APPLICATIONS OF ERROR DATA IN TRAFFIC SAFETY EVALUATION: A REVIEW ON OUR RECENT FIELD STUDIES

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1 Introduction

Most efforts, projects and measures dealing with the development of new information/control strategies and technologies in vehicle equipment aim at an improvement of traffic safety (e.g. PROMETHEUS, DRIVE). Therefore, it has to be highlighted that there is a need for supplying criteria and methods for an evaluation of possible safety effects, because all measures have to be applied and approved under real traffic conditions. Research indicates evidence that an evaluation of safety effects completely relying on accident data will not provide reliable future safety assessments. Without aiming at a detailed discussion about the pros and cons of the accident criterion, one important fact should be taken into account in any case: accident data will not be at our disposal at that time when new technologies are available and ready for use in real world traffic. Therefore, it is necessary to develop a set of criteria and methods to be used for a quick and efficient road safety evaluation without having to rely on retrospective accident data analysis.

2 An Interaction Model of the Traffic System

In the contexts of industrial safety or air traffic control the notion of "critical incidents" has a long tradition (see e.g. Flanagan, 1954). These critical incidents can be ranked on a scale representing the dangerousness of an event. We call the scale "safety continuum", i.e. we consider traffic safety (or the degree of safety of a specific, observable traffic situation) to vary between the extremes of correct behaviour and accidents. Errors in the behaviour of road users, slight traffic conflicts or near accidents should be somewhere in between the two poles. In the direction of the accidents events become more dangerous but less frequent.

The safety continuum as a theoretical idea can be transformed into discontinuous units by clustering similar traffic situations according to certain observable criteria or operational definitions. Thus, the safety continuum can be replaced by a model of the traffic flow that consists of system states and transitions between states. Such a concept is illustrated in figure 1.

***Illustration 1**: Interaction model of the traffic system*

The bottom row of illustration 1 shows that the accident is regarded as the end of a sequence of events. One would expect an accident to have been preceded by dangerous situations and erroneous behaviours, i.e. disturbances in the traffic system. The less disturbances occur, the more reliable the system will be. The number of errors introduced to the traffic system by its various elements gives an estimation of its hazard potential.

Analogous to the human reliability approach from systems engineering we define the driver's reliability by using the ratio between erroneous and correct performance, i.e. by human error probabilities (HEP´s).

The arrows in illustration 1 point to different parts of the model and show strategies in safety efforts:

(1) hazard avoidance by decreasing the exposure to hazards (e.g. by separating traffic streams by means of signalisation)

(2) hazard reduction by increasing the driver's reliability given a specific exposure to risk (most automatic devices in the car are examples of that strategy) and

(3) hazard management: coping with situations including disturbances in the traffic system. As the model illustrates these situations can be of different degrees of dangerousness - depending on safety margins provided by road infrastructural elements, the possibility of error compensation by other traffic participants and the necessity and time available for compensatory action.

The arrows in the model not only structure safety measures and countermeasures but also show different levels at which the traffic system can be diagnosed. The potential of the reliability analysis is given by the simple equation

$$\text{number of errors} = \text{exposure to hazards} \times \text{HEP}.$$

The number of errors (or the amount of disturbance) in the system gives an estimate of the conflict or accident potential and can be reduced by the intervention strategies (1) or (2). According to the model an accident cannot happen without a system disturbance, i.e. the reliability of the system will be closely connected to its safety in terms of numbers of accidents (as long as the transition probabilities between the system states in the "unreliable" part of the model remain unchanged).

A precise definition of all system elements is given in Fastenmeier, Gstalter & v.Benda (1992) as well as a list of errors and operational definitions of the related exposure measures. We shall not go into too much detail here, but describe some typical applications of the error data approach in the next chapter.

3 Examples of Recent Applications of Error Counting Methods for Different Purposes

The prerequisite for an effective application of behavioural and error data is both a precise and detailed definition of these incidents and an objective and reliable observation technique. In this context our working group has produced various techniques which have been applied in several field studies. Some results of these recent field studies will illustrate the broad scope of applications of error counting methodologies.

Safety evaluation of LISB

One example for using behavioural data is a study which evaluated safety effects of a new electronic in-car navigation system (LISB - Leit- und Informationssystem Berlin) on driver behaviour. LISB, which is based on the SIEMENS-EuroScout-System, supplies drivers on the road with current and individual route recommendations which are transmitted to and displayed in the cars. In this study an observation technique for non-standardised test routes was used combining both registration of situational characteristics and driver behaviour (Galsterer, Fastenmeier & Gstalter, 1990; Galsterer & Gstalter, 1990).

