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Risk Analysis - A Tool in Decision-making

Per Näsman

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KTH
Transporter och samhällsekonomi
Gruppen för säkerhetsforskning
Teknikringen 78 B, 1 trappa
SE-100 44 Stockholm
Sweden

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Abstract

In our daily life we are surrounded by different kind of risks and we constantly strive for better methods to quantify and in the prolongation manage these risks. Every activity involves some risks and there are some kinds of risks and some level of risks that we are unwilling to accept. We all like to live a life that is free from risks, but that is impossible.

The word risk has a lot of different interpretations. In this thesis we shall let risk stand for the combination of random or uncertain events with negative consequences for human health, life and welfare and for the environment together with some measures of the likelihood of such events. We believe this is the prevailing concept or understanding of risk; as the probability of an event followed by some negative consequences or activities of that event.

In risk analysis one tries to recognize the nature of various risks and to assess the magnitude of the risks. In the risk analysis it is very important to know what system to consider and this is not self evident in many cases. The situation is clearly different for planning and/or building a system compared with running the same system in a real time state. The system that is going to be the subject to the risk analysis must be clearly defined and the limitations and the boundaries of the system must be set. It is very important to ensure that all persons involved in a risk analysis have a common understanding of the system being considered, including relevant operations.

During the past decades many studies have been carried out on risk related topics and the society has showed a significant interest in the field of risk analysis. Risk analysis is the interdisciplinary field of science that combines results and knowledge of probability theory, mathematical statistics, engineering, medicine, philosophy, psychology, economics and other applied disciplines.

In this thesis we will give some examples of different risk analyses carried out basically within two areas. The first part of the thesis (paper 1- paper V) describes different risk analyses carried out in the area of transportation. This is an area with large differences between the different modes of transportation in respect to, for example number of users, number of accidents, magnitude of the accidents and accessible data. The latter part of the thesis (paper VI and paper VII) describes two risk analyses carried out in the field of medicine. Medicine is a science, which has used methods from the area of risk analysis for a long time. The different papers will be used to discuss risk analysis as a tool in decision-making.

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Preface

Risk analysis is the main theme of this licentiate thesis. The thesis consists of seven different papers, each of them dealing with different aspects of risk analysis. Five of the papers describe risk analyses done within the area of transportation, an area with large differences between the different modes of transportation, and two of the papers describe risk analyses done within the field of medicine.

Added to the presented papers is a general introduction to risk analysis and a description and discussion of the different aspects of risk analysis each of the papers deals with. Since some of the papers are originally published in Swedish, a short abstract in English of each paper is presented in the thesis as well.

The work with, and the production of, the seven papers stretches over a long period of time and the now existing thesis is the result of me joining the Center of Safety Research at the Royal Institute of Technology in Stockholm. My chief and co-worker professor Torbjörn Thedéen is the one to whom I direct my greatest gratitude. His encouraging support, in every area thought of, combined with my supervisor professor Lars-Göran Mattsson's diligence made me finalize my work with the thesis.

The atmosphere within the Center of Safety Research, no matter what department it belonged/belongs to, has made my work very pleasant and I am grateful to all and everyone I worked with during my time at the Royal Institute of Technology.

All the seven papers presented in the thesis are earlier published within the different project they are reporting. I have also presented results from the projects at a number of conferences and/or workshops during the years and lastly I would like to thank my fellow workers, all my colleagues, and co-writers within the different projects. It has been a pleasure working together with you all and I hope we can work together in some constellations in the future as well.

Stockholm, August 2005

Per Näsman

Risk analysis - a tool in decision-making

Introduction

In our daily life we are surrounded by different kind of risks and we constantly strive for better methods to quantify and in the prolongation manage these risks. Every activity involves some risks and there are some kinds of risks and some level of risks that we are unwilling to accept. We all like to live a life that is free from risks, but that is impossible.

During the past decades very many studies have been carried out on risk related topics and the society has showed a significant interest in the field of risk analysis. Risk analysis is the interdisciplinary field of science that combines results and knowledge of probability theory, mathematical statistics, engineering, medicine, philosophy, psychology, economics and other applied disciplines.

The word risk has a lot of different interpretations. In this thesis we shall let risk stand for the combination of random or uncertain events with negative consequences for human health, life and welfare and for the environment together with some measures of the likelihood of such events. We believe this is the prevailing concept or understanding of risk; as the probability of an event followed by some negative consequences or activities of that event.

In risk analysis one tries to recognize the nature of various risks and to assess the magnitude of the risks. In the risk analysis it is very important to know what system to consider and this is not self evident in many cases. The situation is clearly different for planning and/or building a system compared with running the same system in a real time state. The system that is going to be the subject to the risk analysis must be clearly defined and the limitations and the boundaries of the system must be set. It is very important to ensure that all persons involved in a risk analysis have a common understanding of the system being considered, including relevant operations.

Gustafsson [(1)] claims that the formal system description shall include four parts;

- Description of the technical system, including the relevant operations and phases.
- Statement of the period of time to which the analysis relates.
- Statement of the personnel groups, the external environment and the assets to which the risk assessment relates
- Capabilities of the system in relation to its ability to tolerate failure and its vulnerability to accidental effects.

Defining the system will reveal information on what is going to be included in the analysis; components, subsystems, process, time-spans, functions, etc. A complete risk analysis of a system has to include all of its life cycle phases. This will help the decision makers, giving them the best foundation to base their decisions upon.

