vært gjennomført under Norges forskningsråds program "Risiko og sikkerhet i transportsektoren" (RISIT). Et av formålene med prosjektet har vært å videreutvikle metodeverktøy for å analyse farlige hendelser på tvers av transportgrener, med vekt på klassifisering og forklaring av feil som kan føre til ulykker, og av faktorer som påvirker sannsynligheten for slike feil.

Denne rapporten er en beskrivelse av erfaringer med å bruke analysemetoden DREAM ("Driving Reliability and Error Analysis Method") på datamateriale fra trafikkulykker som har vært undersøkt av Statens vegvesens ulykkesanalysegrupper. DREAM er basert på, og bygger på samme metodiske og teoretiske tilnærming som, den mer generelle metoden CREAM ("Cognitive Reliability and Error Analysis Method") som ble utviklet på midten av 1990-tallet av Erik Hollnagel ved Institutt for energiteknikk i Halden.

Utprøvingen på veitrafikkulykker viser at metoden er velegnet for å kartlegge forhold som påvirker hendelsesforløpet i "precrash"-fasen av en ulykke, og at den gir kunnskap om årsakssammenhenger ut over det som allerede kommer fram gjennom de opprinnelige ulykkesanalysene. Siden metoden er basert på forhåndsdefinerte årsakskategorier, gir den også et godt grunnlag for å aggregere resultater fra et større antall hendelser, med sikte på å undersøke hyppigheten av ulike risikofaktorer, og å foreta sammenligninger mellom ulykkestyper, transportgrener eller sektorer. DREAM-analysene påviser dessuten et behov for forbedringer når det gjelder innsamling av data fra veitrafikkulykker.

Undersøkelsen har resultert i noen forslag til modifikasjoner av analysemetoden.

Bakgrunn

CREAM ble opprinnelig utviklet for å analysere sikkerhetskritiske hendelser i kjernekraftverk, men er en generisk metode i den forstand at den opererer med årsakskategorier som i stor grad er uavhengige av hvilken type virksomhet som analyseres. Analysen tar utgangspunkt i et såkalt M-T-O perspektiv (Menneske-Teknologi-Organisasjon), og den består av et klassifiseringssystem med grupper av årsakskategorier innenfor de tre elementene M, T og O, samt et system for identifisering av årsakssammenhenger mellom kategorier. Startpunktet for analysen er identifisering av hva som kjennetegner den handlingen som ligger nærmest opp til selve den kritiske hendelsen (som kan være en ulykke eller en

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nestenulykke). Dette kjennetegnet blir kalt *feilmodus* ("error mode") eller *fenotype,* etter analogi fra biologien, hvor fenotyper betegner observerbare kjennetegn, i motsetning til genotyper, som er de mer eller mindre skjulte årsaker til fenotypen. For en gitt hendelse, velges en generell fenotype fra en liste over ni klasser, som forutsettes å dekke alle mulige fysiske relasjoner mellom objekter, og som kan kjennetegne en handling: tid, varighet, sekvens, objekt, kraft, retning, avstand, volum. Feilmodiene er nærmere spesifikasjoner av de generelle fenotypene, som f.eks. "for kort avstand", "for høy fart" eller "feil retning".

I analysen er en gitt genotype alltid en "antecedent" til en fenotype eller til en annen genotype. Samtidig kan den være en "consequent" til andre genotyper. Klassifiseringssystemet spesifiserer mulige koblinger bakover fra en "consequent" til en "antecedent", som igjen er en "consequent" til en eller flere "antecedents". På denne måten konstrueres et nettverk av (antatte) årsakssammenhenger.

Et annet viktig element i CREAM er spesifisering av såkalte "Common Performance Conditions" (CPC), som omfatter de faktiske omstendigheter omkring hendelsen, som. f.eks. arbeidsmiljø, tid på dagen, arbeidsorganisering, informasjon, etc., og en vurdering av disse forholdenes eventuelle positive eller negative innvirkning på hendelsen. Spesifiseringen av CPC er tenkt som et hjelpemiddel i analysen for å vurdere betydningen av de ulike årsaksfaktorene.

Det er utarbeidet flere varianter av CREAM som er tilpasset bestemte anvendelser eller domener, hvor det i tillegg til de generelle kategoriene (genotypene) er definert en del domenespesifikke kategorier. DREAM er et eksempel på en slik tilpasning av CREAM til hendelser i veitrafikk, hvor det i tillegg til genotypene i CREAM ble lagt til en del kategorier som er spesifikke for veitrafikk, særlig knyttet til kjøretøy og veiforhold. Siden CREAM utgjør kjernen i alle disse, og metoden for årsaksanalyse er den samme, vil vi benytte "CREAM-baserte metoder" som en fellesbetegnelse når det er snakk om generelle aspekter ved metoden.

Datagrunnlag

Datagrunnlaget for undersøkelsen er rapporter og dokumenter fra Statens vegvesens analyser av dødsulykker i veitrafikken. For denne undersøkelsen ble materialet fra 15 ulykker gjennomgått. Det ble forsøkt valgt ut ulykker som virket noe komplekse, dvs. hvor hendelsesforløpet ikke var opplagt og enkelt, slik at en kunne få en best mulig test på DREAM-metodens potensiale for å framskaffe ny kunnskap. Et flertall av ulykkene involverte unge bilførere; disse ulykkene ble valgt fordi unge førere har spesielt høy ulykkesrisiko, slik at det er spesielt interessant å få kunnskap om ulykkesårsaker for denne gruppen.

Metode

Siden bruken av CREAM-baserte metoder gir rom for et visst skjønn, ble det først foretatt foreløpige analyser av et mindre antall ulykker, hvor to personer gjennomførte analysene uavhengig av hverandre. Analysene ble så gjennomgått i fellesskap, og noen uoverensstemmelser ble diskutert, slik at vi kom fram til en felles tilnærming til bruken av metoden. Deretter gjennomførte hver av de to et antall analyser, slik at i alt 15 ulykker ble analysert.

På grunnlag av erfaringene med analysene, ble det foretatt en del justeringer av kategorier i klassifiseringssystemet, og alle analysene ble gjennomgått og revidert i samsvar med endringene i klassifiseringssystemet.

Resultatene av DREAM-analysene ble sammenlignet med foreliggende årsaksanalyser i rapportene fra ulykkesanalysegruppene, og det ble foretatt en vurdering av fordeler og ulemper ved DREAM sammenlignet med de metodene som ulykkesanalysegruppene hadde benyttet - "Sequentially Timed and Events Plotting" (STEP) og "Why-Because-Analysis" (WBA).

Resultater og implikasjoner

Påviste ulykkesårsaker

Når det gjelder årsaksfaktorer for de 15 ulykkene som ble analysert her, var den hyppigste fenotypen "feil retning", dvs. at mange av ulykkene var utforkjøringer eller kollisjoner med møtende kjøretøy. De hyppigste umiddelbare årsaksfaktorene (genotypene) var "manglende observasjon", "informasjonssvikt", "feilaktig situasjonsforståelse (diagnose)" og "variasjon i prestasjonsnivå". De hyppigste forklaringene i neste omgang var (rangert etter hyppighet): sikthindring, uoppmerksomhet, svakhet ved veiutforming/-vedlikehold, utilstrekkelig ferdighet (mangelfull opplæring/erfaring), ruspåvirkning, psykologisk stress, feilaktig mental modell, trøtthet og distraksjon. At utilstrekkelig ferdighet kommer så høyt opp på listen, henger klart sammen med at det var unge bilførere innblandet i de fleste ulykkene.

Vurderinger av DREAM

For de fleste ulykkene var det et rimelig godt samsvar mellom resultatene fra DREAM-analysene og fra de primære analysene som ulykkesanalysegruppene hadde foretatt når det gjaldt identifisering av mulige årsaksfaktorer. Imidlertid var det noen tilfeller hvor DREAM-analysene førte til nye hypoteser om ulykkesårsaker, som ikke var med i de primære analysene.

En viktig forskjell mellom DREAM og de primære analysene er at DREAM opererer med forhåndsdefinerte årsakskategorier, mens både i STEP og i WBA beskrives hendelseselementene ut fra kategorier som velges ad hoc. Dette betyr bl.a. at resultatene fra DREAM kan aggregeres, slik at det kan foretas sammenligninger mellom virksomheter og sektorer når det gjelder forekomst av ulike risikofaktorer. Slik aggregering er ikke mulig når kategoriene er spesifikke for den enkelte hendelse. På den andre siden gir spesifikke kategorier større mulighet for detaljert beskrivelse av den enkelte hendelsen, men det er usikkert hvorvidt det kan bidra til generell kunnskap om årsakssammenhenger.

En mulig innvending mot årsaksanalyser basert på enkelthendelser, som også gjelder DREAM, er at noen av årsaksfaktorene som kommer fram gjennom analysen kan være mer usikre enn andre. Dette framgår ikke nødvendigvis av resultatene, og det kan dermed virke som alle faktorer i en analyse har like stor betydning. En mulig måte å imøtekomme denne innvendingen på, kan være å supplere analysen med en enkel angivelse av hvor sannsynlige de enkelte faktorer er, f.eks. ved å skille mellom "mulige", "sannsynlige" og "sikre" årsaksfaktorer. Et viktig hjelpemiddel for å kunne gi slike anslag er spesifiseringen av "Common Performance Conditions" som gjøres forut for selve analysen, samt øvrige beskrivelser av fakta om hendelsesforløpet. Med en slik kvalifisering av risikofaktorene vil en kunne velge sannsynlighetsnivå når en aggregerer, og f.eks. bare inkludere "sannsynlige" eller "sikre" årsaksfaktorer, avhengig av hva formålet med aggregeringen er.

En begrensning når det gjelder DREAM er at metoden bare kan benyttes for å analysere hendelsesforløpet fram til tap av kontroll (dvs. "precrash"-fasen i en veitrafikkulykke), mens de øvrige metodene også kan beskrive "crash"-fasen og "postcrash"-fasen.

En annen begrensning er at DREAM-metoden ikke er egnet til å analysere betydningen av barrierer som evt. kunne hindre tilsvarende ulykker, selv om analysen gir kunnskap om årsaksfaktorer, som i neste omgang kan danne grunnlag for tiltak i form av barrierer.

Selv om vurderingene ovenfor er basert på erfaringer med DREAM, er det så store likheter mellom DREAM og andre CREAM-baserte analysemetoder at det må kunne antas at konklusjonene gjelder for metoder basert på CREAM generelt.

Implikasjoner for ulykkesanalyser i veitrafikk

Ut fra de fordeler og begrensninger som er nevnt ovenfor, konkluderer vi med at DREAM vil kunne ha en viktig plass som det ene av tre hovedelementer i en total ulykkesanalyse. Hovedfunksjonen til DREAM vil være å analysere de bakenforliggende faktorer som bidrar til at farlige hendelser forekommer. Som det andre element bør ulykkesanalysen suppleres med en metode for å plotte inn alle relevante hendelser før, under og etter en ulykke, som kan ha bidratt til at ulykken inntraff og/eller til dens konsekvenser. STEP er en aktuell metode for dette formålet. Og det tredje elementet bør være en analyse av hvilke barrierer som kan antas å forebygge lignende hendelser og/eller redusere deres konsekvenser.

Det var i mange tilfeller vanskelig å gjennomføre DREAM-analysene grundig nok, fordi datagrunnlaget var mangelfullt. Dette reiser spørsmålet om mulige forbedringer når det gjelder innsamlingen av data som Statens vegvesens ulykkesgrupper gjennomfører. Bruk av en så vidt strukturert analyse som DREAM stiller store krav til kvaliteten av data, og dermed kan metoden også være et godt verktøy for å sikre at det samles inn gode data i første instans.

For å få en fullstendig test av nytten av denne tilnærmingen til ulykkesanalyse, vil det vært ønskelig å prøve ut metoden som en integrert del av den primære datainnsamlingen, slik at analysemetoden kan være med og påvirke hvilke data som registreres.

En mulig begrensning når det gjelder praktisk anvendelse, kan være at en riktig bruk av klassifiseringssystemet i CREAM-baserte metoder forutsetter en god forståelse av den underliggende teoretiske modellen og de kognitive begrepene som benyttes i klassifiseringssystemet. Imidlertid vil klare definisjoner av de ulike begrepene, samt gode eksempler, kunne gjøre det mulig å bruke metodene uten omfattende opplæring ut over grunnleggende kunnskap om den virksomheten som analysen skjer innenfor.

1 Introduction

1.1 Background

In order to prevent accidents it is important to understand how failures in the interaction between human operators, technical systems and operational conditions may result in hazardous situations and accidents. Over the last few decades the focus in accident analysis and prevention has moved steadily from an emphasis on "human error" to an MTO systems perspective ("Man-Technology-Organisation"). Although the concept of human error is still used, investigators now tend to focus on contextual variables to explain why errors occur. Thus it has been acknowledged that the identification of a given action as an "error" is dependent on the context in which that action takes place. An action that is considered correct in one setting may be seen as an error in a different setting.

The study presented in this report is part of a project to assess methodologies for the analysis of transportation errors and their associated causes The different levels of analysis can range from the interface between operators and technical systems ("the sharp end") to background factors related to individuals, social factors, working environment, or work organisation ("the blunt end"), including "latent errors" (Reason, 1990). The aim is to identify a generic methodology or analytical tool that can be applied in different transport modes to enable comparison of accident causes and risk factors across domains.

The first phase of the project consisted of a literature review of different methods for error analysis and a critical discussion of the concept of "human error" (Massaiu, 2005a,b).[1] As a consequence of this we decided to concentrate on the "Cognitive Reliability and Error Analysis Method CREAM", developed by Erik Hollnagel (1998) in subsequent case studies and methodological development.

CREAM is an approach to error, incident, and accident analysis that is based explicitly on the MTO systems perspective and its focus on context. Although originally developed for analysis of critical events in nuclear power plants, the approach is supposed to be applicable across domains. DREAM – the Driving Reliability and Error Analysis Method (Ljung, Furberg and Hollnagel, 2002) – is an adaptation of CREAM to the analysis of road accidents. In the case studies described in this report, analyses are mainly based on DREAM, with the addition of some modifications made during the project, and the inclusion of aspects of the original CREAM that were not a part of DREAM.

[1] For a wider overview of methods in accident investigation and safety assessment we refer to the comprehensive books by Johnson (2003) and Everdij (2004).

1.2 Aim of the study

The purposes of this study are to assess the usefulness of DREAM for analysing the causes of road crashes, to discuss possible improvement of the method, and to give recommendations for data collection. This is done by analysing a number of available crash investigation reports provided by the Norwegian Public Roads Administration (NPRA), and then using the results to discuss the following issues:

1) Does use of DREAM result in added knowledge about causal factors for a given accident (compared to more traditional approaches to crash investigation)?

2) What limitations to DREAM should be considered when analysing road crashes?

3) Can the method be improved by extending the taxonomy (i.e. increasing the selection of available causal factors that can be used to explain an accident)?

4) To what extent do the DREAM analyses reveal limitations about current ways of collecting data from road crashes?

The latter issue has direct practical importance regarding the question of how the road authorities carry out their accident investigations, whereas the former issues are related to more general methodological aspects of DREAM and other methods based on CREAM.

2 Brief description of CREAM and DREAM

CREAM (Cognitive Reliability and Error Assessment Method) was developed by Erik Hollnagel (1998) for the analysis of safety-related errors in MTO (Man-Technology-Organisation) systems, and to determine the human, technological and organisational factors that may be involved in error causation. Although originally developed in a setting of nuclear power plant operation, it is a generic approach including a taxonomy of cognitive reliability and error concepts that are relevant to any MTO system. However, to capture the domain-specific technological and organisational factors, the taxonomy needs to be adapted when the method is applied in other domains.

The Driving Reliability and Error Assessment Method DREAM (Ljung, 2002; Ljung, Furberg and Hollnagel, 2002; Huang & Ljung, 2004) is an adaptation to the road transport domain. The method has also been adapted to the railway sector (Hollnagel, Lindberg, Sverrbo, Olsson and Skriver, 1999) and to maritime accidents (Hollnagel, internet communication, 2006: http://www.ida.liu.se/~eriho/CREAM_M.htm). Although the taxonomies differ between domains, there is a common core in all applications, and the method of causation analysis is the same, which potentially makes this approach useful for comparative studies across domains.