Illustration 2*: LISB-Observation sheet for non-standardised test-routes*

To get an idea of if and how LISB has an impact on safety and driver behaviour, in a first part of the study a related sample of 25 drivers out of the 700 in total in the large scale test was accompanied by an observer at three different phases: without LISB, shortly after the installation of LISB and nine months later after the drivers had got used to the system. The observer scored errors and traffic conflicts during routine trips of the subjects on a standardised observation sheet, based on the "Vienna Driving Test" (Risser & Brandstätter, 1985). Driver behaviour was assessed according to various aspects of speed, intervals and gaps, tracking and lane use, blinker-signals and communication, guarding in general, approaching intersections, behaviour in intersections and behaviour against non-motorised traffic participants. How the observer has to assess driver behaviour is fixed by means of observation guidelines. Two examples of error definitions shall illustrate how the observer has to judge the observed driver's behaviour:

1. Speed too fast: the running speed of a driver should be as it is both prescribed by law and recommended by characteristics of the traffic situation. Driving more than 10 km/h above the speed limit is regarded as an exceedence of speed not being adequate to the traffic situation. In residential roads even driving at the recommended speed limit can be regarded as inadequate.

2. Lateral distance too short: the driver has to keep an adequate lateral distance both to other cars, objects or obstacles and to non-motorised road users being on the same carriageway or on a lane for opposing flow. As a rule of thumb we suggest: a correct lateral distance against moving objects should be at least 1,5 m, against fixed objects at least 1m. In this context, the speed is of importance, too. This rule also holds true only for cases, where circumstances in the traffic surroundings do not force other manoeuvres upon the driver.

The observer also collected several kinds of exposure data: he described the traffic situations, i.e. characteristics of road segments and intersections, by indicating their type in the top row of the sheet. In addition, he counted the frequency of different manoeuvres of the drivers, e.g. lane-changing, overtaking and turning. These measures served as basic exposure information so that error rates for different driving tasks in defined situational classes of the traffic environment could be calculated. The traffic situations are classified by means of a classification system for traffic situations (Fastenmeier, 1993), which combines traffic engineering characteristics of traffic situations with the driver's point of view. So far, this system could be labelled as a "fuzzy classification system of traffic situations", because its categories are based on the drivers' subjective representations of traffic situations, which then have been classified according to technical standards. This classification system contains various elements with a number of categories as follows:

A	Type of motorway / highway (5 categories)
L	Type of rural and country roads (2 cat.)
C	City roads (7 cat.)
H	Horizontal shape (2 cat.)
V	Vertical shape (2 cat.)

E Lane closures, bottlenecks (2 cat.)

F Direction (3 cat.)

The system is completed by time-variable characteristics such as traffic density, visibility- and weather conditions.

In the observation sheet, shown in figure 2, for instance the abbreviation C1 represents city roads with two carriageways and separating strip (ring roads) and the abbreviation C6 stands for smaller residential roads.

Some of the main results were as follows: exposure data showed marked changes with respect to the type of roads and intersections used. With LISB both the proportion of main roads and the relative number of signalised junctions increased. The frequency of lane-changes, overtaking and turning manoeuvres decreased.

With only few exceptions the error rates followed a V-shaped distribution over the three different investigation periods: after the introduction of the navigation system drivers behaved safer and drove more cautious and exact. The overall error rate dropped significantly from 32% to 27%. The number of speed errors was smaller than before. Nine months later, nearly all of these positive effects had vanished or at least had become smaller; the overall error rate was up to 30% again at that time.

Illustration 3: *Error rates with and without LISB*

Our explanation is, that we can find here a typical habituation effect. The initial tension and attention with the new system had become routine. During nine months that the drivers had been guided from the same sources to the same destinations, they had been driving all variations of streets possible. If a system message came now at the beginning of the trip, the driver could clearly guess which alternative would be used that particular day. It follows that longer term planning for the driver was possible again and driving behaviour shifted into the direction of the initial behaviour.

The usefulness of a navigation system like LISB should clearly increase with decreasing knowledge of the area the driver has to find his way in. The orientation task increases the mental workload of the driver and less cognitive resources are left for the guidance and control level of the driving task. Therefore, 18 of our original subjects were observed during trips in unknown areas of the Berlin network. In order to compare their driving performance with the routine trip results all other independent variables were held constant. One remarkable working step of this analysis was to compare those error data with some accident data, demonstrating a significantly increased accident risk of strangers in bigger German towns (accident data taken from Engels & Dellen, 1989).