After the phase of defining the system there are five major steps in a risk analysis:

1. Risk identification
2. Risk estimation
3. Risk perception
4. Risk valuation
5. Decision

The first step, risk identification, is to pose questions like "what can happen" and/or "what can go wrong that could lead to an outcome of a hazard exposure". Since risk identification is non-numerical to its nature methods like a think-tank are recommended and widely used. A problem with risk identification is that risk sources may be overlooked for the simple reason that they not have resulted in any accident so far. Failure to identify important sources of risk will lead to an underestimation of the total risk and may be the explanation to some accidents, accidents that might be fatal. One also has to try to describe the possible connection between causes and consequences. It is quite impossible to describe a system so well, so it will cover every possible situation. Simplifications will be necessary.

The second step, risk estimation, is to estimate the risks and the likelihood for the different events and/or outcomes. This can be done with statistical methods and/or risk analysis methods. Risk estimation is by many researchers referred to as Probability Safety Assessment (PSA). Kopustinskas[(2)] states "it should be understood that any risk estimation contains limitations and a certain degree of subjectivity".

Most human activities and many natural phenomena are possible sources of risk and Kopustinskas[(2)] groups the types of risks in three groups:

<u>Natural hazards.</u> This type of risk include all naturally occurred phenomena (e.g. earthquakes, storms, floods, volcanic eruptions, drought, lightning etc.) that can have a direct impact on humans and also may increase the likelihood of accidental hazards from fixed installations or network systems.

<u>Accidental hazards.</u> This type of risk is mainly caused by accident in various human activities, including industry, transportation, waste disposal facilities and others. Severe accidents may have serious consequences for the public and the environment.

<u>Continuous hazards.</u> Continuous emission to air, water and land from industrial, commercial or residential activities is the last type of hazards. A transportation network, including vehicle emissions, is one example of continuous hazards.

The third step in the risk analysis, risk perception, is the way we perceive the risks. Risk perception is associated with the psychological aspect of risk and this is very important to understand when we interpret and try to understand the risks. Risk perception is also very important in public risk communication. The psychology of risk is closely related to the question of what is an acceptable risk.

The term acceptable risk is a complex issue, which involves not only technical assessments but also the values of society believes and societal risk acceptance. Risk only makes sense if it is perceived by someone.

The fourth step, risk valuation, is to value the risks and to find possible ways of controlling and reducing them. The valuation of the risks is always tied together to risk perception.

Mankind often appears to be reluctant to accept new technology. This resistance is often based on the fear that use of the new technology implies potential losses, which can be monetary losses, human life losses and/or environmental losses. This fear is related to the lack of experience of the technology and the fear tends to decrease as experience in the use of the technology in question increases. Fear in this context refers to the risks we believe are involved with usage of the new technology. However, we are willing to take these risks when we get benefits and have the freedom to choose, e.g. flying, hill climbing or smoking. We tend to accept larger risks when it is a free choice rather than imposed from the outside, e.g. hill climbing contra radiation [3].

After going through the four first different steps of the risk analysis different decision alternatives should be compared with respect to the results of the risk analysis together with the benefits and the costs as a basis for the decision.

Examples of two different schemes for risk analysis can be represented by the following two figures, figure 1 and figure 2.

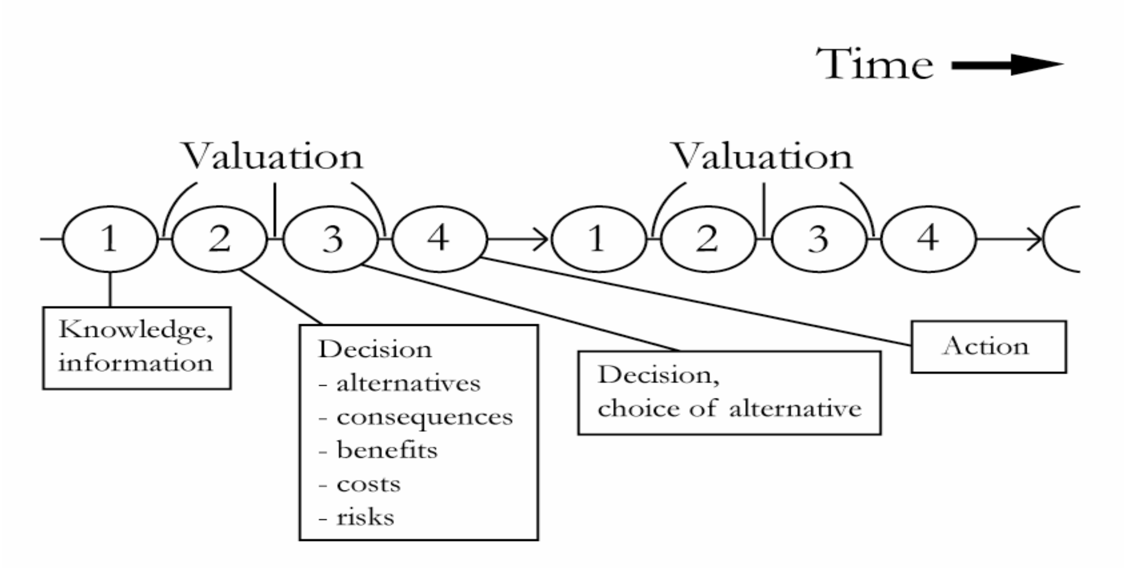

Figure 1. Risk analysis chain, adopted from Näsman [4] (Paper I).