The starting point of a CREAM-based analysis is the identification of the action (by a human operator or by a system such as a driver-and-car) immediately leading up to the critical event. This action is called the *error mode* or, using a biological analogy to designate *observable events,* a *phenotype,* as opposed to a *genotype*, which is a more or less covert cause of a phenotype. For a given incident, the relevant general phenotype is chosen from a list of nine classes, presumed to cover all possible physical relations between objects, which characterise an action: Timing, Duration, Sequence, Object, Force, Direction, Speed, Distance, and Volume. The error modes are specifications of the general phenotypes, such as for example “too short distance”, “too high speed”, or “wrong direction”. Possible causal factors are thus specified in a predefined classification system, and the analysis consists of establishing links backward from the phenotype to the different genotypes that are considered relevant to the phenotype in question. In the analysis, a given genotype is always an *antecedent* either to a phenotype or to a different genotype. At the same time it may be a *consequent* of other genotypes. The taxonomy specifies the possible connections backward from a consequent to an antecedent, which in turn is the consequent of one or more other antecedents. In this way, and according to the rules for the analysis, a network of (assumed) causal relationships is constructed. The relationship between the various categories in the taxonomy is based on a cognitive theoretical model. Thus, the whole analysis is built on three components, which according to Hollnagel (1998) are necessary preconditions for any valid causal analysis; the MCM framework: a Model of human cognition, a Classification scheme, and a Method describing the links between the model and the classification.

An important additional part of the CREAM analysis is the specification of "Common Performance Conditions" (CPCs), which is a specification of the facts regarding the circumstances of the event to be investigated (for example, environment, time of day, work organisation or information) and an assessment of their possible importance in influencing the course of events. The CPCs are specified in advance of the causal analysis, and are used as a background against which to judge the validity of a possible causal factor appearing in the analysis.

In the original DREAM manual (Ljung et al. 2002) the taxonomy was written in Swedish. More recently, an English taxonomy was produced as part of the EU project SafetyNet (Paulsson, 2004) under the new name SNACS ("Safety Net Accident Causation System"). In our analyses we used both sources, as well as the original CREAM taxonomy (Hollnagel, 1998). Appendix 1 gives an overview of the main causal factors in CREAM, DREAM and in the revised taxonomy used in the present case studies. For more details about the specific categories of causal factors used in CREAM and dream, we refer to the mentioned sources.

3 The primary data

All fatal crashes in Norway are analysed by multidisciplinary crash investigation teams organised by the NPRA. The teams collect data from on-the-scene and/or on-the-site investigations and produce a comprehensive report of each crash. For the purpose of this study we obtained reports and related data from a large number of accidents, and selected 15 crashes for the DREAM analyses. The 15 crashes were not selected randomly, but on the basis of the following two criteria:

1. We tried to select crashes that appeared to be relatively complex, on the assumption that the main strength of DREAM is in the analysis of complex events.
2. We selected primarily crashes involving young drivers. This was done because young drivers are over-represented in crashes, and it is therefore especially interesting to get more knowledge about crash causation for that group.

None of the criteria were used exclusively. Thus, not all the analysed crashes were complex, and not all involved young drivers.

4 DREAM analyses of fifteen road accidents

In this section, following a brief description of each crash, the results of the DREAM analysis are described, and then illustrated in a diagram. The results are briefly discussed, and special issues regarding methodological aspects of the analysis or regarding the data collection are noted. The findings from the DREAM analyses are compared to the conclusions from the accident investigation team and to results from analyses by STEP[2], which is a method currently used by most accident investigation teams of the NPRA.

1. Car running off the road in right-hand curve

1.1 Short description of the accident
On an early winter morning, a vehicle drove off the road on the left side in a right-hand curve. The male driver in his 20's died on the scene of the accident. There were no witnesses. The driver did not wear a seat belt, but the airbag was released. The driver came from a party and drove under the influence of alcohol (BAC 0.2%). According to witnesses, he had been very upset when he left the party. Also, a witness stated that the driver had said that he wanted to commit suicide[3]. The place of the accident did not have a guardrail and the condition of the road was poor – a narrow road without edgelines. It was clouded over, dark and there was no road light.

1.2 Results of DREAM analysis
This was a driving-off-the-road accident, and consequently "Wrong direction" was chosen as a phenotype. Since the driver was killed, and no people witnessed the accident, it is difficult to know what actually caused the change of direction. Likely assumptions are that the driver did not observe the sharp right-hand curve ("Observation missed"), due to inattention, or that he misperceived it ("False observation"). Alternatively this can be considered "Information failure", implying that the driver was not informed of the curve, by a warning sign for instance. This in turn could be considered to be a result of "Inadequate design" of the road system and/or "Inadequate quality control". "Faulty diagnosis" of the

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[2] STEP ("Sequentially Timed Events Plotting") is a method developed by Hendrick and Benner (1987), as an improvement of a previous method called MES ("Multilinear Events Sequencing", Benner, 1975).

[3] If the assumption of suicide is correct, this event may not be interesting to analyse with a focus on driver error. However, there may be alternative explanations, and the analysis is performed in order to consider other possible causal factors than suicide.

situation (incorrect idea of the road ahead) is a related, and also plausible, explanation.

Since it was early in the morning, and the driver was influenced by alcohol and was very upset, "Fatigue", "Substance influence", and/or "Psychological stress" are probable antecedents contributing to the factors already mentioned. The results of the analysis are presented in more detail in Figure 1.

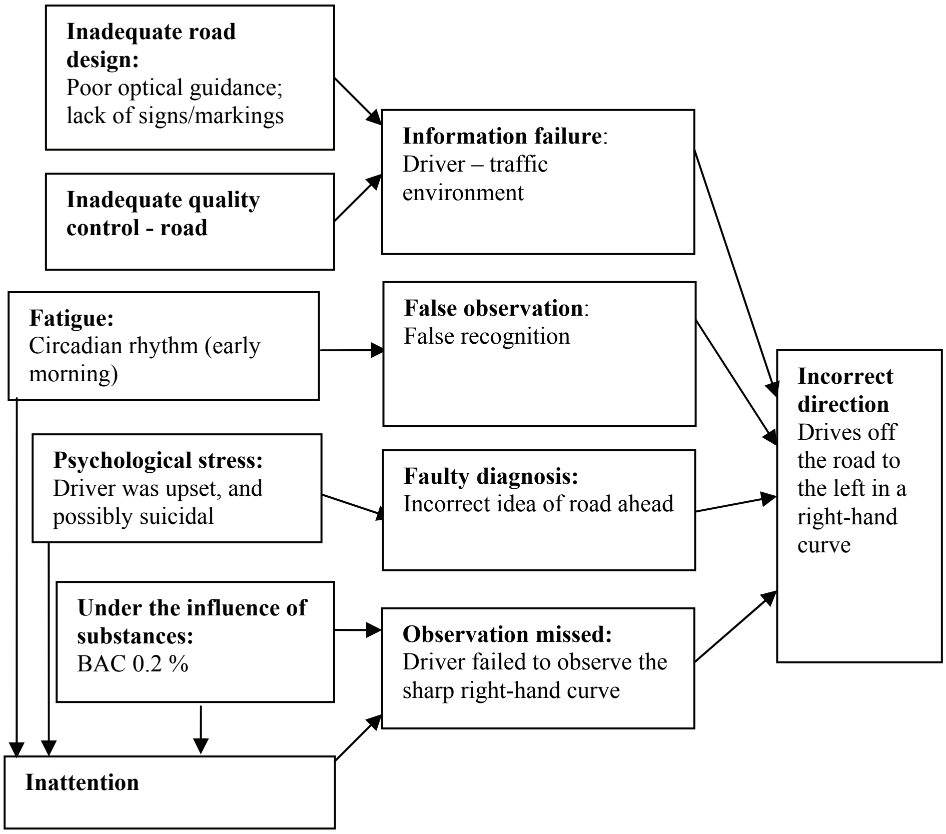

Figure 1. Results of CREAM analysis of crash 1.

1.3 Methodological considerations

This case illustrates a possible problem concerning the choice of causal factors in the analysis. The factors "Information failure", "False obsevation", "Faulty diagnosis", "Observation missed", and "Inattention" all refer to cognitive factors related to information processing, and it may be difficult to choose between them, especially for an analyst that is not very familiar with the cognitive model(s) underlying the concepts. Thus there is a need for clear definitions of the concepts.

2. Motorcyclist running off the road in right-hand curve

2.1 Short description of the accident

Late at night, a young rider of a light motorcycle drove off the road on the left side in a right-hand curve. After leaving the road he fell down a rock cut and landed on an underpass about 2.5-3 metres below the road level. The crash investigators concluded that the motorcycle had been in good condition before the crash, and that the visibility was good. The road may have been wet (according to the police), but no measurements of the road friction were conducted. Because of an agricultural access road there was no guardrail at the site where the motorcycle left the roadway, and there was no road light. The driver was inexperienced (having held a license for a few months), and he was most likely tired. He made a phone call to a relative right after the accident and said “I misjudged the curve”. He died before he was found.

2.2 Results of DREAM analysis

“Wrong direction” was chosen to describe the direct cause of the accident (the phenotype). “Observation missed” (curve sharper than assumed), “Faulty diagnosis” (driver misjudged curvature), and “Information failure” (no warning) were chosen as general antecedents for the wrong direction. The “Observation missed” is likely to be explained by “Inattention” (caused by fatigue due to the circadian rhythm), as well as by the faulty diagnosis of the road alignment. Also, “Performance variability” (lack of training/experience – driver was 16 years old) was probably an indirect cause of the incident. The results are presented in more detail in Figure 2.

2.3 Methodological considerations

The method is helpful in identifying driver(rider)-related genotypes, but is less suitable for identifying shortcomings of the road environment (e.g., no road lights, no guardrails). Thus, this case illustrates that the DREAM method should be supplemented by a method for barrier analysis in order to give a complete accident analysis with practical implications for countermeasures.

The case also illustrates the possibility of analysing additional aspects of the accident, such as the fact that the long delay before finding the injured motorcycle rider may have contributed to the fatal consequences. Many accidents can be considered as consisting of more than one event, which could be analysed separately.

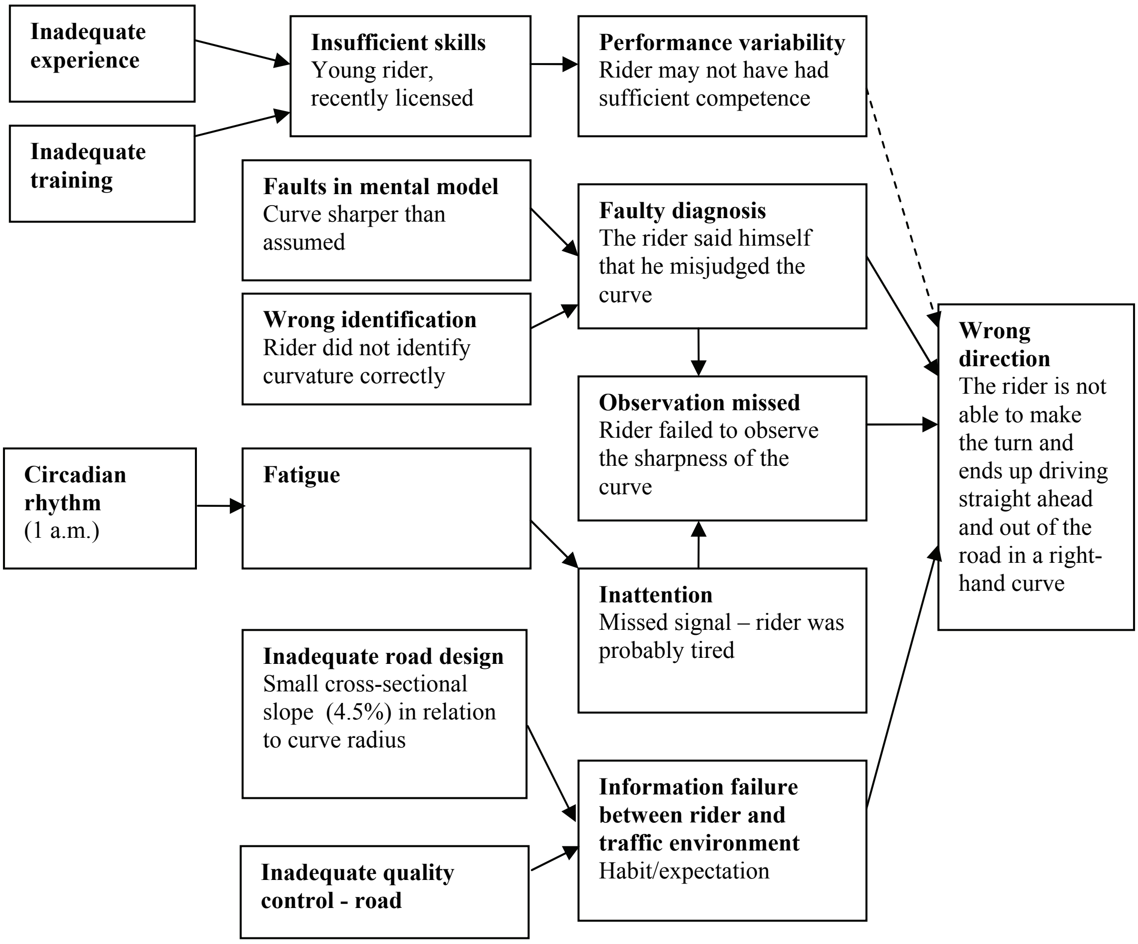

Figure 2. Results of DREAM analysis of accident 2.

3. Car running off the road on left-hand side

3.1 Short description of the accident

A late winter evening, a car with two persons drove off the road on the left side. The passenger was killed in the accident. There were no road lights and the road was wet and slippery. The car was in good condition. The young driver had got his licence only a few days prior to the accident. According to the accident report he was driving too fast for the conditions.

3.2 Results of DREAM analysis

The point of departure of this analysis was “Wrong direction” as it was a driving-off-the-road accident. “Faulty diagnosis” (faults in mental model, unexpected change of conditions), and “Observation missed” (darkness made it difficult to observe slippery road) are plausible causes of the vehicle ending up in the wrong direction. The “Observation missed” may be explained by “Inattention” due to “Cognitive bias” (the driver had no expectation about losing control). An indirect cause of this accident is likely to be “Performance variability” (lack of experience/training), since the driver got his driver licence about a week prior to the incident. The results are presented in Figure 3.

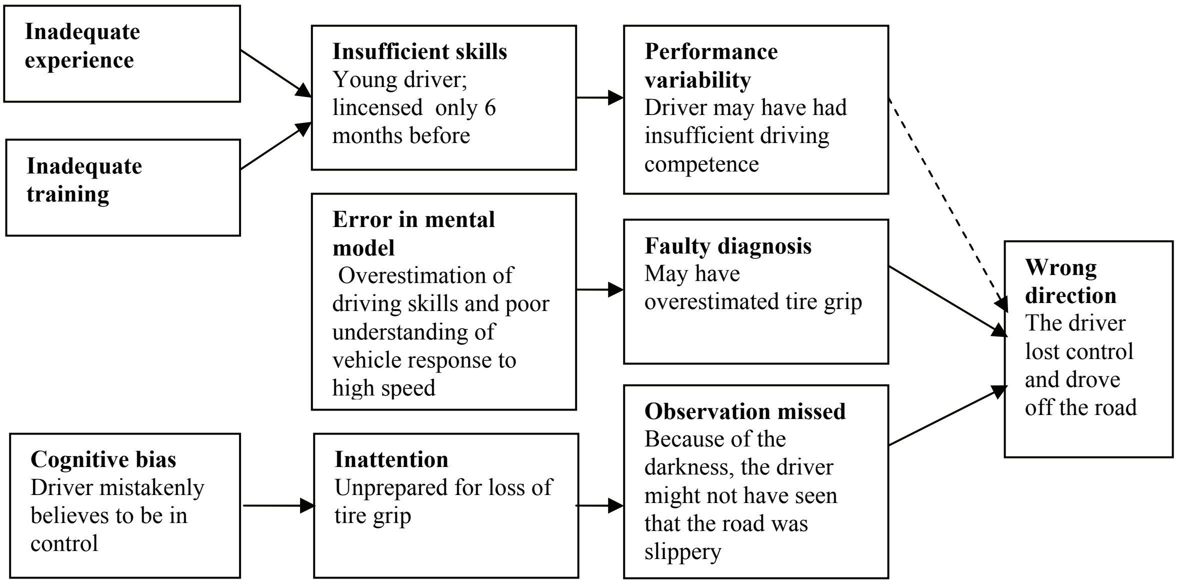

Figure 3. Results of DREAM analysis of accident 3.