Illustration 4: *Comparison of error rates (e r) and strangers accident risk*

Illustration 4 shows the error rates for the routine trips (left column) and the corresponding values for the unknown areas (right column). The rectangular and the star represent estimates of an expected error rate value, based on the average accident risks for strangers in general (stars) and for Munich (rectangular), respectively. The total error rate remained unchanged. The expected rate was clearly higher: the conclusion is that the navigation system had been helpful. The next two pairs of columns show the error rates on broad main roads (C1/C2/A) and on minor roads (C4/C8). Here, the influence of LISB is evident: error rates between intersections do not rise in unknown areas but even show a strong tendency to drop, whereas the usual strangers risk is high for these classes. Obviously, the early announcement of the route direction, the lane recommendation by the system and the bar graph -an analogous indication at the display of the remaining space to the next turning point- had been powerful means in supporting the drivers orientation task.

Errors in speed (driving too fast) and distance (too short headways) are not specific for the orientation problem. Therefore, the accident causation risk is equal for these accident types both for residentials and for strangers. For that reason we did not expect the error rates to change in the unknown environment. Indeed, errors according to speed and distance even decreased in that part of the field study where trips in unknown areas were under observation.

A different result could be noted in the intersections: Error rates went up for all types of errors inside the junctions in the unknown parts of the road network. This is primarily because LISB has nothing to offer in helping the drivers in their orientation task within the intersections. The rise of the error rate for all kinds of errors in junctions was as big as we had expected from the stranger's risk data (compare Gstalter, 1991).

As a whole, the structure of the accident risk data and of the error rate data show a very interesting correspondence that should attract more attention in the future.

A study on driver information needs

The second example for an effective application of behavioural and error data is a field study dealing with different driver populations. The purpose of this study was to analyse driver information needs in order to know more about how different types of drivers (inexperienced, routine, elderly and expert drivers) could be effectively assisted, i.e. which kind of information-assistance is adequate and appropriate in which kind of traffic situation (e.g. Fastenmeier, Reichart & Haller, 1992).

This was based on the assumption that various kinds of driver-assistance- and driver-information systems are needed in order to compensate group-specific driver deficiencies:

- information processing of drivers in general is dependant on distinct situational characteristics to be found in traffic reality
- heterogeneous types of drivers are confronted with these varying situational demands, i.e. there are different levels of driving experience, driving skills and performance characteristics
- there are different kinds of critical tasks and situations for different kinds of drivers as well as there are different information needs for different kinds of drivers

In this field study one of the main elements of analysis was an observation sheet for representative and standardised test trials. This was, because on basis of detailed drivers' exposure data, a catalogue of traffic situations for representative trip purposes was compiled and transferred into the construction of a representative test route suited to the traffic reality of Munich (Fastenmeier, 1993). This catalogue includes traffic situations for representative trip purposes of drivers as follows:

- Driving from/to work: this comprises the daily route from/to work (this catalogue was taken for the representative test route).
- Driving for carrying out purposes such as: consulting doctors and authorities, to go shopping, etc.
- Driving for leisure purposes: all kinds of driving in leisure time, usually for short distances, in order to visit friends, performances, etc.

- Driving on weekend: as far as it is cross-country and leading back downtown.

This representative test trial

- allows for a generalization of results e.g. gained by investigating driver behaviour,
- takes the quantitative and qualitative exposure of drivers into account,
- contains "typical" traffic situations, i.e. tasks, drivers are confronted with daily, and
- includes the analysis of the task complexity of each traffic situation on the test trial.

Driver behaviour and driver errors were observed by means of categories and variables quite similar to the LISB-study, but due to the purpose of the study on a much broader scope.

The data gathering logic of this study worked well as for example a vast number of variables differentiating between the examined samples could be revealed and some relevant recommendations for individual/group specific aids could be given. Due to the registration of both situational and behaviour-related data, again error rates and rates of correct performance could be calculated on a very detailed level.

Giving a short survey about driving performance of the subjects in general, this study indicates evidence that elderly and novice drivers could be labelled as "problem" groups.