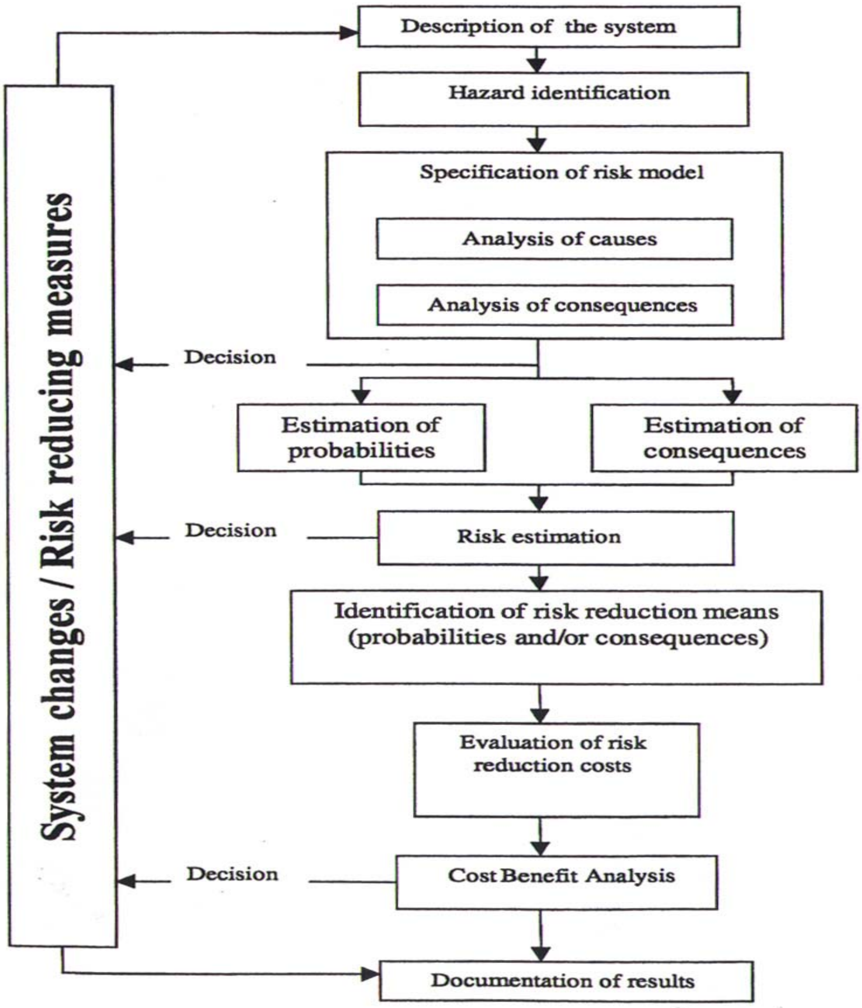

Figure 2. Risk analysis, adopted from Bäckman [5]

The key question in risk assessment is *how safe is safe enough?* This is primarily connected to the concept of risk and it is strongly dependent on the benefits someone receives by taking certain risk. One of the ways to set up an acceptable risk level is to try to compare different kinds of risk. Many sources provide information on risk from different hazards but of course the estimates of risk may differ depending on the initial data and statistics used.

However, if one tries to take into account most of the possible effects of a decision that might lead very far. For example, when comparing different ways of producing energy it has been proposed that also risks in producing material for the energy plant as well as possible negative effects from waste material in the far future should be included. Due to the long time span the long-term consequences are very difficult to study in this case. The same could be argued about, for example, building constructions, which might have a life length of several hundred years. The question of global warming is another example of the same kind. Again, it is very important to clearly define the system that is going to be the subject of the risk analysis and the limitations and the boundaries of the system must be carefully set.

Although there might be some fundamental factors that all risk analyses have in common the nature of applications can be very, very different. Compare for example the safety of a transportation network and the safety of a nuclear power plant including its nuclear waste.

Risks are always connected with some type of decision; the choice between different alternatives and the last step in the presented risk analysis scheme, the decision, is far from unproblematic. Rowe [6] states "Decisions in a pluralistic society are made in myriad institutions, public and private. Identifying the decision makers (individuals, groups, institutions) is at least as problematic as determining how a decision is reached." There are three groups, more or less separated, involved in the decision taking; the decision makers, the cost and benefit takers and the risk bearers.

In this thesis we will give some examples of different risk analyses carried out basically within two areas. The first part of the thesis (paper 1- paper V) describes different risk analyses carried out in the area of transportation. This is an area with large differences between the different modes of transportation in respect to, for example number of users, number of accidents, magnitude of the accidents and accessible data. The latter part of the thesis (paper VI and paper VII) describes two risk analyses carried out in the field of medicine. Medicine is a science, which has used methods from the area of risk analysis for a long time. The different papers will be used to discuss risk analysis as a tool in decision-making.

Risk analysis methods

There are several methods within the field of risk analysis. Many of the methods can furthermore be used in different ways depending of the purpose of the risk analysis. The first steps in the risk analysis are always of qualitative nature. Describing the system, identifying the hazards and specifying the causes and modelling the risks are for sure of qualitative nature. But after the system to study is set, there is a variety of ways to go and the risk analysis will be depending of the way one chooses to go.