3.3 Methodological considerations

Based on the accident report it is difficult to identify the actual cause of this accident. The driver did not remember much of what happened prior to the accident, but he stated that he did not drive too fast. Since his friend was killed in the accident, it is likely that he did not want to remember much or did not want to tell what he remembered. To get reliable information from drivers who have been involved in fatal crashes is obviously difficult, due to the strong emotional impact of such a serious event.

When there is so limited information about a crash as in this case, there is probably little value added by the DREAM analysis to that obtained from a common-sense description of the accident. It is a challenge for the accident investigators to collect better on-the-scene or on-the-site information in order to reconstruct how the event may have developed.

4. Car running off the road in left-hand curve

4.1 Short description of the accident

An early winter morning, a young driver drove off the road in a left-hand curve. The passenger was killed after being thrown out of the car and landing about 5-10 metres from the car. The driver was influenced by alcohol (BAC not specified), and neither of the two wore seat belts. It was dark, there were no road lights, and the road was wet and bare.

4.2 Results of DREAM analyses

Two phenotypes could be relevant for this accident: “Too high speed” and “Wrong direction”. Direction is regarded as the most important phenotype, but as speed was not fully covered in the analysis of that phenotype, we also chose to conduct a separate analysis for speed. For “Speed”, “Faulty diagnosis” (improper judgement of road condition and own competence) and “Decision error” (chosing too high speed) were considered the primary antecedents, both being (at least partly) caused by the influence of alcohol. A likely antecedent to the “Decision error” is “Insufficient skills”, due to inadequate experience and/or training.

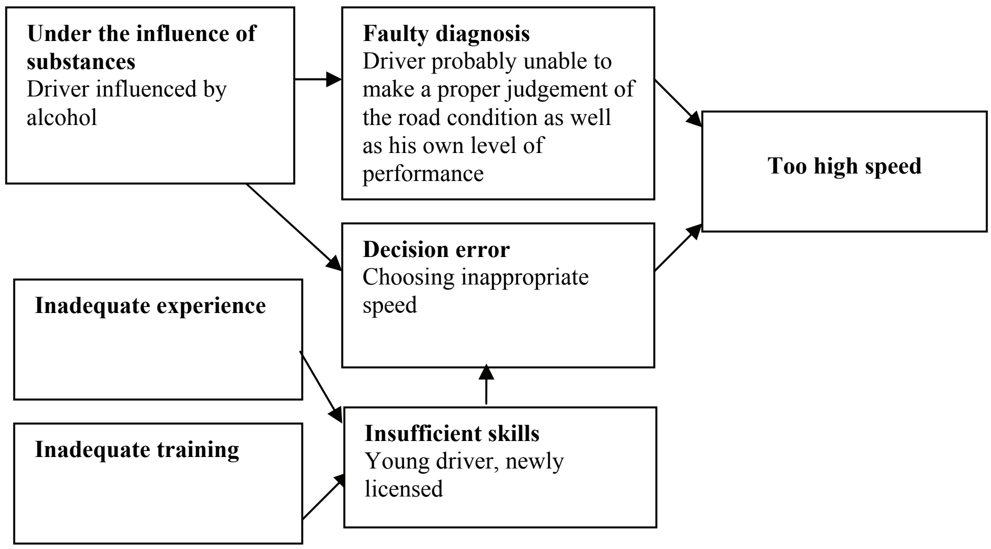

Figure 4. DREAM analysis of the phenotype “Too high speed” for accident 4.

For “Wrong direction”, “Inattention” (due to influence of alcohol), “Faulty diagnosis” (partly due to faulty assessment of curvature), and “Performance variability” (due to lack of experience/training, and alcohol influence) were chosen as general antecedents. See Figures 4 and 5 for further details.

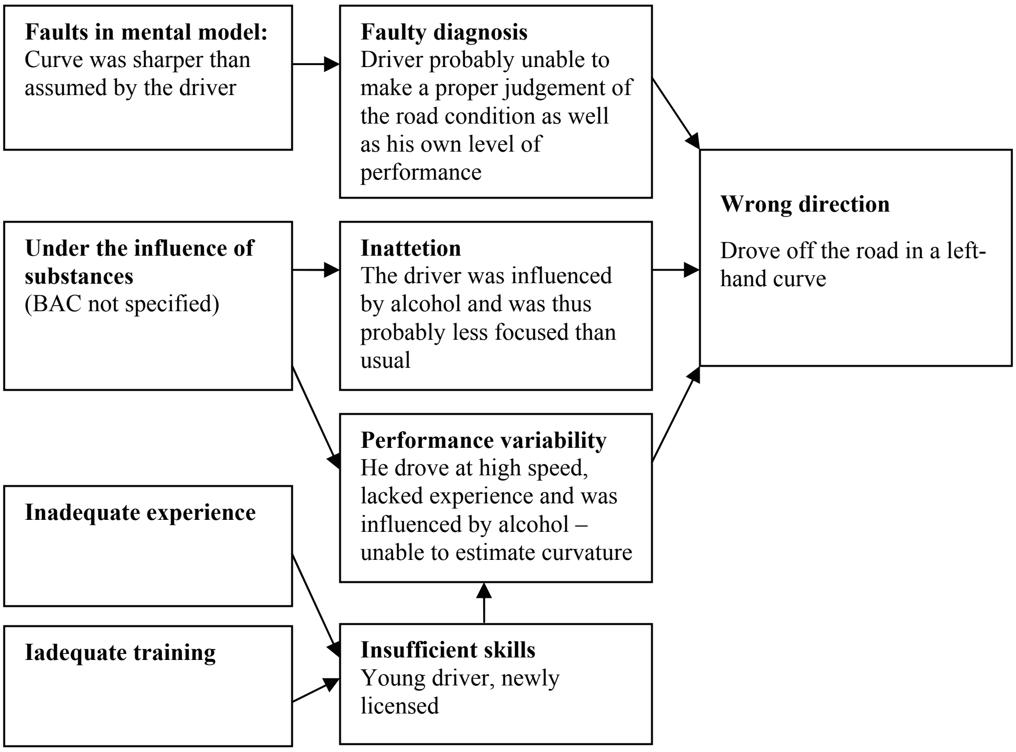

Figure 5. DREAM analysis of the phenotype "Wrong direction" for accident 4.

4.3 Methodological considerations

This case illustrates that sometimes it may be useful to decompose the accident into different events (phenotypes), which are then analysed separately. In this case, the choice of a too high speed can be considered as one event to be analysed, whereas driving off the road is a second one, although there may be a causal relationship between the two. In such cases it may be useful to plot the events on a timeline, in order to visualise the temporal relationship between critical events leading up to an accident. It may also be useful to combine the diagrams for the separate events, in order to visualise the common causes of the events. An example showing both the use of a timeline and the analysis of more than one phenotype will be shown for case 8. A different way of taking speed into consideration as a causal factor influencing the phenotype wrong direction, is to include too high speed as an example of "Inadequate plan", which is a possible antecedent to wrong direction in the DREAM/CREAM taxonomies.

Concerning data quality it should be noted that the BAC level is not specified, although it is said in the accident report that the driver was influenced by alcohol.

5. Car driver losing control on slippery road and crashing with two other vehicles

5.1 Short description of accident

On a winter afternoon, Car A (male driver in his late 20's) got into a skid which subsequently brought the car over in the opposite lane and into the guardrail. Car A then skidded sideways (right side first) into an oncoming car (Car B). After hitting Car B and the guardrail, Car A was thrown back into its original lane. By this time Car A had rotated 180 degrees counterclockwise from its original course, and it crashed frontally into a third car (Car C), which had originally been driving behind Car A. The passenger sitting in the front passenger seat of Car A was killed. The road was covered by snow and ice. The friction was measured to be between 0.15 and 0.20; i.e., lower than the threshold for extended winter maintenance (sanding or salting) set by the NPRA. The driver of Car A knew that the condition of the tyres was poor and stated that he therefore had been driving slowly.

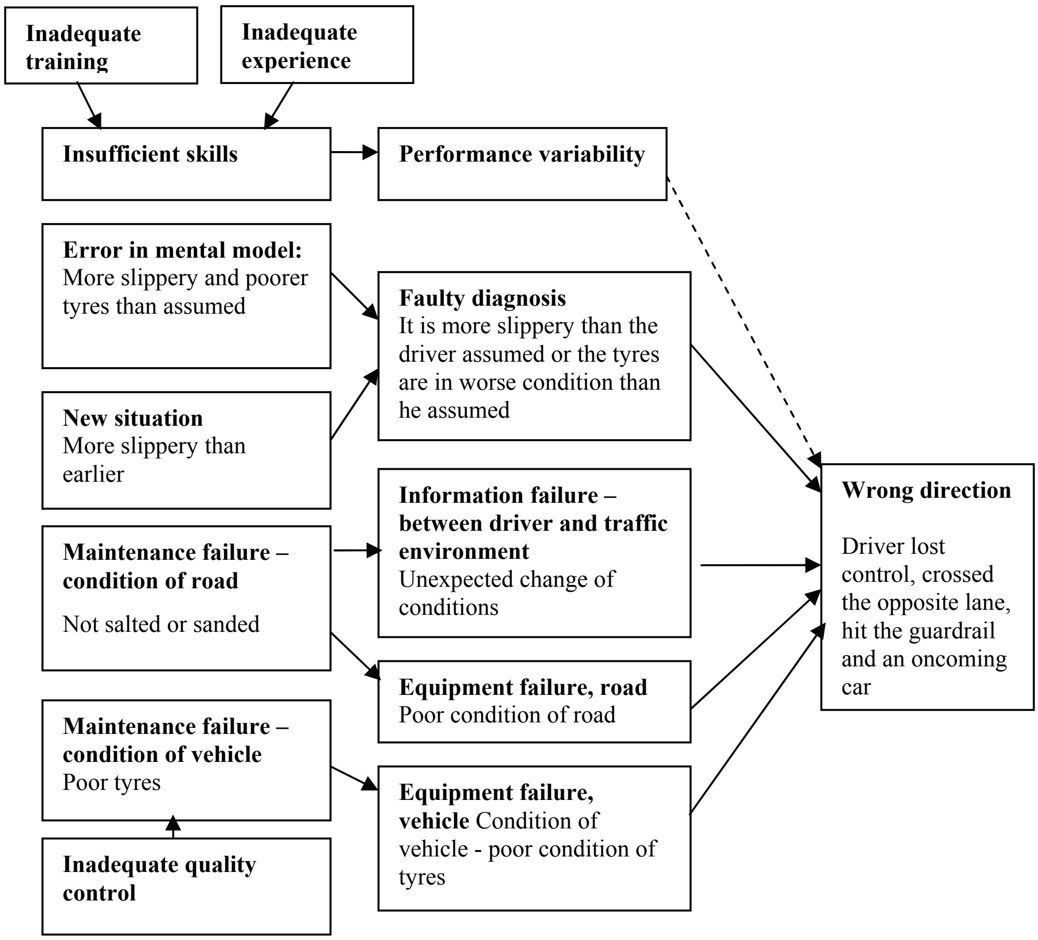

Figure 6. Results of DREAM analysis for Car A in accident 5.

5.2 Results of DREAM analysis (Car A)

The loss of control by the driver of Car A was the initiating event leading to the crash, and therefore a DREAM analysis was conducted only for that driver. However, an analysis might as well have been conducted for the driver of Car B, focusing on his failure to avoid the crash when the oncoming driver lost control, and even on Car C, which may possibly have followed Car A too closely. Since Car A got a skid, “Wrong direction” was chosen as phenotype. “Faulty diagnosis” (of condition of tyres and condition of road), “Information failure” (unexpected change of conditions), and “Equipment failure” (poor condition of road and of tyres) were chosen as general antecedents of the “Wrong direction”. An indirect cause of the accidents could have been “Performance variability” (i.e., lack of training/experience of driving on snow and ice). One might argue that a certain speed is necessary for the car to get into a skid. Thus, an analysis could also have been conducted with "Speed" as a phenotype, like in case 5. See Figure 6 for further details.

5.3 Methodological considerations

When analysing road accidents with more than one vehicle/driver involved, one would normally carry out (at least) one analysis for each driver, in order to get a complete picture of the event. In the case analysed here, we have made the analysis only for the driver who obviously initiated the event, since the primary purpose of our cases is to demonstrate the strengths and limitations of the method rather than to perform a complete accident analysis.

6. Car hitting deer, which in turn hit driver of oncoming car

6.1 Short description of the accident

A late spring afternoon, Car A hit a deer, which was subsequently thrown against an oncoming car (Car B). The deer hit the windscreen of Car B and penetrated into the car compartment. The driver of Car B was seriously injured and died the following day. The place of the accident was inspected by the police the day after the crash and by the accident investigation team two days later. The road was dry. It was reported that animal accidents had become an increasing problem in the area and that several accidents were not reported to the police. There were, however, no animal warning signs on that road section. Also, due to vegetation close by the road, the sight distance for spotting animals approaching the road was limited.

6.2 Results of DREAM analysis

The analysis was conducted for Car A. The phenotype "Timing (too late)" was chosen to describe this accident. Moreover, "Missed observation" (driver did not see deer) and "Information failure" (driver – traffic environment) were considered as likely general antecedents. The "Information failure" in turn could be explained by "Permanent obstruction of view" (vegetation alongside road), and "Missed observation" could be explained by "Inattention". See Figure 7.

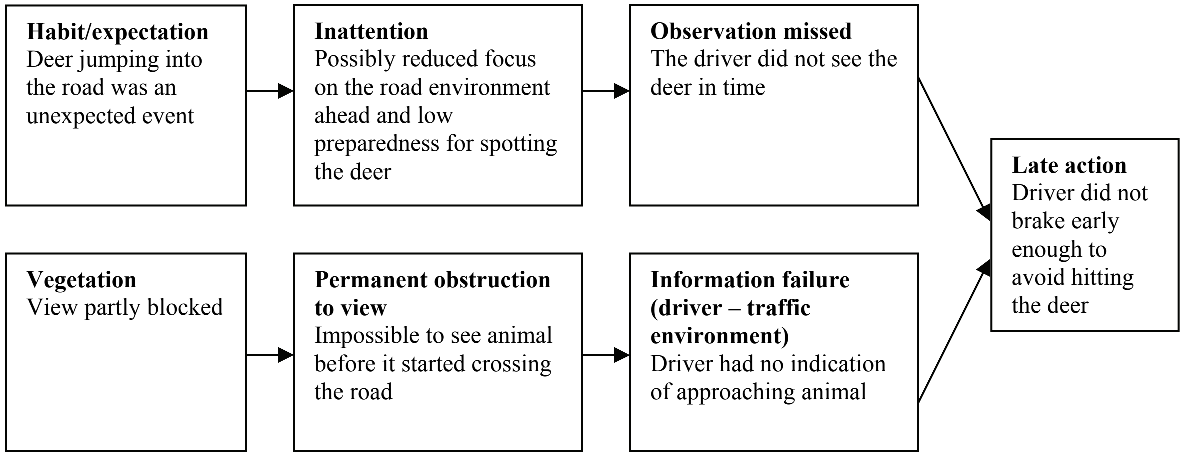

Figure 7. Results of DREAM analysis of Car A in accident 6.

6.3 Methodological considerations

This case raises the issue of the importance of barriers for preventing accidents and/or reducing their consequences. For example, it could be argued that the lack of warning signs could be a relevant additional genotype here, especially since such a barrier could possibly have influenced the driver's behaviour by making him look out for animals. In the analysis, this factor is taken into account in the category "Information failure".

This accident also illustrates the importance of an injury-reducing barrier. Could it for example be considered an error that a car is constructed in a way that makes it possible for a deer to penetrate the windscreen instead of being thrown up and over the vehicle? And could such an error be analysed with CREAM? It seems that such barriers cannot be included in this type of analysis, because the analysis concerns only the factors that influence some *action* by the system components.

Therefore, it should be pointed out that the CREAM/DREAM does not yield an exhaustive analysis of all aspects of an accident, and should therefore be supplemented by other methods, focusing among other things on the role of barriers. This issue will be discussed when summarising the strengths and limitations of CREAM/DREAM.

This accident could also have been investigated from the point of view of the other driver, focusing on her failure to brake at the moment when she could possibly have predicted that the oncoming car might hit the deer.