Examination of inexperienced drivers showed marked deficiencies according to the following list:

- errors in lane keeping and lane changing
- low guarding in general
- low guarding especially in the presence of non-motorised traffic participants
- avoiding obstacles
- too short lateral distances to pedestrians/cyclists
- slow speed combined with sudden inadequate accelerations
- high speed in "easy to handle" situations
- corner-cutting
- orienting in general.

Viewing strategies are remarkably ineffective: when gathering information prior to executing manoeuvres (lane changes, merging, curves, turning) novice drivers are significantly more often turning their head around (instead of using mirrors) than experienced drivers. Moreover they prefer more direct looks, fewer glances to the outdoor mirrors of the car and fewer glance sequences.

Elderly drivers rank high especially on topics such as

- red-light errors
- passing intersections with right of way for other road users
- turning in intersections in the presence of pedestrians/cyclists
- inadequate deceleration
- velocity either too slow or oscillating
- lane keeping and lane changes
- corner cutting
- guarding in general

- loss of car-handling skills.

The viewing behaviour of elderly drivers shows significant reductions in several aspects: decreasing use of information acquisition by outside and inside mirrors of the car and omitting turning their heads prior to executing manoeuvres, on the contrary more direct looks to the front.

Moreover it turned out that experienced drivers seem to be worse than their reputation, because this field study revealed a relevant number of marked deficiencies as well (especially lane keeping, turning in intersections, traffic violations and the frequency of critical incidents), whereas the "expert drivers" could be labelled as "best-case"-drivers with high preview and anticipation capacities, high information processing speed and highly automated handling of the car.

Illustration 5*: Red-light errors and Non-guarding of experienced, inexperienced and elderly drivers in C2-K1-situations -*

Illustration 5 gives an example, demonstrating the more detailed level of analysis: In an intersection, regulated by traffic lights (K1), on a special type of a broader main road (C2) we can find a strong and significant correspondence between red-light errors (please mark: not intended red-light violations!) and non-guarding of all driver groups of the study as well as we can find distinct differences between inexperienced, experienced and elderly drivers; but especially elderly drivers are "worst cases" in this type of situation, which is a typical example of a class of situation with high task complexity, deficiencies in road layout and where the driver needs parallel information capacities. Some solutions to be discussed in this case are improving the visibility of traffic lights by other placement, better contrast-control and supplying in-car traffic information, e.g. by Head-up Displays.

Another example for attaching specific aspects of driver behaviour to specific types of traffic situations is shown in illustration 6. By means of this error counting methodology it is not only possible to demonstrate significant differences in general between various populations of drivers as far as their viewing strategies are concerned, but also to show in which kind of traffic situation which kind of viewing behaviour can be found. In nearly all kinds of roads and situations both inexperienced and elderly drivers show marked deficiencies in their viewing behaviour and in information acquisition. As -for instance- the use of the car's outdoor mirrors is concerned, this holds true especially for main roads such as city roads with two carriageways and separating strip (C1) and roads with one carriageway, at least 4 lanes and a fixed-guideway transit system as well as for smaller roads with one carriageway and 2-3 lanes (C4, C5), residential roads (C6) and one-way roads (C7). The only exception in this case are broad main roads with one carriageway and about 4-7 lanes.

Type of road	Experienced (Group 1)	Inexperienced (Group 2)	Elderly (Group 3)	Significant Differences
C1	29,39	21,61	17,60	1 vs. 2 | *1 vs.3*
C2	27,57	22,42	24,61	n.s.
C3	20,45	11,93	9,61	1 vs. 2 | 1 vs.3
C4	25,97	14,28	9,34	1 vs. 2 | *1 vs.3*
C5	24,54	8,18	15,38	1 vs. 2
C6	19,31	9,65	8,65	1 vs. 2 | 1 vs.3
C7	22,72	14,09	15,38	1 vs. 2 | 1 vs.3

Illustration 6 *: The use of the car's outdoor mirrors by experienced, inexperienced and elderly drivers in different road types (frequency in %; $p<.05$; $p<.01$)*

As mentioned above, we also did some more theoretical work on the driver errors' topic recently. So far, we can supply a classification of driver errors and respective exposure data, which is theoretically sound. In the context of PROMETHEUS, our methodology is actually applied in field studies, dealing with Dual Mode Route Guidance Systems (CED 9) and Autonomous Intelligent Cruise Control Systems (CED 5). Altogether, our error counting approach and methodology is to become one important element of an integrated safety assessment by efficiently supporting already existing methods (accident estimations, expert assessments, safety checklist).

4 References

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