Lindberg, Thedéen and Näsman [(7)] (Paper II) state at least three different methods of application that can be of interest to choose among and within:

a) Preliminary hazard analysis or detailed hazard analysis. In many cases a preliminary analysis may be sufficient and it might be enough to work with rough and easy to grasp risk, cause and effect categories whereas other problems requires a more detailed analysis broken down to lowest possible level. A detailed analysis of the different components service life length and fault probabilities might be necessary to do.

b) Qualitative or quantitative analysis. As mentioned above the first step in all risk analyses, the task of describing the system is of qualitative nature and so is identifying the hazards. If the purpose with the risk analysis is to identify risk sources and the risks within the given system under study, a qualitative analysis could be sufficient. If, on the other hand, the aim is to estimate numerical values of the risks one has to use quantitative methods. The quantitative methods give us methods for estimating probabilities for the events of interest. The case of accident rates is one example.

c) Inductive or deductive analysis. In some cases the data and the data sources are sufficient in order to be able to use statistical methods and statistical analysis for the estimation within the risk analysis. In cases where no data are given one is forced to work in a deductive way to generate commencement material for the risk analysis. In a majority of cases the risk analysis comprises of inductive as well as deductive parts so in a practical situation it is necessary to use both ways.

The different risk analysis methods can then be divided in to three groups depending on the type of objects they are designed to analyse; technical systems, organisational risks or human reliability [(7)] (Paper II). The following table (table 1) shows the breakdown the authors used in their report.

Method	Short description
Technical systems	
Fault tree analysis - FTA	Analysis of the causes of a given incident
Event tree analysis - ETA	Analysis of alternative consequences of a given event
Failure modes and effects analysis - FMEA	Analysis of faults of technical components
Hazard and operability study - HAZOP	Analysis of possible risks/disruptions in processes
Maximum credible accident - MCA	Analysis of worst possible consequences
Organisational risks	
Management oversight and risk tree - MORT	Organisational demands are compared with actual organisation
Administrative safety analysis	Organisational conditions are judged according to form
Human reliability	
Work safety analysis	Working conditions are analysed
Action error analysis - AEA	Analysis of dangerous divergences from pre-specified working procedures
Human reliability analysis - HRA	Analysis of human inclination to act erratically during certain working tasks

Table 1. Some examples of risk analysis methods, adopted from Lindberg, Thedéen and Näsman [(7)] (Paper II).

The list in table 1 contains examples of the methods used in risk analysis and there are many variants and methods not described here. For a review of more variants and methods see for example Rausand [(8)].

In Lindberg, Thedéen and Näsman [(7)] (Paper II) the authors also give a more comprehensive description of the different methods and furthermore the report presents methods to analyse the interaction between man, technology and organisation within the field of risk analysis.

Data and data sources for risk analysis

Data and the accessibility of data are very crucial for a risk analysis. This is stressed upon in the majority of the papers presented in this thesis. In the different papers there is an exposition of the data and data sources given for the risk analysis at hand.

In the olden times when technical innovations gradually were introduced, one could gain empirical experience and acquire data about how often different events occurred, for example accidents. This could then be used in the risk estimation. But nowadays many systems are built in large and often unique units. In cases like this it is no longer possible to rely on professional experience. We have to use the structural mechanics in the system and computer programs to do the risk calculations. This is in particular the case in the planning and construction phase of the life cycle. The physical system corresponds to a logical system, consisting of a number of components, and the functioning of the components will determine whether we will have a collapse of the system or not.

There are three steps on the information staircase presented by Thedéen [9] (figure 3).

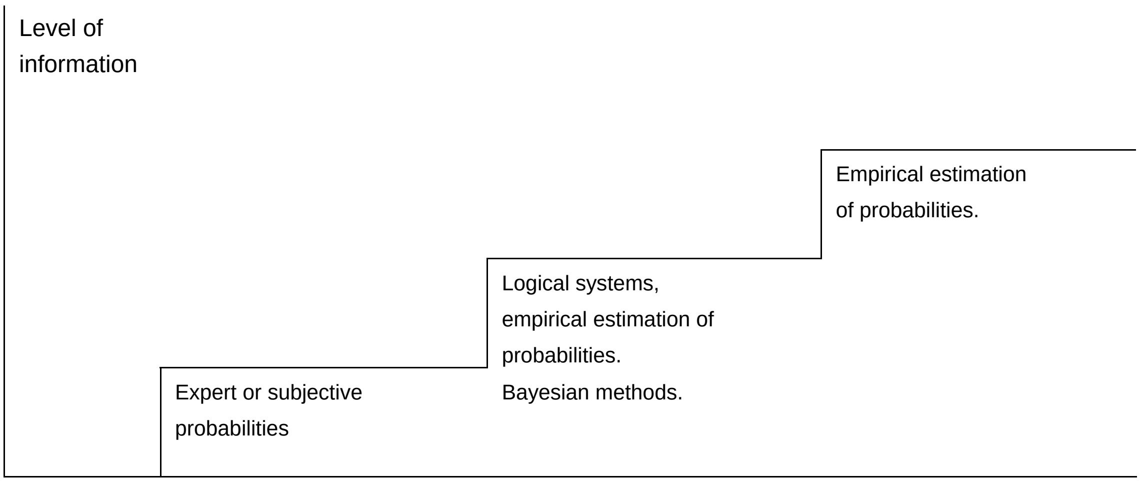

Figure 3. The information staircase, adopted from Thedéen [9].

- In areas where there are many data available one can use ordinary statistical methods to estimate the probability or likelihood for the different events. The ideal situation is when you have stable time series giving the number of occurred events (Paper IV, Paper VI, Paper VII).

- On the middle step, the second one, you have few data but you can base your estimation on a logical system. You can combine knowledge of the components in the logical system with empirical estimators of the probability or likelihood. You can use Bayesian methods to calculate the probabilities, based on experts and the events that occur (Paper III, Paper V).