7. Head-on collision between two cars on hill crest

7.1 Short description of accident

On a summer evening, a young man was driving his car at high speed on the wrong side of the road up a hill crest, where he collided with an oncoming car. He was killed in the crash, and the two occupants in the oncoming car were injured. No braking marks were found; i.e., there were no indications of an attempt to reduce speed. For the oncoming car there were braking marks. The 'at fault' driver was influenced by alcohol (BAC 0.13 %), and witnesses stated that he was upset and angry when he started his trip. Seen in his driving direction, the road had a permanent obstruction of view due to the hill crest.

7.2 Results of DREAM analysis

The analysis was conducted for the "at-fault" driver only. "Incorrect direction" was chosen as phenotype as the driver drove on the wrong side of the road over a hill crest. "Observation missed" (did not observe oncoming car, possibly due partly to alcohol influence), "Information failure" (due to permanent obstruction of view), and "Faulty diagnosis" (overestimating own ability to avoid a potential oncoming car) are plausible explanations of why the driver drove on the wrong side of the road. See Figure 8 for further details of the analysis.

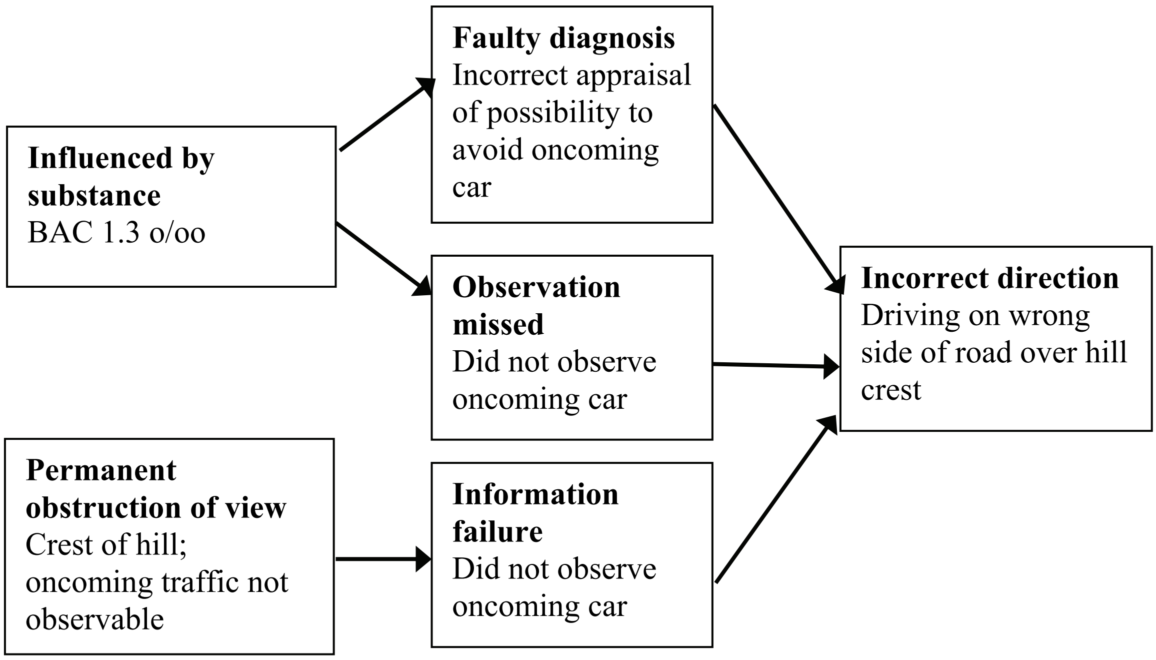

Figure 8. DREAM analyses for "at-fault" driver in accident 7.

7.3 Methodological considerations

The accident report contained very scarce information about the driver (e.g., driver licence, experience of driving etc.); this limited the possibilities of a more comprehensive analysis. There was also limited information about road and weather conditions. This may illustrate a general problem with some of the reports from the accident investigation teams. In cases where the driver at fault has committed some clear violation such as excessive speeding and/or driving clearly influenced by drugs or alcohol, the registration of other contributing factors may tend to be somewhat superficial. It can be discussed whether other causes are relevant also in such cases, since even when a driver is drunk and speeding, there are usually some additional preconditions that seem to be necessary for an accident to happen, and it is of interest to prevent, or to reduce the consequences, of such events.

8. Car driver losing control and colliding with heavy-goods vehicle

8.1 Short description of the accident

An early afternoon in March, a young woman was driving her car on a long straight road section towards a flat left-hand curve. The accident investigation team estimated the speed to have been approximately 120 km/h. The car got into a skid in the curve and ended up in the opposite lane where it hit a fully loaded 50-ton truck-and-trailer. It was assumed by the investigation team that the right pair of wheels of the car had come outside the sealed pavement on the right-hand side, and that the skid started when the driver tried to steer back onto the road. There were, however, no skid or tyre marks found to prove this assumption. The heavy-vehicle driver tried to avoid the crash by hitting the brakes and steering to the right, but it was impossible to avoid the crash. The car hit the truck in front, got stuck under it and was dragged 62 metres before stopping. The truck driver pushed his brakes until the vehicle stopped, lying on the side in the ditch. The car driver was killed in the crash. The pavement condition of the road was poor, but it was dry and the weather conditions were good. The car driver may have been in a hurry (according to a witness she had an appointment with a friend). It is mentioned in the report that there may have been an incoming mobile telephone call; however, the source of this information is not mentioned. For the purpose of the analysis it is assumed that this information is correct.

8.2 Results of DREAM analyses

A DREAM analysis was conducted for the car driver only. Three different phenotypes could possibly be relevant for describing this accident: “Speed”, “Direction” and “Distance”. Thus, three separate analyses were conducted. “Speed” was chosen as phenotype in the first analysis. The most plausible general antecedent of the speed in this incident was “Psychological stress” (time pressure because of an appointment). The phenotype “Distance” was chosen for the second analysis since the car came outside the edge of the sealed pavement. General antecedents for distance were “Observation missed” and “Performance variability”. Finally, “Direction” was chosen as a phenotype in the third analysis, and “Performance variability” was used to explain why the car ended up in the opposite lane. Se Figures 9, 10 and 11 for further details.

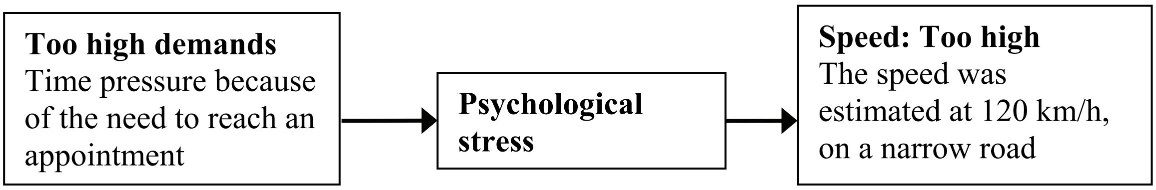

Figure 9. Results of DREAM analysis of accident 8 using "Speed" as phenotype.

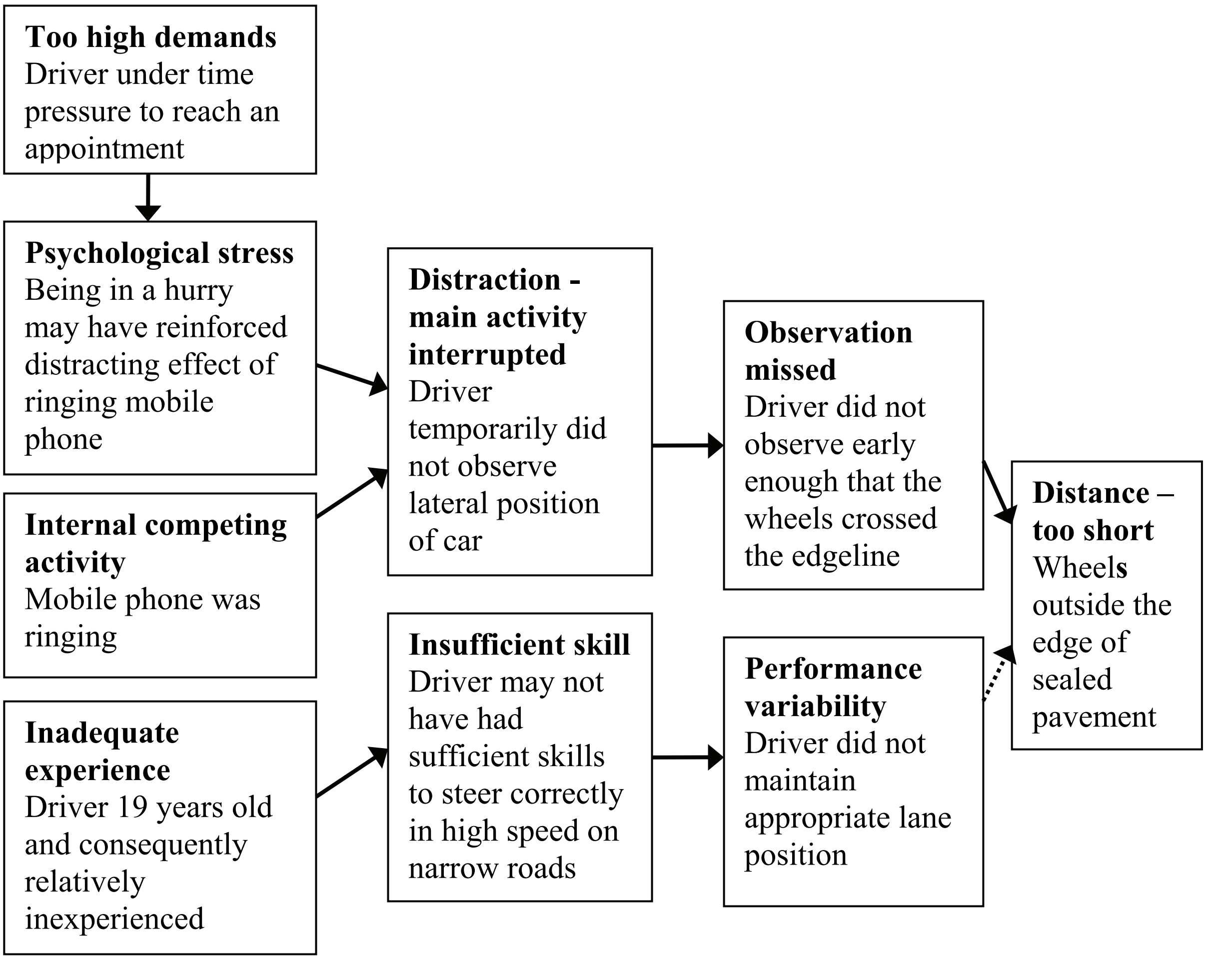

Figure 10. Results of DREAM analysis of accident 8 using "Distance" as phenotype

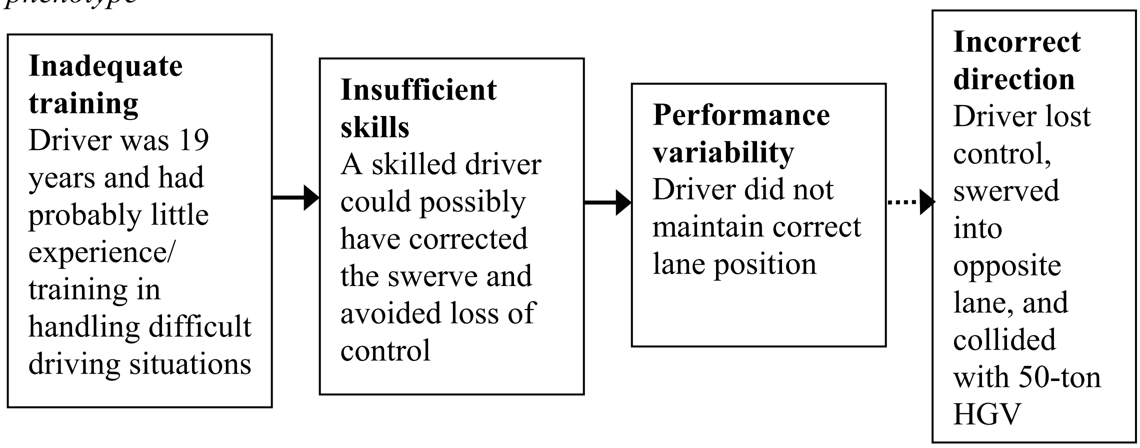

Figure 11. Results of DREAM analysis of accident 8 using "Direction" as phenotype.

In Figure 12 the results of the three separate analyses have been combined into one diagram, together with a timeline showing the temporal relationship between the three phenotypes that were analysed. This way of presenting the results seems to give a much better overview of the causal relationships than presenting the three analyses separately.

8.3 Methodological considerations

An additional factor that could have been considered in this analysis, is the road condition. The absence of a hard shoulder outside the edgeline may have contributed to the loss of control. Assuming, however, that the DREAM analysis in a complete investigation would be supplemented by a barrier analysis, it can be argued that the absence of a road shoulder should rather be included in the barrier analysis.

Concerning the data collected by the accident investigation team, it is mentioned in the report from this event that the use of a mobile phone may have distracted the driver, but the source of this information is not specified, and therefore it is not possible to judge the importance of this factor. This would counsel that observations that are used in formulating hypothesis about contributing factors should be specified in accident investigation reports.

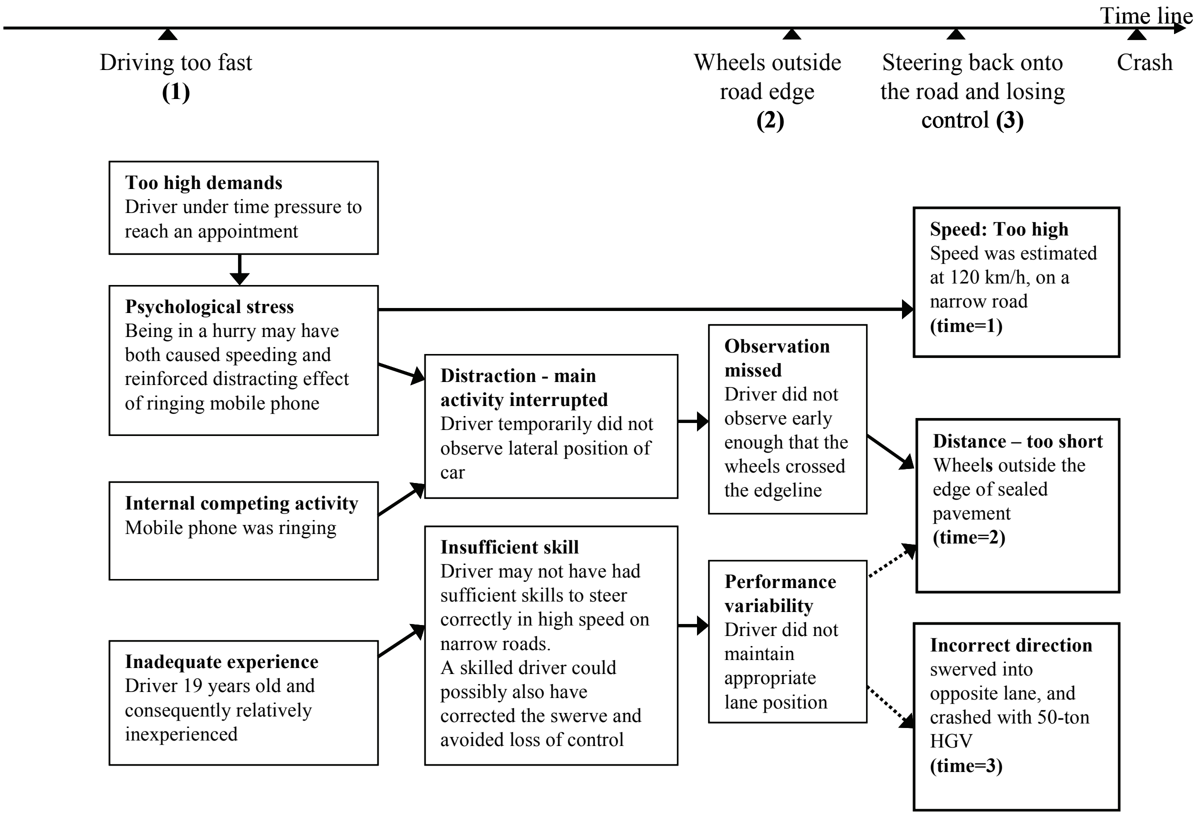

Figure 12. Combined analyses of three phenotypes, occurring at different points in time.

9. Car driving off the road and falling onto a cycle path

9.1 Short description of the accident

On an early winter morning, a passenger car with 2 persons was driving in a right-hand curve approaching a roundabout. In the curve, the car continued almost straight ahead, crossed the opposite lane and hit the guardrail. The car then rotated over to the left, was lifted off the ground and landed upside down on a bicycle path 3.5 metres below road level. Both the driver and the passenger were young males. The driver was killed in the accident, while the passenger was slightly injured. The driver had held a license for 1 to 2 years (exact figure was not given). Several incidents of drug use by the driver had been registered by the police, and he was influence by alcohol (BAC 0.10 %) and cannabis when the accident occurred. The driver did not wear a seatbelt, whereas the passenger did. It was raining at the time of the accident, a fact which might have affected the tyre grip as well as the visibility. The accident was reported by a phone call from the passenger.

9.2 Results of DREAM analysis

"Wrong direction" was chosen as phenotype as the driver drove straight ahead in a right-hand curve and out of the road on the left side. It is likely that the driver was not sufficiently focused and thus that he did not observe the right-hand curve in due time. He was influenced by alcohol and cannabis and he was probably tired. See figure 13 for further details. He may also have fallen asleep, and in that case the reduced visibility would not be a relevant causal factor. But in this case we have included this as an alternative explanation.

9.3 Methodological considerations

This accident could alternatively (or additionally) have been analysed with speed as the phenotype.

The guardrail was considered by the accident investigation team to be inadequately designed, and therefore it could be argued that the insufficient barrier should be included in the analysis as a genotype. On the other hand, a different guardrail would not have influenced the loss of control in the first place, but would most likely have influenced the consequences. Since the DREAM analysis is supposed to cover the event up to the point of loss of control, it does therefore not seem correct to include the design of the guardrail in the DREAM analysis. However, it is clearly relevant in the wider accident investigation, including also a barrier analysis.

Heavy rain may have contributed to the accident, by reducing the visibility (and possibly also by aquaplaning?) but is not mentioned as a possible contributing factor in the report from the investigation team. We have, however, chosen to include it in the DREAM analysis.

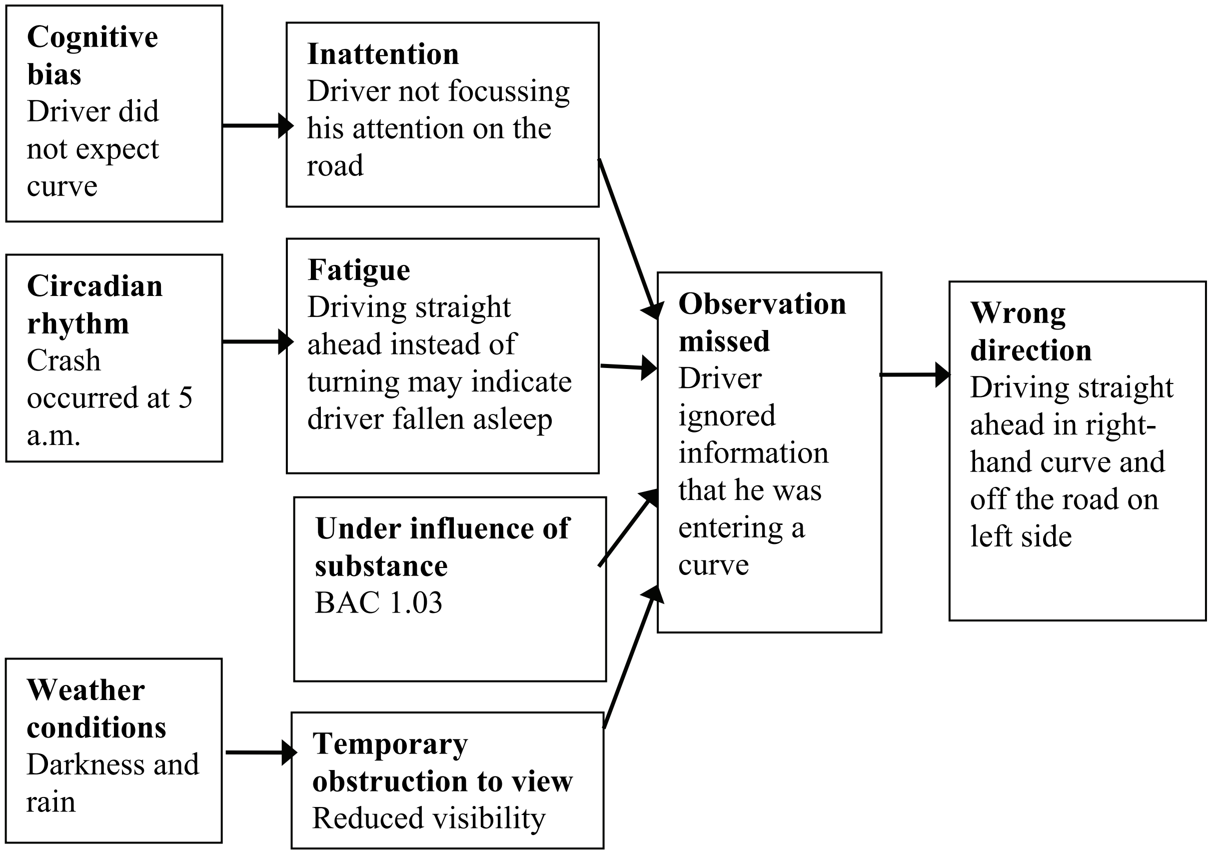

Figure 13. DREAM analysis of accident 9.

10. Car running off to the right on a straight road section

10.1 Short description of the accident

An early summer morning a single vehicle with a young male driver gradually drove off a straight road and ended in a one metre deep ditch by the road. The driver was thrown out through the side window after the car hit the right side of the edge of the ditch. The driver was brought to hospital, where he died. Road, car and weather conditions were good, and the driver was familiar with the road. He got his driver licence 6 months prior to the accident. There were no witnesses to the accident.

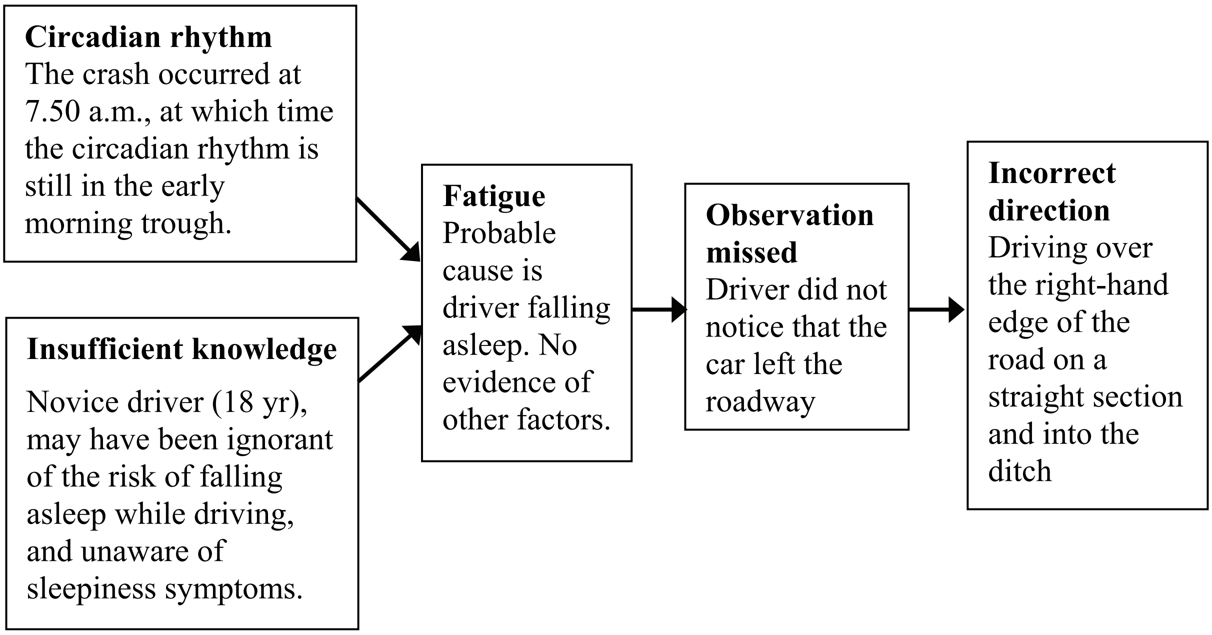

Figure 14. DREAM analysis of accident 10.

10.2 Results of DREAM analysis

"Incorrect direction" was chosen as phenotype, as the driver drove over the right-hand edge of the road on a straight section. Probably the driver did not notice that the car left the roadway, and thus "Observation missed" was selected as a general antecedent of wrong direction. It was early in the morning and the driver may have fallen asleep at the wheel. There was no evidence of other factors influencing the incident. The driver did not wear a seatbelt. See figure 14 for details.

10.3 Methodological considerations

Here it would seem appropriate to supplement the DREAM analysis with an analysis of the absence of barriers. The fact that the driver was killed because he was ejected from the vehicle obviously points to the causal relationship between not wearing a seatbelt and the fatal outcome of the accident.

11. Car hitting pedestrian in pedestrian crossing

11.1 Short description of the accident

A night in early spring, a passenger car drove up a hill towards an intersection. The driver was a female about 40 years old. In a pedestrian crossing on the far side of the intersection, two elderly pedestrians were crossing the street, coming from the driver's left-hand side. The car hit the first pedestrian, who subsequently died from severe head injuries. The headlights from an oncoming car might have blinded the driver. It also rained heavily at the time of the accident, and the view was therefore limited. The driver told the police that she was not able to see the pedestrian before the collision. She also stated that she drove slowly and carefully. A simulation estimated the speed to have been 28-38 km/h at the time of the collision.

11.2 Results of DREAM analysis
"Distance" was chosen as phenotype to describe the cause of the accident. Moreover, "Observation missed" (did not see pedestrian) and "Information failure" (difficult to see pedestrian crossing signs) were chosen as general antecedents of distance. The "Observation missed" is likely to be explained by both permanent and temporary obstructions to view, glare from oncoming car, and "Inattention" (not looking for pedestrians). For further details, see Figure 15.

11.3 Methodological considerations
Regarding this accident it could be discussed whether "No action" (not braking for pedestrians) would be a more appropriate phenotype than "Too short distance". In our judgement either would be relevant, and the results in terms of causal factors would probably have been very similar.

Concerning the data source, the report from the accident investigation team contained no information regarding the driver's licensure or driving experience. This could have been relevant information for the analysis.

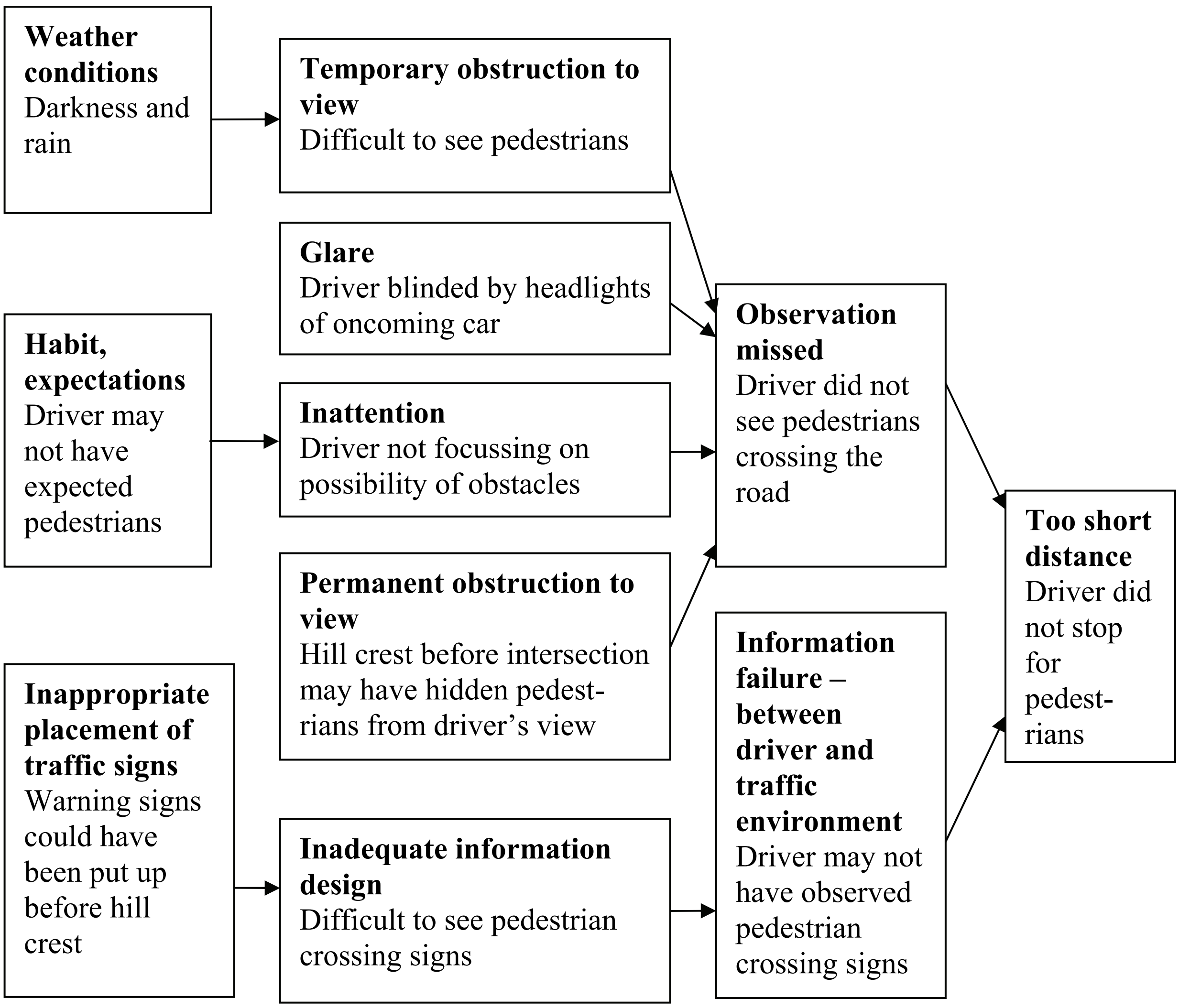

Figure 15. DREAM analyis of accident 11.

12. Car with two young females crashed with oncoming car

12.1 Short description of the accident

A summer afternoon, a car (Car A; young female driver) swerved into the opposite lane on an undivided two-lane road and crashed with an oncoming car (Car B). The driver of Car A was seriously injured, and the passenger (female aged 19) was killed. The driver of Car B was slightly injured. In car A only the driver wore a seatbelt. Road and weather conditions were good, and it was a straight road section. The sun was low and the glare could possibly have blinded the driver of Car A. The windscreen was dusty on the outside (a fact that might have been important if blinding did actually happen). The driver of Car B stated that Car A headed against his lane and that he tried to avoid hitting the car by driving to the left. However, Car B suddenly drove back into its correct lane, an action that made the crash unavoidable.

12.2 Results of DREAM analysis

"Incorrect direction" was chosen as phenotype to describe the accident. "Information failure" (due to the glaring sun and equipment failure) was a plausible general antecedent of the wrong direction. Moreover, a possible indirect antecedent of the wrong direction is "Performance variability" (insufficient competence and too high demands). See Figure 16 for details.

12.3. Methodological considerations

"Communication failure" could have been added as an antecedent to wrong direction, because there were indications that the driver of the oncoming car tried to avoid the collision by steering towards the left. If the driver in the other car had noticed this, it might possibly have influenced her behaviour.