- On the first step you have no data at all. In this case you can use experts to help you to estimate the risks and you can use their subjective probabilities for the events in the risk analysis (Paper III, Paper V).

Lack of data within a risk analysis causes problem. There is, for example, a problem trying to analyse railway safety with statistical methods (Paper I, Paper II). Few accidents occur and it is difficult to get reliable estimates of the expected number of fatalities per year. One possible way of solving the problem with lack of data would be to report incidents in detail and to use this incident data for statistical analysis (Paper V). It would be very profitable for the area of risk analysis if both accident data and incident data together with adequate appurtenant information were collected in a formal way and stored in a data base for easy access to the researchers. This would make it easier to apply more powerful statistical methods. Regression analysis and multivariate methods are some examples of such methods.

Included papers and short summaries

I. Näsman, P. (1993).
Empiriska demonstrationsexempel av data och datakällor för riskanalys/riskvärdering inom järnvägsområdet.
Rapport (in Swedish). Centrum för säkerhetsforskning, KTH, 1993.
TRITA-AMI REPORT 3031.

II. Lindberg, E., Thedéen, T., Näsman, P. (1993).
Riskanalyser/riskvärdering inom järnvägsområdet.
VTI Rapport 381 (in Swedish).
Statens väg- och trafikinstitut , 1993.

III. Leden, L., Claesson, Å., Gårder, P., Näsman, P., Pulkkinen, U., Thedéen, T. (1997).
Metodik för före-/efterstudier. Tillämpat på cyklisters trafiksäkerhet.
KFB-Rapport 1997:15 (mainly in Swedish, parts in English).
Kommunikationsforskningsberedningen, 1997.

IV. Näsman, P., Thedéen, T. (1995).
Säkerhetsanalys beträffande föreslagen ny vägsträckning jämfört med gammal vägsträckning av väg E 22, delen Söderåkra-Hossmo vid Vassmolösa.
Rapport (in Swedish). Centrum för säkerhetsforskning, KTH, 1995.
TRITA-AMI REPORT 3028.

V. Näsman, P., Thedéen, T. (1996).
En statistisk utvärdering av de mått SAS använder för att kontrollera uppfyllelsen av de flygsäkerhetsmål man satt upp.
Rapport (in Swedish). Centrum för säkerhetsforskning, KTH, 1996.
TRITA-AMI REPORT 3029.

VI. Pieper, R., Kager, L., Näsman, P. (1982).
Acute Appendicitis: A Clinical Study of 1018 Cases of Emergency Appendectomy.
Acta Chirurgica Scandinavia, No 148: 51-62, 1982.

VII. Pieper, R., Kager, L., Näsman, P. (1983).
Clinical Significance of Mucosal Inflammation of the Vermiform Appendix.
Annals of Surgery, Volume 197, No. 3, 1983.

Paper I.

Näsman, P. (1993).

Empiriska demonstrationsexempel av data och datakällor för riskanalys/riskvärdering inom järnvägsområdet.

Rapport (in Swedish)
Centrum för säkerhetsforskning
KTH
1993
TRITA-AMI REPORT 3031.

Summary

The present study gives empirical demonstration examples of data and data sources for risk analysis/risk evaluation within the area of railway traffic.

The report presents the main actors in the Swedish railroad traffic system, SJ and Banverket, and some of their work with safety issues and their goals with the safety work. The data sources and the measurements of safety and/or risk they use are presented and analyzed. Different methods are proposed to improve the methodology they are using and ways to improve the data and data sources are also proposed.

The analysis done in the report shows that risk analysis/risk evaluations, even though they always constitute a simplification in relation to reality, and the risk estimations that are made may include considerable uncertainty and/or inaccuracy, should be able to contribute to the daily work for the prevention of accidents and raise the level of the safety work that is done within the area of rail road traffic.

One of the recommendations from the study is to construct a database containing basic statistics from real accidents and relevant surrounding variables. The database should then be used for the estimation of the different factors contributing to the likelihood for an accident. At the construction of the database it is very important to define the different variables to collect and also to define the way they should be used. All risk and/or safety estimators computed should also be expressed with their uncertainties i.e. confidence intervals should be given. This would give a chance to distinguish between real changes and random fluctuations. This is especially important when you look at the long-term changes in the number of accidents.

The report shows examples of how the proposed methods with time series and confidence intervals can be used. It also describes how multivariate methods could be used in the risk analysis, if the database would consist of more relevant surrounding variables.

Paper II.

Lindberg, E., Thedéen, T., Näsman, P. (1993).

Riskanalyser/riskvärdering inom järnvägsområdet.

VTI Rapport 381 (in Swedish)
Statens väg- och trafikinstitut
1993

Summary
The project, consisting of two studies, presented in the report describes risk analysis/risk evaluation in a railway context.

The project was aimed at studying the feasibility of using risk analysis methods in a railway context. The report starts with a discussion of a number of concepts that are central to risk analysis and risk evaluation. Thereafter, an overview of different steps in a risk analysis is given, and considerations, which need to be made in each step, are discussed.

Examples are given of methods developed in order to analyze risks emanating from technical systems, organizational conditions and lack of human reliability. Further, a few examples are given of methods designed to analyze event sequences with respect to the interaction of human, technical, and organizational causes of accidents.

A literature review of published risk analyses in the road and railroad traffic sectors is also presented in the report. These analyses attest to the feasibility of using risk analysis as an aid to decision making with many varied applications within the transportation sector.

A number of possible applications of risk analysis in a railway context are discussed, and, in an appendix to the report, the frame of reference developed in the project is applied to an issue concerning platform safety.

Finally, the role of risk analysis as an aid to decision making is discussed, and a number of suggestions for how it might best be used in a railway context are offered.

Paper III.

Leden, L., Claesson, Å., Gårder, P., Näsman, P., Pulkkinen, U., Thedéen, T. (1997).

Metodik för före-/efterstudier.
Tillämpat på cyklisters trafiksäkerhet

KFB-Rapport 1997 (mainly in Swedish, parts in English)
Kommunikationsforskningsberedningen
1997

Summary
The extensive resources spent on expanding the bicycle network in Gothenburg have given us a unique opportunity to use before and after studies for evaluating the effects on safety of different measures. Since 1992 the City of Gothenburg has annually spent approximately 30 million kronor (around U.S. $5 million) on such measures.

Gothenburg has a database containing police reported as well as hospital reported accidents. In the project we were able to extract data from this database for the period January 1988 to September 1996. The velocity of bicycle traffic as well as various types of interactions, such as stopping behaviour, was studied with the help of video recordings at four of the five chosen junctions. The speeds were measured for turning free-moving motor vehicles at the point of potential conflict with cyclists. Extensive conflict studies were carried out at one junction.

The primary hypothesis was that a raised bicycle path through the intersection would improve the safety of cyclists because of lower speeds of motor vehicles crossing the path. To further accentuate the bicycle path, it was given a red pavement. The primary goal of our studies was to investigate different methods for evaluating the safety effect of this measure.

Some of the most important results from the project are:

- Bicycle flows have increased by 70 to 100% on the two sections where measurements were taken before and after the reconstruction. Bicycle flows on one of two control sections decreased by 10% and increased by 30% on the other. The two control sections can be seen as independent representations of typical changes in bicycle flows. Together, they indicate a growth in bicycle flows of around 22%. The extra increase on our experimental sections would then be at least 50%, a result of better layout.

- The raised bicycle path has generally led to reduced motor vehicle speeds. The velocity for right-turning motor vehicles was on average reduced by 40% as a result of this intervention. The velocity of motor vehicles crossing the raised path is generally around 10 to 15 km/h.

- The velocity of cyclists was measured at all five intersections before as well as after the intervention. This velocity was reduced significantly at two intersections, increased significantly at one, and remained approximately constant at the other two. An increase in speed around 13% was seen as typical.

- We developed a quantitative model based on the stated opinions of experts based on relations between the initial speed of the motor vehicles and bicycles respectively and collision risk. The average velocity of motor vehicles turning right was reduced by 40%. According to our model this implies a 14% reduction in the number of bicycle - motor vehicle accidents. According to experts collision risk is more sensible for speed changes for cyclists than cars and a 13% increase in speed among bicyclists would increase the risk by 40%. However, the model estimates the combined effect of decreasing vehicle speeds and increasing bicycle speeds as a 10% decrease in the number of bicycle - motor vehicle accidents, indicating that the positive effect of the reduced automobile velocities is almost completely cancelled out by the increased speed of bicyclists.

- The analysis of the relationship between bicycle flow and the number of accidents in the experimental area shows that the relative risk (when risk is defined as the number of expected accidents per passing bicyclist) decreases with increasing bicycle flow. A 50% increase of the flow reduces the relative risk by about 24%. However, the increase of the bicycle flow means that the total number of bicycle accidents is expected to increase by about 15%. If the bicycle flow is doubled, e.g. from 50 to 100 bicyclists per hour, the relative risk will be reduced by 38% while the total number of accidents will grow by 25%.

- Bicyclists were asked about their assessment of the safety after the reconstruction compared to before. On average, they perceived a 20% improvement, without any great variation between the four different locations included in this query.

- The experts consulted estimated on average a 30% improvement in safety of raising the path 10 cm and paving it red. It has to be kept in mind that the experts were told that all other external factors, including bicycle flow volumes, were to be considered unchanged.

- The total time of conflict studies performed at the five experimental junctions amounted to 315 hours. The majority of this time (225 hours) focused on Södra Vägen - Olof Wijksgatan. Here, the number of conflicts per 100 hours of observation was reduced from 39 in the before situation to 20 after the reconstruction. Target conflicts, i.e. conflicts involving bicyclists cycling along Södra vägen, was in the before situation only 10% of the total number of conflicts. The number of conflicts involving bicyclists was decreased by about 20%, the number of conflicts involving only motorists was reduced by about 60%, and the number involving pedestrians was reduced by about 80%. In other words, bicyclists' safety was improved the least while other road-users, especially pedestrians, gained much more. The reason for this ought to be the reduced speeds among motorists without compromising the visibility of pedestrians.

- The stopping behaviour of motorists at the raised path changed only marginally.

- A theoretical, stochastic model for road-user interactions at junctions was sketched. It was concluded that background material is lacking for creating any type of sophisticated model. Entering data into this simplistic model gives predictions of an increase in the number of accidents but a reduction in the relative risk of an accident for an individual bicyclist. In other words, the same tendency was found as indicated by the other methods of prediction.

- One result from the questionnaire with the experts consulted, looking at the relation between the initial speed of the motor vehicle and the risk of a collision was used in the quantitative model. The experts were also in concurrence with respect to the shape of the relationship between time-to-accident and speed, between initial speed of motor vehicle and risk of collision, as well as between motor vehicle speed at impact and risk of injury. However, there was no agreement regarding to risk of collision versus conflicting automobile flow or risk of collision versus bicycle flow.