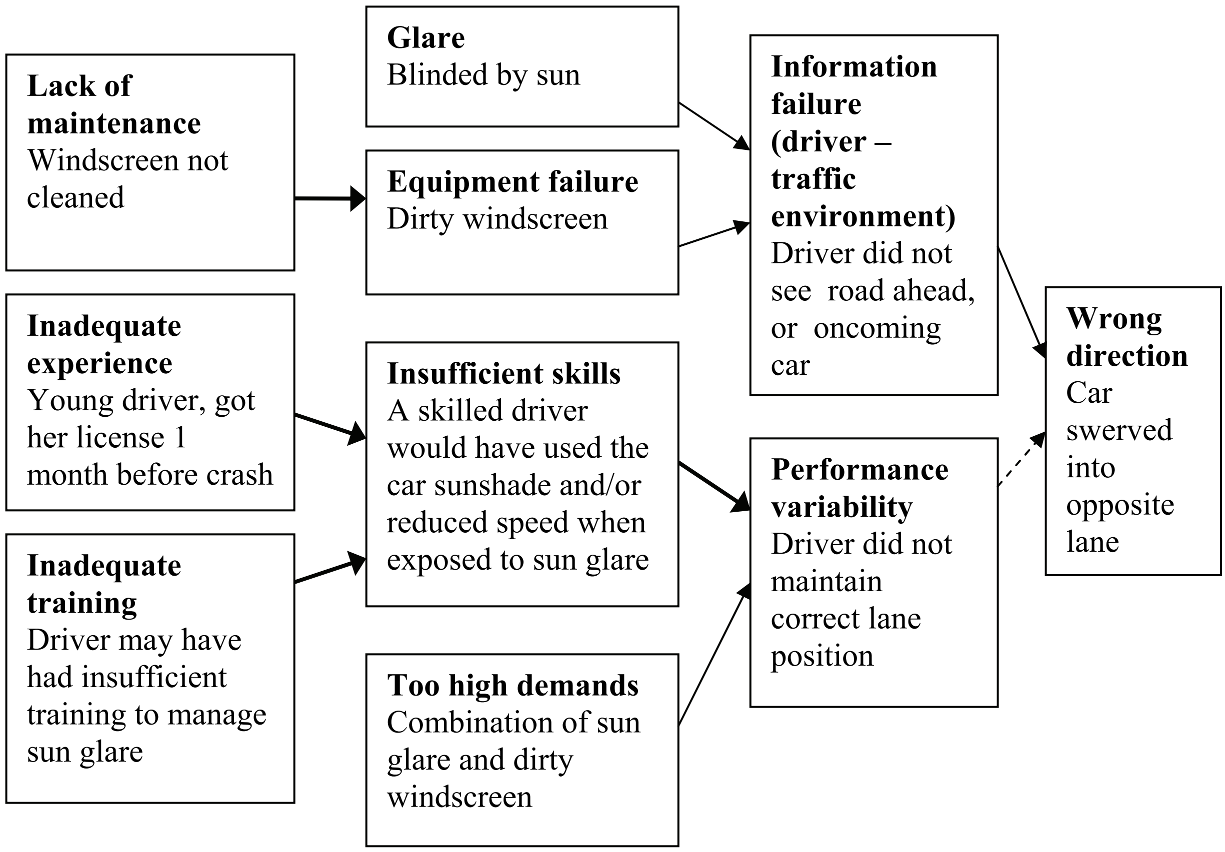

Figure 16. DREAM analysis of accident 12.

13. Delivery van backing and hitting pedestrian (HS15)

13.1 Short description of the accident

On a spring afternoon, the male driver of a delivery van stopped outside a grocery store and started to reverse (because he had driven a short distance past the entrance). The van then hit an 85-year-old female pedestrian who was crossing the road behind the car; she was killed in the crash. The design of the delivery van made it difficult to see objects behind the vehicle, i.e., there was a large blind zone behind the van. In addition, there were no road markings indicating a pedestrian crossing. According to the accident report, it is likely that the driver was backing at a relatively high speed. Road and weather conditions were good.

13.2 Results of DREAM analysis

“Distance (too short)” was chosen as phenotype, and “Observation missed” (due to permanent obstruction of view, psychological stress and inattention) and “Inadequate plan” (error in mental model) are likely general antecedents of “Too short distance”. See further details in Figure 17.

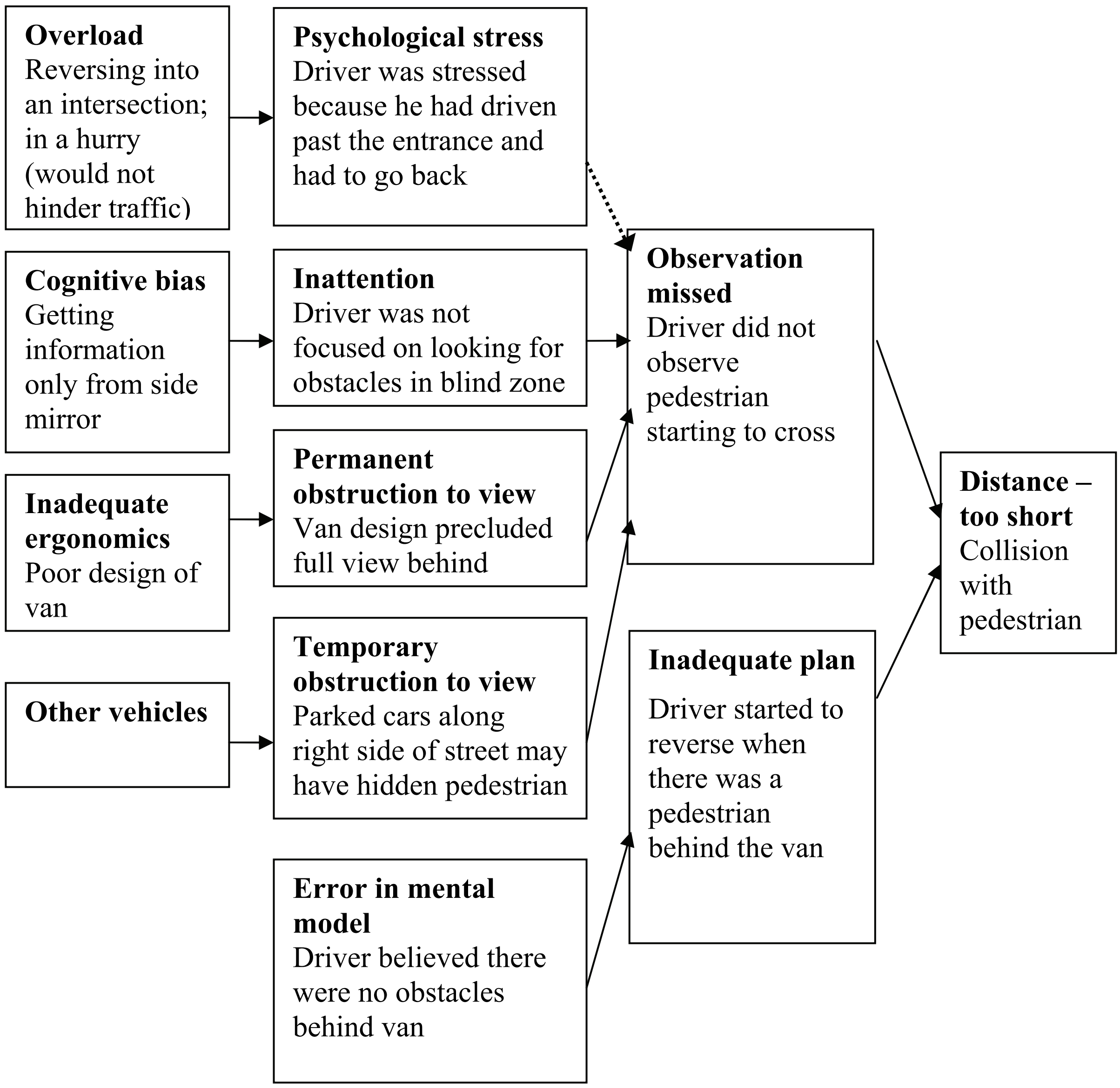

Figure 17. DREAM analysis of accident 13.

14. Car driver losing control in curve on slippery road and crashing with oncoming car

14.1 Short description of the accident

On a night in spring, a middle-aged man was driving a car (car A) on its way to reach a ferry. There were three passengers, a middle-aged woman in the front, and a younger woman and a girl in the backseat. All passengers wore seatbelts. In a left-hand curve the car got into a skid and subsequently swerved into the opposite lane, where it collided with a delivery van coming from the ferry (Car B). The driver and the front seat passenger in Car A were killed. The two backseat passengers were seriously injured. The driver of Car B was slightly injured. Car A may have been driving at high speed to reach the ferry. The road was covered with snow and ice, and the friction coefficient was most likely below 0.20. The road had no road lights and no signs indicating a sharp curve.

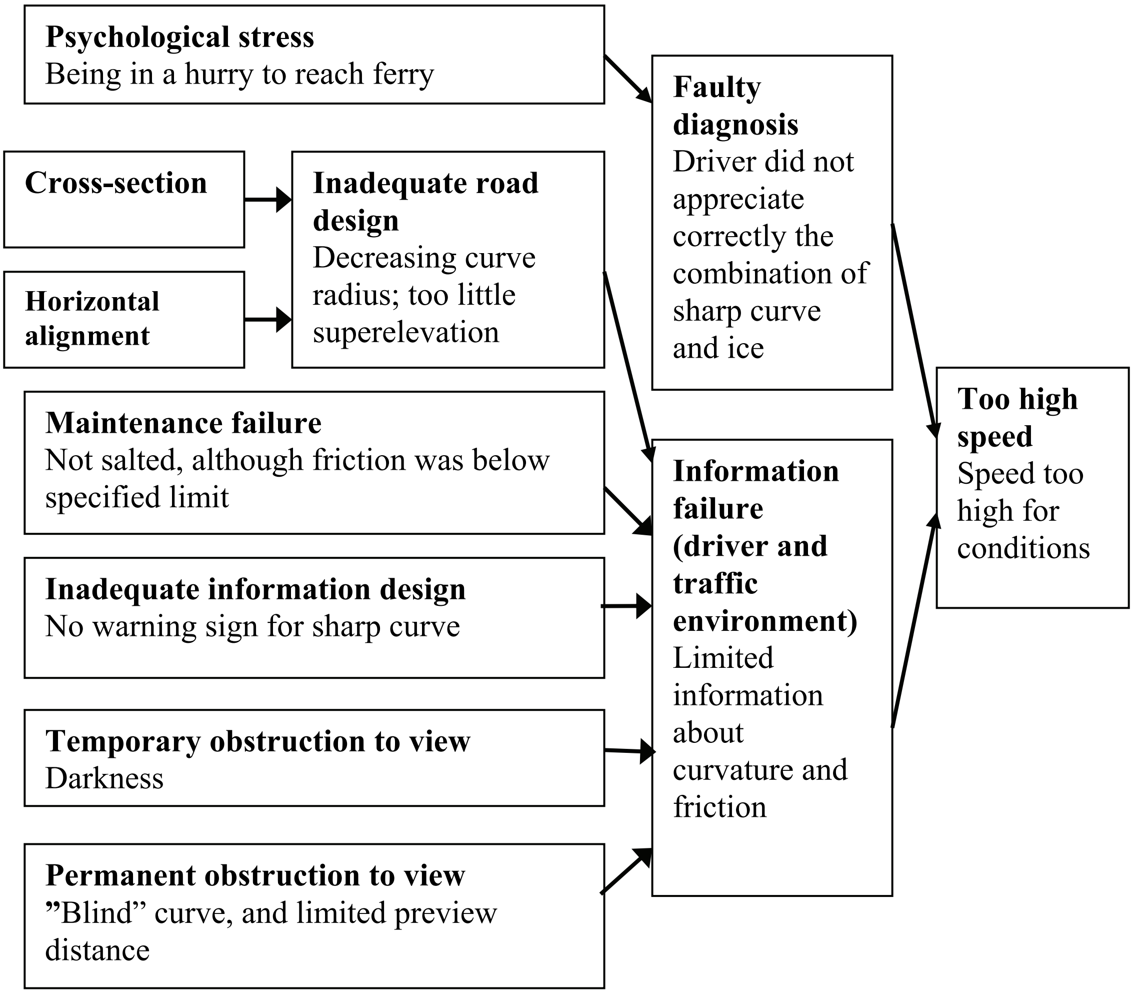

Figure 18. DREAM analysis of accident 14.

14.2 Results of DREAM analysis

"Too high speed" was chosen as phenotype. "Faulty diagnosis" (unexpected ice in curve, and curve possibly sharper than expected) and "Information failure" (obstruction of view, darkness) are likely to be the general antecedents of speed. See Figure 18 for further details.

14.3 Methodological considerations

In this case it would be relevant to include an analysis for the phenotype "Wrong direction" in addition to the one for "Too high speed", since the car got a skid and came over in the opposite lane.

15. Light motorcycle rider hit by garbage truck during passing

15.1 Short description of the accident

On a springtime afternoon a young boy asked some friends "Do you think I can overtake and pass that garbage truck?" The garbage truck was then coming against them, and the boy had a light motorcycle. The boy followed the garbage truck when it had passed, and subsequently rode up on the left side of the truck. There was a fence on the left side of the truck (short distance between fence and truck). According to the friends, who were watching the entire incident, the motorcycle first hit the fence and then fell under the truck. The rider was killed in the crash.

15.2 Results of DREAM analysis

The DREAM analysis was carried out for the truck driver. "Too short distance" was chosen as phenotype. "Observation missed" (driver did not observe MC approaching), and "Communication failure" (driver did not notice overtaking manoeuvre) were identified as general antecedents of "Too short distance". Both the "Observation missed" and the "Communication failure" could probably be partly explained by "Inattention" (driver not focussed on other traffic), and "Distraction" (driver talking in mobile phone). An indirect antecedent was "Performance variability" (variable lateral position). See Figure 19.

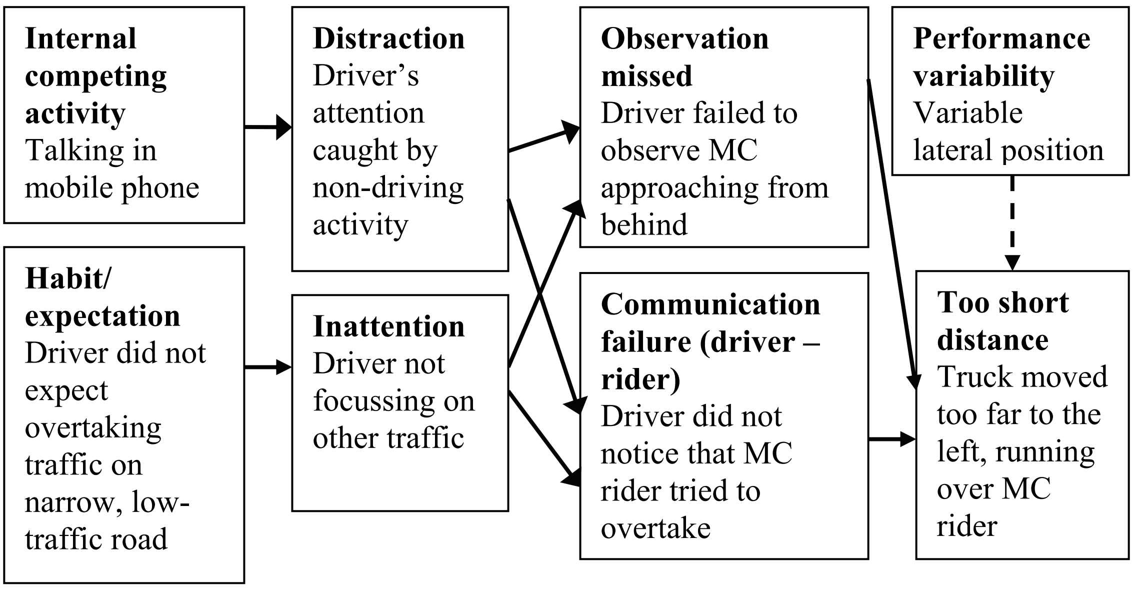

Figure 19. DREAM analysis of accident 15.

5 Summary of analyses

The DREAM analyses of 14 of the 15 accidents are summarized in Figure 20 (the accident involving only a motorcyclist was excluded). All factors occurring in two or more of the accidents are shown in the diagram. In addition, the factors that occur in only one or two of the accidents are listed.

First, it is notable that the most frequent phenotype is “Wrong direction”, reflecting partly that a significant number of accidents were running-off-the-road crashes. Since the accidents were primarily selected to include young drivers, this is not surprising, since novice drivers seem to be over-represented in such crashes.

The most frequent antecedents to the phenotypes are “Observation missed”, “Information failure”, and “Faulty diagnosis”. In addition, “Performance variability” is rather frequent, which was mainly considered to be the result of insufficient skills, and in turn inadequate training and/or experience. This is most likely also a reflection of the fact that our sample mainly included young drivers.

Other frequent “second-order” genotypes were inattention, poor road design or maintenance, permanent or temporary obstruction to view, habit or expectation, influence by substance, and psychological stress.

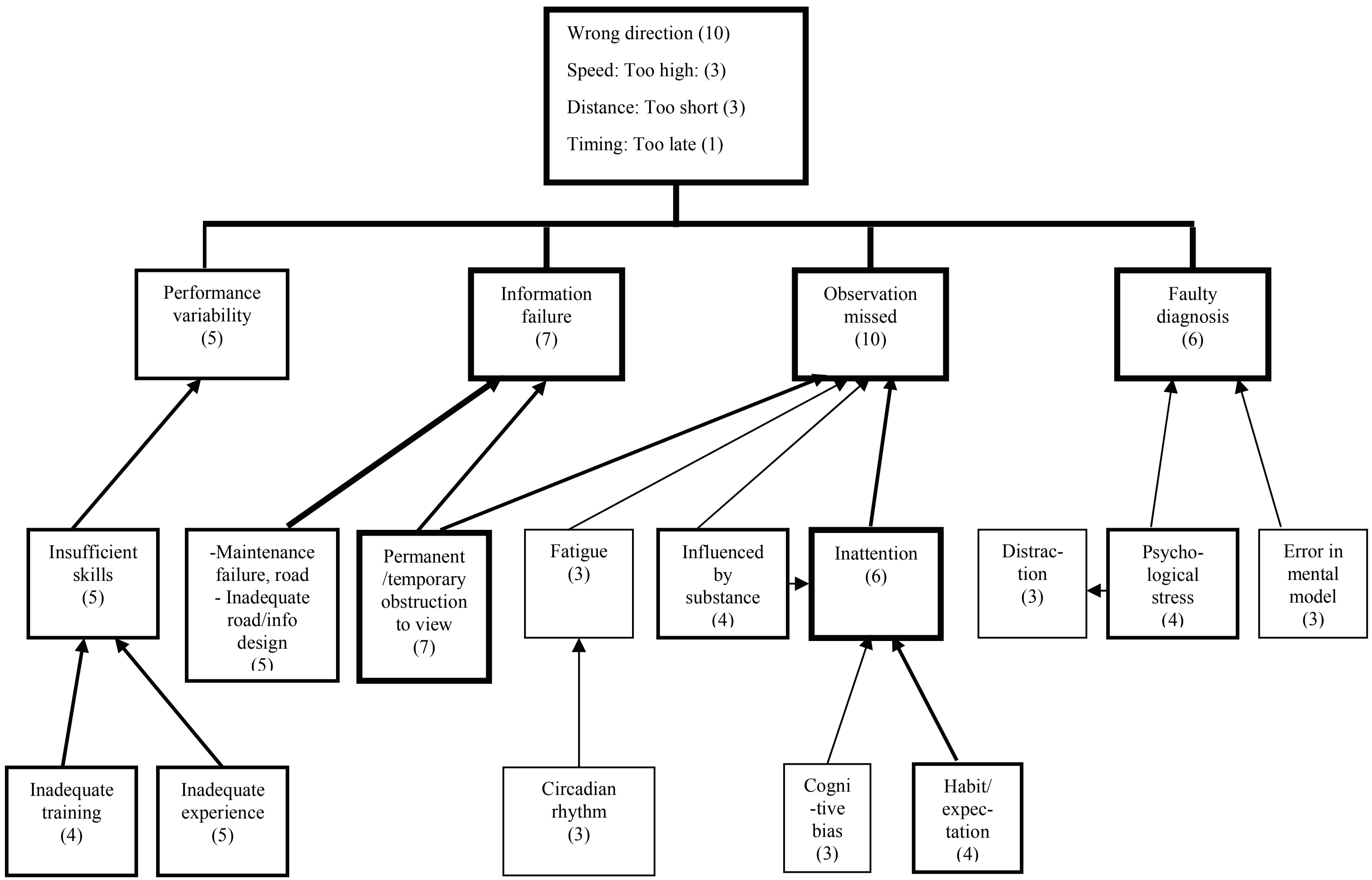

Figure 20. Summary of causal factors based on DREAM analyses of 14 road accidents involving car drivers. Different arrow/line types indicate frequency of occurrence of connections: Narrow = 2-3, Medium = 4-5, Wide = 6+. Source: TØI report 912/2007.

Additional factors, appearing in 1 or 2 accidents:

- Poor weather – temporary obstruction of view
- Other vehicles – temporary obstruction of view
- Darkness – temporary obstruction of view
- Equipment failure road – wrong direction
- False observation – wrong direction
- Insufficient knowledge – fatigue
- Inappropriate placement of information – inofrmation design
- Vegetation – permanent obstruction to view
- Poor car design – permanent obstruction to view
- Inadequate quality control - vehicle maintentance
- Inadequate quality control, road – equipment failure, road
- Cross-section – inadequate road design
- Horizontal alignment – inadequate road design
- New situation – faulty diagnosis
- Communication failure driver-rider - too short distance
  - Decision error – too high speed
  - Overload – psychological stress
  - Maintenance failure, vehicle
  - Equipment failure, vehicle
  - Glare
  - Inadequate plan
  - False observation
  - Too high demands
  - Internal competing activity

6 Some methodological considerations based on the case studies

The main purpose of our work was to assess the usefulness of DREAM for analysing road accidents. Additional and related purposes were to get new knowledge about road accident causation as well as to assess the quality of data collected by the NPRA accident investigation teams. In this document, however, the focus is on methodological aspects of DREAM, and we will summarise the methodological issues and questions that have arisen during our analyses. We will also present some suggestions for possible improvements, as a basis for further discussions with other users of the CREAM-based approach to accident analysis. In this methodological chapter some references will be made to specific analyses to exemplify certain issues.

6.1 The choice of phenotype(s)

In some accidents there may be more than one action that qualifies as a phenotype. This problem is discussed in the DREAM manual, and it is recommended to choose the phenotype that the investigator considers to give the best explanation of the incident.

This seems, however, to be an oversimplification of this methodological problem. There may be cases where one phenotype seems to be causally related to another phenotype. For example, when a driver gets a skid and drives off the road or into the opposite lane, “Wrong direction” seems to be the most appropriate phenotype (for example, accidents no. 8 and 14 in this document). However, one reason for the skid may be too high speed, so it might be appropriate to analyse the phenotype “Too high speed” as well. This problem could possibly be solved by allowing analysis of more than one phenotype for the same driver in an accident, and also make links between the two analyses. In accidents 4 and 8 we have analysed two and three different phenotypes, respectively.

6.2 Absence of barriers as causative factors?

In some accidents it is rather obvious that various measures or *barriers* could have prevented the accident or its serious outcome (e.g. accidents 9 and 10). Would it be possible to use the CREAM-based approach to analyse why a known barrier was not implemented or used, in other words, to consider the absence of the barrier as an error? Examples are: non-use of seatbelts, lack of guardrails at dangerous sites, lack of warning signs.

Our conclusion, as suggested for several of the cases analysed, is that the most appropriate approach would be to combine the DREAM analysis of the driver actions with a different approach to analysing barriers, such as e.g. the AEB method (Svenson, 1991).

6.3 DREAM/CREAM taxonomy contains few organisational factors

The CREAM and DREAM methods seem to have little focus on the “O” part of the “M-T-O” triangle. Would it be useful to extend the taxonomy by including more “O” categories? For example, in accident 5, when the analysis shows that poor road maintenance may have contributed to the accident, it would have been interesting to analyse the organisational factors behind this failure.

In general, it would be relevant to link back to organisational factors from both road design and vehicle design categories.

Separate analyses of apparent organisational failures may also be relevant in some accidents, in addition to the analysis of the driver actions. For example, in accident 6 the failure to get assistance by ambulance helicopter may have contributed to the fatal outcome. CREAM could possibly be used to analyse such failures, but as a different analysis, clearly separate from that of the primary event.

6.4 Extending the taxonomy

The analyses often reveal the need for additional categories. In this project some modifications of the taxonomy have been made. The possibility of extending the taxonomy on the basis of practical experience from accident analyses, is an important aspect of the CREAM-based methods, giving them the property of “learning” tools. An important requirement when modifying the taxonomy, however, is that all links involving the added categories have to be updated, so that the basic rules for linking between categories are still applicable.

6.5 Driver background factors

In many cases it seems relevant to analyse background factors of drivers in order to understand the variations in cognitive reliability. For example, factors like “Psychological stress” or “Fatigue” could possibly be traced back to individual as well as organisational background factors (amount of sleep, sleep habits, conflicts, working conditions, violations of hours-of-service regulations, etc.). It may possibly be an advantage to include more such factors in the taxonomy. In this study this was not done, because the background information provided in the accident reports were generally scarce. If the method is to be used for primary data collection, it might be useful to include more categories for background information.

6.6 Most suitable for complex incidents with good data?

In some accidents the cause is rather obvious, e.g. when a driver runs off the road after falling asleep. Furthermore, like any other investigation method, DREAM requires valid and detailed information about the possible contributing factors for a good analysis. For simple accidents or accidents with poor data availability it can be questioned whether DREAM can add much to the knowledge obtained through an unstructured investigation based on general domain knowledge. A pertinent question is therefore whether DREAM should be applied only to accidents that seem to have a rather complex causation, and also where good data are available. On the other hand, when the event is rather simple, applying DREAM is correspondingly easy, and therefore requires relatively little additional effort compared to an unstructured investigation.

6.7 Uncertainty of causal factors

A possible objection against causal analysis based on single incidents, which is also applicable to DREAM, is that there will be uncertainty associated with some of the factors that are identified, and that the results of the analysis thus may give the impression that all factors are equally important. A possible way to partly overcome this objection, is to include a qualification of each factor in terms of a simple probability statement, e.g. differentiating between "possible", "probable", and "certain" factors. An important tool to aid in making such judgements is the specification of "Common Performance Conditions" that is carried out in advance of the causal analysis.

6.8 High competence among analysts may be necessary

In some cases it may be difficult to choose among the available antecedents for a given phenotype or genotype, and to decide which factor is most "correct". For example, the factors "Information failure", "False observation", "Faulty diagnosis", "Observation missed", and "Inattention" all refer to cognitive factors related to information processing, and it may be difficult to choose between them, especially for an analyst that is not very familiar with the cognitive model(s) underlying the concepts. Thus, a good understanding of the underlying theoretical model(s) and the cognitive concepts used in the taxonomy seems to be a necessary requirement for a consistent and effective use of CREAM-based methods of analysis. On the other hand, clear definitions of the concepts, supported by good examples, should make it possible to use the methods without very comprehensive training beyond the basic knowledge of the domain of the particular analysis.

7 Comparing DREAM results to analyses by accident investigation teams

7.1 Current analysis using STEP and WBA

The NPRA accident investigation teams use the STEP method to identify "safety problems". STEP (Sequentially Timed Events Plotting) consists of plotting a diagram of important events leading up to an accident, and to identify connections between the events by arrows. The diagram has several time lines, one for each "actor" (person or object) involved. A safety problem is defined as any connection in the STEP diagram which could reasonably have been broken by some countermeasure or barrier, or which appears deviant or unexpected.

The identification of safety problems in STEP is somewhat similar to identifying phenotypes in CREAM/DREAM. The STEP method does, however, not go behind the safety problems in order to identify their causes, as the CREAM does.

However, in order to find explanatory factors behind the safety problems identified by STEP, the investigation teams also use an approach based on the so-called WBA ("Why Because Analysis") developed by Ladkin and Loer (1998). This method consists mainly in asking why the safety problem appeared, and to list all possible ad hoc factors that may have contributed.

Thus, the combination of STEP and WBA can be considered to achieve the same purpose as CREAM, namely to identify the critical events and find their causes.

7.2 Pros and cons of DREAM vs STEP/WBA

One important advantage of CREAM/DREAM compared to STEP/WBA for a causal analysis is the use of a cognitive model as well as a classification system, which makes it possible to aggregate results from several analyses, and to make comparisons across domains regarding causal factors. This is very difficult by using STEP/WBA due to the ad hoc nature of the causal factors (lack of a taxonomy).

The STEP is however useful for providing an overview of the development of an accident or incident, as a basis for a deeper causal analysis. One asset of STEP is that it covers all phases of the event, including the crash and post-crash phases of an accident. The CREAM-based methods only cover the time period up to loss of control.

Neither approach includes a thorough model for analysing barriers. Thus, neither approach is sufficient for a complete analysis of all factors that are relevant for a causal explanation of accidents and incidents from the perspective of finding adequate countermeasures.

In Table 1 we have compared the results of our DREAM analyses with the results as they appear in the reports from the accident investigation teams, mostly based on STEP and WBA.

The main difference between the STEP/WBA analyses of the accident investigation teams on one hand, and the subsequent DREAM analyses on the other, as given in Table 1, is that the DREAM analyses uses predefined categories, whereas the causal factors in the STEP/WBA are *ad hoc* factors, partly specific to each particular accident. From this comparison it cannot be concluded which method yields the most relevant causal factors. To a large extent the factors resulting from the STEP/WBA seem to be encompassed by the more generic factors of the DREAM analysis.

The use of predefined categories in DREAM has two obvious advantages compared to the ad hoc allocation of categories:

1) Possibility of aggregating data from several accidents, as was shown in Figure 20. Such data aggregation can not easily be made from the STEP or WBA results.
2) The systematic application of the DREAM analysis reveals which data should be collected from the accident in order to get a most comprehensive causal analysis. Thus, the method of analysis guides the data collection. The current data collection is primarily guided by checklists, which however are not sufficient for securing a detailed collection of data relevant to understanding the pre-crash phase of accidents.

On the other hand, the STEP/WBA approach identifies very specific factors related to each particular accident. The value of such detailed information can however be questioned, since the effects of countermeasures based on specific causes are very uncertain, as long as no information about the prevalence of the causal factors is available. In other words, much of the ad hoc knowledge from accident investigations cannot be generalised to accidents in general.

It should also be noted that the WBA as used by the NPRA accident investigation teams is a simplified approach compared to the “real” WBA as described by Ladkin and Loer (1998), which contains a rather complex formal system for causal analysis.

Table 1: Comparison of results between DREAM and STEP/WBA.(Only precrash factors analysed by STEP/WBA are included) Source: TØI report 912/2007

		Results of DREAM analysis			Results of STEP/WBA analysis		
	Accident description	Pheno-type(s)	Primary causal factors*	Antecedents*	Safety problems	Causal factors	Comments
1	Car running off road in right-hand curve	Incorrect direction	- Information failure - False observation - Faulty diagnosis - Observation missed - Inattention	- Inadequate road design - Inadequate quality control (road) - Wrong identification - Under influence of substances - Inadequate plan - Distraction - Psychological stress - Fatigue	1) Coming from a party, driving under the influence and without seatbelt 2) Looses control of car 3) Driving off the road on left-hand side 4) Car hitting rocks	Re 1: mental instability; heartsickness; low apprehension probability; low priority by police; not prevented by others from driving when drunk; others did not care, did not notice or did not dare to stop him; possibly to drive when drunk; no ignition interlock. Re 2: Inappropriate speed; carelessness; underestimating curvature; inattention; fatigue; influenced by alcohol; darkness; no illumination Re 3: No guardrail; road not prioritized by authorities.	
2	Motorcyclist running off road in right-hand curve	Incorrect direction	- Performance variability - Faulty diagnosis - Observation missed - Inattention - Information failure	- Insufficient skills - Inadequate experience - Inadequate training - Error in mental model - Wrong identification - Distraction - Fatigue (circadian rhythm) - Inadequate road design - Inadequate quality control	1) Riding home from party late at night 2) Losing control of MC in curve	Re 1: Fatigue; circadian rhythm; alternative transport too expensive or unavailable. Re 2: Lack of experience; high speed; slippery road; tyre dimension differed between front and rear wheel; inattention; darkness; low temperature (insufficient clothing); underestimating curvature.	

* Generic factors. In the analysis each factor is further specified explained with reference to the accident situation (see diagrams for each accident, Figures 1 through 19).