- The whole area of experimentation contained 18.7 km of street and 44 intersections along the following streets of Gothenburg:

- Eklandagatan, between Gibraltargatan and Korsvägen, 5.6 km, 7 intersections.
- Första Långgatan, between Barlastgatan and Järntorget, 2.4 km, 5 intersections.
- Vasagatan, 2.7 km, 12 intersections.
- Linnegatan, 3.8 km, 9 intersections.
- Sprängkullsgatan, 1.5 km, 6 intersections.
- Övre Husargatan, 2.7 km, 5 intersections.

There were 287 reported accidents involving bicyclists within this specified area during the eight-year period 1988 - 1995. Bicycle-vehicle accidents as well as bicycle-pedestrian accidents are much more frequent here than in Gothenburg as a whole. Single bicycle accidents accounted for only 47% of all bicycle accidents in this area as opposed to 64% for the city as a whole.

- The number of accidents in the before and after periods in central Gothenburg (excluding the area of experimentation) were used for comparison purposes. Indices of efficiency and their standard error were calculated for the reconstructed sites. Bicycle-vehicle accidents from 1898 intersections in Gothenburg were studied to get information of the accident frequency function. Based on a methodology developed by Hauer (Hauer 1992a, Hauer 1992b), an example is shown of how one can assess the accuracy of the estimate based on the number of accidents recorded at the experimental sites and the accident frequency in a population of (similar) sites.

- From a strategic perspective, one can attempt to reduce the number of serious injuries. The priority with respect to accident types according to accident analysis turns out to be:

1. Bicycle - pedestrian
2. Bicycle - automobile
3. Single
4. Bicycle - bicycle

Paper IV.

Näsman, P., Thedéen, T. (1995).

Säkerhetsanalys beträffande föreslagen ny vägsträckning jämfört med gammal vägsträckning av väg E 22, delen Söderåkra-Hossmo vid Vassmolösa.

Rapport (in Swedish)
Centrum för säkerhetsforskning
KTH
1995
TRITA-AMI REPORT 3028.

Summary
The project presented in the report compares two different road sections; the existing one with a new planned one, by use of risk analysis/risk evaluation.

The study was aimed at studying the feasibility of using risk analysis methods in a road construction context, comparing two different road sections. The comparison was focused on transportation of hazardous goods.

The report starts with a discussion of a number of concepts that are central to risk analysis and risk evaluation. Thereafter, an overview of different steps in a risk analysis is given, and considerations, which need to be made in each step, are discussed.

The results of the project show that risk analysis and risk evaluation are methods well worth to be used in the context in question. The results also show that the new road section, compare to the old one, is a better alternative given that you try to minimize the risk for an accident with hazardous goods. This is of key interest, for the project, since the two different road sections that are compared run through a water supply that supplies a fairly large city, Kalmar, with water.

The report gives examples of, and shows, that there are a lot of data in the area of road traffic, which can be used in a risk analysis/risk evaluation. The data sources are well described and risk measures are computed based on the information in the data sources. The different risk measures are then used in the risk analysis/risk evaluation, and the different decision alternatives are discussed.

Road traffic is an area where you can base risk analysis/risk evaluations on observed events and there are a lot of data collected regarding the roads, the traffic and the number of accidents. All this gives the opportunity to base your risk analysis/risk evaluation on "real" data and use statistical methods to estimate different kind of risks in the system.

This also gives the opportunity to model the traffic flows on the different road sections and compute the different risks that occur within the different road sections. In this way you can minimize the risks, i.e. the number of accidents with hazardous goods, with and within different road sections.

Finally the report identifies two major risk objects within the new road section and proposes measures to be taken to minimize the risks with these two risk objects.

Paper V.

Näsman, P., Thedéen, T. (1996).

En statistisk utvärdering av de mått SAS använder för att kontrollera uppfyllelsen av de flygsäkerhetsmål man satt upp.

Rapport (in Swedish)
Centrum för säkerhetsforskning
KTH
1996
TRITA-AMI REPORT 3029.

Summary
The aim of the study presented in the report was to evaluate the risk measures the Scandinavian airline company SAS uses to control their fulfillment of the air safety goal they have established.

Safety is one of the most important aspects of quality for airline companies. The overall safety should be possible to follow both as the actual level and as the trend. To manage the risks also incidents for different aircraft types and their dependence of different variables should be studied. The influence of random errors should be taken into account using confidence intervals.

The primary goal in the safety work is to avoid accidents, i.e. mainly events leading to fatalities and/or big material losses. Such accident data are reported both in the companies and to the aviation authorities. The reporting can be considered to have a high quality. If there were many data and they formed relatively stable time series the safety development could be studied in a rather straightforward way plotting the number of accidents in relation to time. Luckily from a safety point of view, but troublesome from a statistical one, this is not the case. The data are few and accordingly the random fluctuations are large.

Next step is data about incidents, i.e. events that are not causing large damages but nevertheless may be used as indicators of risk. The flight incident data for the airline companies, in this case SAS, are mostly collected automatically and then classified into ten risk classes, from 1 (lowest) to 10 (highest). Together with these data a number of parameter values are given such as date, aircraft type, stage of the flight, type of error (human, technical), etc. The quality of the “classified” incident data is not as reliable as that of accidents, since it is partly dependent of the (subjective) classification and of reports from the crew. In order to say something about the safety standard we also need information about the number of departures and flight hours for each aircraft type.

SAS applies a Flight Safety Index constructed as follows. Each incident is given the number of the corresponding risk class as its mark. The average of all risk marks during the period in question - month, year- is then the Flight Safety Index.

The Flight Safety Index is used to present the Board with information about the safety standard and possible trends - hopefully downwards. It might then also comply, or not comply, with some goal for the safety work of the company. As a measure of safety it has some evident drawbacks.

(i) If the reports of incidents with small marks due to safety campaigns become more frequent, that fact will lower the Flight Safety Index. In reality the standard might not have changed at all.

(ii). If in one time period incidents of all classes increase with the same percentage then the Flight Safety Index will remain the same albeit the safety has decreased.

(iii). The Flight safety Index should be accompanied by some confidence interval, that with an upper bound best suited to the use of the Flight Safety Index. Such a bound takes into account the random fluctuations due to differences in traffic volume and number of reported incidents.

Another way to study the overall safety standard is to concentrate on the more severe risk classes - index 3 or larger. One SAS standard is to prescribe that "99.86% of all operations should be without occurrences classified with Flight Safety Index 3 or higher", i.e. at most 0.14% of all operation could have a safety index higher than 2. The Safety Measure S should then be the percentage of operations with incident index larger than 2. As a safety measure it has better properties than the Flight Safety Index.

(i). The number of incident free operations influences this measure S, cf. with above!

(ii). It gives a higher weight to more severe incidents.

As with the Flight Safety Index this measure S should be accompanied by an upper confidence bound to take into account random fluctuations.

Another way to interpret the safety measures given above is the following:
The Flight Safety Index is the mean “mark” or average risk for a random SAS passenger, given he encounters an incident during the flight. The measure S gives the probability for a random SAS passenger to encounter a severe- index > 2- incident during a flight. In a way both measures give some information of the risk for a passenger.

A goal for the company could then be that a passenger nearly never will suffer any incident at all and if there is an incident that it will not be a severe one. More precisely:

Let S_1 be the probability that no incidents occur during a flight and S_2 the probability that the severity index is larger than 2, given that an incident occurs during the flight. A high S_1 then indicates that nearly all flights have no incidents and a low S_2 that, if an incident occurs it will be a minor one.

Goals for the safety work at SAS could then be:

$S_1 > a\%$ (e.g. 99.99%)

$S_2 < b\%$ (e.g. 0.001%) and decreasing by 10% during 1996!

It is important to decide how often these figures should be presented to the governing board. We have a clear cyclical variation of e.g. S_2. That means that it is difficult to compare a particular month with the preceding one. One way to go is to use smoothing but then monthly data for some years should be analyzed. On a yearly basis standard statistical procedures could be used to get upper confidence bounds for the safety measures including estimation of trends.

The “inner” safety management should of course have the goal to lower the risks. The statistical methods will then be very similar to those discussed above but here the risks of different aircraft types are studied.

Paper VI.

Piper, R., Kager, L., Näsman, P. (1982).

Acute Appendicitis: A Clinical Study of 1018 Cases of Emergency Appendectomy.

Acta Chirurgica Scandinavia
No 148: 51-62
1982

Summary

The article reports a clinical study of 1018 primary appendectomies. There were 521 females and 497 males with ages between 1 and 89 years. The median age was 22 year. The specimens were microscopically examined in 92.5% of the cases. The accuracy of the surgeons' diagnosis was 67.6%. Other surgical diseases were present in 4.1% of the study group. The frequency of perforation was 13.2% of all operated and 19.5% of the cases with proven appendicitis. Perforation was equally common in both sexes, but was more frequent in young and elderly patients. Symptomatology and clinical findings showed only slight differences between the different age groups. Duration of symptoms showed no differences for patients of different ages in cases with perforation, but a pre-operative delay in the hospital of at least 6 hours occurred more often in perforative cases, where it occurred in nearly 75% of the patients under 10 years of age. Two fatalities occurred in the study group. Both patients were above the age of 70, and one of them had a normal appendix removed. Post-operative complications were found in a total of 169 patients. Septical complications predominated over non septical (11.5% versus 8.1%), and were most frequent in perforative cases. The mean hospital stay was substantially prolonged by septical complications (12.9 versus 5.3 days for uneventful cases). The age of the patients was without any influence on the frequency of septical complications, but non-septical complications occurred more often in elderly patients. Among the non-septical complications, cardiac and thrombo-embolic problems as well as intestinal obstruction were found worthy of special attention. It is concluded that in the management of appendicitis every attempt should be made to increase diagnostic accuracy and to operate without delay in those cases where appendicitis is diagnosed or strongly suspected.

Paper VII.

Piper, R., Kager, L., Näsman, P. (1983).

Clinical Significance of Mucosal Inflammation of the Vermiform Appendix.

Annals of Surgery
Volume 197, No. 3
1983

Summary
In 942 emergency appendectomies, the clinical data of 77 patients with inflammatory changes confined to the mucosa of the vermiform appendix were compared with data from 622 patients with diffuse acute appendicitis and 243 patients without evidence of inflammation in the appendix. In all cases, routine histologic sections of the specimens were reviewed. Of the 77 patients with mucosal appendiceal inflammation, 50 were female and 50% were under 17 years of age. In several clinical aspects, such as incidence of nausea, vomiting, migration of pain, and localized muscular rigidity, there existed significant differences between patients with mucosal inflammation and patients with diffuse appendicitis. Conversely, no statistically significant differences were found between patients with mucosal inflammation and patients without evident appendiceal inflammation. These results in addition to the frequent finding of histologically indistinguishable changes in appendices removed incidentally suggest that the condition is not responsible for the actual complaint.

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