	Accident description	Results of DREAM analysis			Results of STEP/WBA analysis		Comments
		Pheno-type(s)	Primary causal factors*	Antecedents*	Safety problems	Causal factors	
3	Car running off road on left-hand side of straight road section	- Incorrect direction	- Performance variability - Faulty diagnosis - Inattention -Observation missed	- Insufficient skills - Inadequate experience - Inadequate training - Error in mental model - Cognitive bias	1) Speeding 2) Skidding 3) Driving off the road (across opposite lane)	Re 1: Low apprehension risk; influenced by passenger; time pressure(?); showing off; sensation seeking; testing car; inexperienced; no barriers against speeding. Re 2: Steering error; slippery road; darkness; inattention; incorrect road superelevation. Re 3: Failure to correct skid; inadequate driving skills.	
4	Car running off road in left-hand curve	- Incorrect direction - Too high speed	- Performance variability - Inattention - Faulty diagnosis - Decision error	- Insufficient skills - Inadequate experience - Inadequate training - Under influence of substance - Error in mental model	1) Driving under influence of alcohol 2) Speeding 3) Not wearing seatbelt 4) Car crashing into deep roadside ditch	Re 1 or 2: No alternative transport; disrespect of laws and regulations; no risk of apprehension; show off to girlfriend Re 3: Common in certain subcultures Re 4: Dangerous road environment	Insufficient skills/experience not listed as causal factor in accident report.
5	Car driver losing control on snowy road and crashing with two other vehicles	- Incorrect direction	- Performance variability - Faulty diagnosis - Information failure - Equipment failure, road - Equipment failure, vehicle	- Insufficient skills - Inadequate experience - Inadequate training - Error in mental model - New situation - Maintenance failure – road condition - Maintenance failure – vehicle condition - Inadequate quality control	1) Skidding 2) Fails to correct skid	Re 1: Worn tyres; slippery road; rutted road; poor car maintenance; poor pavement maintenance; delayed ice and snow removal. Re 2: Insufficient skill Re 3: Lack of knowledge; poor risk awareness	Good correspondence between the two approaches

		Results of DREAM analysis			Results of STEP/WBA analysis		
	Accident description	Pheno-type(s)	Primary causal factors*	Antecedents*	Safety problems	Causal factors	Comments
6	Car hitting deer, which was thrown into oncoming car	- Late action	- Observation missed - Information failure	- Inattention - Habit/expectation - Permanent obstruction to view - Vegetation	1) Animal crossing road	Re 1: View ahead obstructed by vegetation	STEP/WBA has little focus on driver factors
7	Head-on collision between two cars on hill crest	- Incorrect direction	- Faulty diagnosis - Observation missed - Information failure	- Influenced by substance - Permanent obstruction to view			No STEP/WBA by investigation team
8	Driver losing control and colliding with heavy vehicle	- Too high speed - Too short distance - Incorrect direction	- Psychological stress - Observation missed - Performance variability	- Distraction - Too high demands - Internal competing activity - Insufficient skill - Inadequate experience	1) Speeding 2) Steering to the right 3) Steering too abruptly onto road 4) Car gets a skid	Re 1: Time pressure Re 2: Inattention; lack of concentration; ringing mobile phone Re 4: Poor pavement maintenance	
9	Car driving off the road in right-hand curve and falling onto underpass	- Incorrect direction	-Observation missed	- Inattention - Cognitive bias - Fatigue/circadian rhythm - Under influence of substance	1) Driver under influence of substance 2) Driving without seatbelt 3) Worn tyres 4) Missing guardrail	No further causal factors identified.	No WBA.

		Results of DREAM analysis			Results of STEP/WBA analysis		
	Accident description	Pheno-type(s)	Primary causal factors*	Antecedents*	Safety problems	Causal factors	Comments
10	Car running off to the right on straight road section	- Incorrect direction	- Observation missed	- Fatigue / circadian rhythm - Insufficient knowledge	1) Not wearing seatbelt 2) Car hits side of ditch	Re 2: Sleep, illness or inattention	
11	Car hitting pedestrian in pedestrian crossing	- Too short distance	- Observation missed - Inattention - Information failure	- Temporary obstruction to view - Weather conditions - Glare - Permanent obstruction to view - Habit, expectations - Inadequate information design - Inappropriate placement of traffic signs	1) Glare from oncoming car 2) Inattention 3) Hitting pedestrian	Pedestrians in dark clothes without reflectors; poor illumination; inadequate location of pedestrian crossing and placement of sign; inattentive pedestrian.	
12	Frontal crash between two cars on straight section	- Wrong direction	- Information failure - Communication failure? - Performance variability	- Glare - Equipment failure - Lack of maintenance - Insufficient skills - Inadequate experience - Inadequate training - Too high demands	1) Not wearing seatbelt 2) Inattention? 3) Wrong avoidance manoeuvre (oncoming driver)	Glare is mentioned as a possible cause. Otherwise no possible causes of safety problems are listed.	

		Results of DREAM analysis			Results of STEP/WBA analysis		
	Accident description	Pheno-type(s)	Primary causal factors*	Antecedents*	Safety problems	Causal factors	Comments
13	Delivery van hitting pedestrian during reversing	- Too short distance	- Observation missed - Inadequate plan	- Psychological stress - Overload - Inattention - Cognitive bias - Permanent obstruction to view - Inadequate ergonomics - Temporary obstruction to view - Other vehicles - Error in mental model	1) Driver decides to back 2) Looks only in left-hand rear mirror while reversing 3) Reversing with high speed 4) Pedestrian crosses behind parked cars	Re 1: No hazards and no traffic as perceived by driver. Re 2: Focussing only on possibility of car traffic; does not consider possibility of pedestrian. Re 3: Time pressure to complete reversing while road is clear Re 4: Pedestrian walking through opening in hedge (shortest route to shop); no hazard perceived; poor understanding of traffic.	Obstruction to view, and car ergonomics not listed in accident report
14	Car driver losing control in slippery road curve and crashing with oncoming car	- Too high speed - Wrong direction?	- Faulty diagnosis - Information failure	- Psychological stress - Inadequate road design - Cross-section - Horisontal alignment - Maintenance failure - Inadequate information design - Temporary obstruction to view - Permanent obstruction to view	1) Skidding 2) Failing to correct skid	Re 1: More slippery road than expected (local ice); no winter maintenance (sanding/salting); curve with decreasing radius ("eggshaped"); high speed; time pressure. Re 2: lack of skid training;	
15	Light MC rider hit by garbage truck during passing	- Too short distance	- Observation missed - Inattention - Communication failure - Performance variability	- Distraction - Internal competing activity - Habit/expectation	1) Talking in mobile phone 2) Driving over overtaking MC rider	Re 1: Little traffic; low risk of apprehension. Re 2: Fence close to road; no side impact barrier on truck; driver not observing rider; MC without headlight.	

7.3 A complete approach to accident investigation: Combining different methods

In some recent studies focusing on road accident analyses, SINTEF (Alteren et al., 2005; Hokstad et al., 2007) have combined the STEP method with a barrier analysis model based on the AEB model (Svenson, 1991) and the discussion of barriers and accident prevention by Hollnagel (2004). In addition to the STEP and barrier analyses, the approach included a listing of “risk influencing factors” related to road and environmental conditions. Those are similar to some of the “common performance conditions” (CPCs) used as a basis for CREAM/DREAM analyses.

This combined approach is a clear improvement compared to using STEP alone. However, a limitation of the analysis model used in the SINTEF approach is the failure to include analysis of driver actions. Therefore, CREAM/DREAM would have been a very useful supplement to the analysis of critical events by STEP and the subsequent analysis of barriers.

On the basis of experiences with different approaches to accident and incident analysis methods, we would suggest that a complete accident analysis should include at least the following three components:

1) Identification of critical events before, during and immediately after the crash. By critical events we mean actions or energy release that has an impact on the occurrence and/or the severity of an accident.
2) Analysis of the causal factors influencing the critical events
3) Analysis of the barriers that could possibly have prevented the accident and/or reduced its severity

STEP (or similar timeline plotting approaches) seems to be useful for the first part. CREAM seems to be the method of choice for the second part. It is clearly preferable to WBA for the reasons given above. The AEB model, and subsequent adjustments as e.g. in the approach by SINTEF, certainly has some merits for analysing the barriers.

The CREAM-based approaches seem to be a very useful addition to existing methods. The present assessment of DREAM for analysing road accidents has, however, suffered from an important limitation regarding data availability, since it is based on secondary data from the accident investigation reports, rather on direct on-the-scene or on-the-site observation. Since the method of analysis to a large extent guides the data collection, as stated by Hollnagel (2006): “What You Look For Is What You Find (WYLFIWYF)”, integrating DREAM in the toolbox of the accident investigation teams would most likely have resulted in collection of more data that would have been helpful in analysing important causal factors as a bsis for suggesting countermeasures.

An example of using DREAM for primary data collection from road accidents is the approach used in the recent FICA project (“Factors Influencing the Causation of Accidents and incidents”) in Sweden (Sandin and Ljung, 2006; Sandin, 2006). The work reported by Sandin and Ljung (2006) consisted of on-scene and in-depth investigations of 38 single-vehicle-crashes by using DREAM for analysing causation factors. The authors conclude that this approach is particularly useful in order to identify *combinations* of causal factors and to identify the best options for implementing countermeasures.

8 Conclusions

The application of DREAM to a series of road accidents has resulted in knowledge on different levels: a) regarding the general applicability of DREAM for causal analyses of road crashes, including a comparison to some alternative approaches, b) regarding possible modifications of the DREAM method, and c) regarding the need for improved data collection from road accidents by accident investigation teams.

8.1 Applicability of DREAM

- DREAM is a useful way of analysing the possible causal factors occurring in the "pre-crash" phase of an accident, regarding the interaction between driver, road system and vehicle, as well as the background contributing factors.
- Compared to STEP (which is the main method of analysis used by the accident investigation teams of NPRA) DREAM has the following advantages:
    - A more comprehensive causal analysis
    - A classification system (a taxonomy) with predefined causal factors, which facilitates the aggregation of results from a large number of accidents, and for making comparisons of accident causation across domains
    - An underlying theoretical model, which specifies the connections between the various categories of the classification system, and thus presumably contributes to increasing the validity of the causal inferences.
- The two latter characteristics of DREAM makes it preferable also compared to the "Why-Because-Analysis" (WBA), which is used by some of the accident investigation teams. The WBA may be useful for identifying specific causal factors for each individual accident. The possible advantage of WBA in terms of more specific factors may, however, be outweighed by the use of predefined factors as well as a theoretical model in CREAM.
- For a complete analysis of a road accident, including both the precrash, crash, and postcrash phases, as well as identification of effective countermeasures, DREAM should be supplemented with a method for the analysis of barriers as well as a method for plotting of temporal relationships between critical events during the evolution of an accident or incident.
- An advantage of CREAM compared to methods identifying causal factors ad hoc, is the possibility of aggregating results from a set of events and making comparisons between different sets (accident types, transport modes, sectors).

- The CREAM-based methods may have a somewhat higher user threshold than simpler methods like STEP, in terms of requiring a certain level of theoretical competence on human factors.

8.2 Implications for data collection

The input to the present analyses were reports, checklists and other information already collected by the accident investigation teams, and there was no possibility of collecting additional information. In several cases the analyses were limited by the lack of relevant information. Therefore, in many cases statements about causal factors are only hypotheses, whereas additional information could possibly have provided a basis for less uncertain causal inferences, based on the principle of counterfactual reasoning. Thus, it seems that in order to reap the full benefits of the DREAM approach, the data collection procedure has to be improved. Several types of more detailed information would be useful:

- Self-reports from drivers (in the case of surviving drivers) and/or witnesses, regarding their observations and behaviour during the time interval immediately preceding the accident (distractions, driver state, observation or non-observation of traffic information, speed).
- Details of the road and road environment leading up to the site of accident.
- Background information about the drivers (stress factors, sleep, driving experience, training, work situation, etc.)

One advantage of using a structured method of analysis like DREAM is that the method will guide the data collection. With a more or less *ad hoc* approach it is easy to miss information that is subsequently deemed important, and it may be too late to get it afterwards.

As a further assessment of DREAM it would be useful to try and use it in the primary data analysis, and integrate the method into the work of the accident investigation teams.

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Appendix 1: Overview of general causation factors in CREAM, DREAM and in present revised taxonomy

Table A-1. Human-related genotypes (M factors in MTO perspective) in different CREAM based taxonomies.

CREAM (Hollnagel, 1998)	DREAM/SNACS (Ljung et al., 2002)	Revised version (Present project)
Observation Observation missed False observation Wrong identification	**Observation** Observation missed False observation Wrong identification	**Observation** Observation missed False observation Wrong identification
Interpretation Faulty diagnosis Wrong reasoning Decision error Delayed interpretation Incorrect prediction	**Interpretation** Faulty diagnosis Wrong reasoning Decision error	**Interpretation** Faulty diagnosis Wrong reasoning Decision error Delayed interpretation Incorrect prediction
Planning Inadequate plan Priority error	**Planning** Inadequate plan Priority error	**Planning** Inadequate plan Priority error
Temporary person related functions Memory failure Fear Distraction Fatigue Performance variability Inattention Physiological stress Psychological stress	**Temporary person related functions** Memory failure Fear Distraction Fatigue Performance variability Inattention Under the influence of substances Physiological stress Psychological stress	**Acute behavioural impairment** Memory failure Fear Distraction Performance variability Inattention Cognitive bias **Temporary person related functions** Fatigue Under the influence of substances Physiological stress Psychological stress
Permanent person related functions Functional impairment Cognitive style Cognitive bias	**Permanent person related functions** Functional impairment Cognitive bias	**Permanent person related factors** Functional impairment Cognitive style

Table A-2. Technology-related genotypes (T factors in MTO perspective) in different CREAM based taxonomies.

CREAM (Hollnagel, 1998)	DREAM[4] (Ljung et al., 2002)	Revised version (Present project)
Equipment failure Equipment failure Software fault **Procedures** Inadequate procedure **Temporary interface problems** Access limitations Ambiguous information Incomplete information **Permanent interface problems** Access problems Mislabelling	**Equipment failure** Equipment failure Software fault **Temporary HMI problems** Access limitations Incorrect information Temporary sight obstruction **Permanent HMI problems** Access problems Mislabelling Sound Illumination Permanent sight obstruction	**Equipment or infrastructure failure** Equipment failure Software fault **Procedures** Inadequate procedure **Interface problems** Access limitations Access problems Incorrect information Ambiguous information Incomplete information Mislabelling Permanent sight obstruction Temporary sight obstruction Sound problem Illumination problem

[4] In DREAM the factors in this group are vehicle-related factors, whereas infrastructure factors are shown together with organisational factors in Table A-3.

Table A-3. Organisation-related genotypes (O factors in MTO perspective) in different CREAM based taxonomies.

CREAM (Hollnagel, 1998)	DREAM[5] (Ljung et al., 2002)	Revised version (Present project)
Communication Communication failure Missing information	**Communication** Communication failure (driver – driver) Missing information (driver – vehicle/ environment)	**Communication** Communication failure Information failure Missing information
Organisation Maintenance failure Inadequate quality control Management problem Design failure Inadequate task allocation Social pressure	**Organisation** Inadequate procedures Overload (too high demands) Inadequate supervision Inadequate training	**Organisation** Deficient instructions or procedures Overload (too high demands) Management failure Inadequate training Inadequate quality control Management problem Design failure Inadequate task allocation Social pressure Inadequate role allocation Standard and rule problem Inadequate managerial control
Training Insufficient skills Insufficient knowledge	**Training and experience** Insufficient competence Insufficient knowledge	**Competence** Insufficient skills Insufficient knowledge
	Maintenance Maintenance failure Inadequate quality control	**Maintenance** Maintenance failure

[5] In DREAM this group includes both infrastructure and organisation factors

Table A-3 continued

CREAM (Hollnagel, 1998)	DREAM[6] (Ljung et al., 2002)	Revised version (Present project)
	Traffic environment design Inadequate road geometry Sight obstruction Inadequate information design	**Road and road environment design** Inadequate road design Inadequate information design Inadequate roadside design
	Vehicle design Unpredictable system characteristics Inadequate MMI Inadequate ergonomics Inadequate design of communication system	**Vehicle design** Unpredictable system characteristics Inadequate HMI Inadequate ergonomics Inadequate design of communication devices Inadequate construction
Ambient conditions Temperature Sound Humidity Illumination Other Adverse ambient conditions		**Ambient conditions** Temperature Sound Humidity Illumination Other Adverse ambient conditions
Working conditions Excessive demands Inadequate workplace layout Inadequate team support Irregular working hours		**Working conditions** Excessive demands Inadequate workplace layout Inadequate team support Irregular working hours

[6] In DREAM this group includes both infrastructure and organisation factors

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