# THE NEED FOR A SYSTEMS APPROACH TO ROAD SAFETY

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## Abstract

The traditional approach to road safety, the road-user approach, has been that the individual road-users utterly are responsible when crashes occur. Countermeasures have thus mostly been aimed at changing the behavior of the road-user in order to adapt him/her to the road transport system.

The Vision Zero approach to road safety is built around two axioms; the system must be adapted to the mental and physical conditions and limitations of the human being and the responsibility for road safety must be shared between the road-users and the designers and professional operators of the system.

In other hazardous socio-technical systems in society systems theory is considered a promising way to better understand and manage safety.

The two road safety approaches were contrasted with a safety approach based on systems theory in order to identify important features differentiating these approaches.

It was found that the important features of systems theory with regard to safety; safety seen as an emergent property, the variability of system performance due to component variability and the hierarchical structure of a socio-technical system, cannot be found in the road-user approach. The Vision Zero approach on the other hand is clearly a step forward towards a systems theory approach. Road safety is seen as an emergent property due to the complex relationships between the main components of the road transport system. However it is not quite clear how the Vision Zero approach views and handles performance variability. Furthermore the road transport system is viewed as a hierarchical system in the Vision Zero approach but the control processes between the different levels and their constraints have not yet been clearly defined and operationalized.

**Acknowledgements**

This master thesis is the result of a growing understanding from my point of view that there are safety research and safety strategies in other hazardous complex socio-technical systems which differ from the ones in the road safety area. It should be possible to apply them to the road safety work of today in order to make it more efficient.

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# Introduction

## *Background*

Road traffic injuries are a major, but often neglected global public health problem. According to WHO (2004) approximately 1,2 million people are killed in road traffic crashes annually and as many as 50 million are injured. There is an obvious risk that these figures will increase substantially without increased efforts and new initiatives, especially if the increasing traffic in the developing countries is taken into account (WHO, 2004).

The traditional approach to road safety has been that the individual road-users utterly are responsible when crashes occur. One important basis for this view is findings claiming that human error is the cause of approximately 90% of road crashes (WHO, 2004) and the remedies hence primarily should be focused on persuading the road-users to adopt an error-free behavior. Such remedies consist of information, education, legislation and police surveillance. Efforts have also been put on the safety improvement of the two other components in the road traffic system; the vehicle and the road. But the safety features of the three main components mostly have been developed and optimized in isolation from each other (C. Tingvall, personal communication, June, 2007).

In other hazardous complex socio-technical systems where safety is more or less a prerequisite for the survival of the system, e.g. nuclear power safety, software safety and aviation safety, systems theory is considered as a promising way to better understand and manage safety. (Leveson, 2002).

The Vision Zero, which was presented in Sweden 1996 and constitutes the road safety strategy in Sweden, intends to take a more holistic and systemic approach to road safety (Ministry of Transport and Communications, 1997). It may therefore be a step closer towards a safety approach based on systems theory.

## *Scope*

After an introduction in which different road safety approaches, the thesis is focused on contrasting two of them; the road-user- and the Vision Zero-approach, with a safety approach based on systems theory. In the discussion the possible implications of a systems theory approach to road safety is elaborated.

The literature study of systems theory is focused on identifying features which are important from a safety point of view and can be used to contrast the two road safety approaches with. The study touches general systems theory but is mainly based on the interpretations of systems theory from a safety point of view proposed by Hollnagel (2004) and Leveson (2002).

## *Purpose and Research Question*

The purpose of this master thesis is to contrast the road-user focused approach and the Vision Zero approach in road safety work with an approach based on systems theory in order to identify important features differentiating these approaches. These features may have an influence on the identification of road safety countermeasures and their implementation. Hence the research question of this master thesis is: *Could a systems theory approach improve the effectiveness of current road safety work?*

## Different Approaches to Road Safety

### *Introduction*

The approaches to improve road safety have varied over time and reflect the way researchers and society explain accidents and how they can be avoided (Wegman, 2002). From the scientific literature it is quite difficult to identify a clear line of development of different approaches to road safety. Tingvall and Lie (2001) consequently points out that it is hard to give an entire picture of the development of the view on the safety problem in the road transport system since it is a system that has grown without any actual planning of how to take care of the safety problem. This could be explained by the theory of path dependence. According to Liebowitz (nd.) second-degree path dependence means that:

> ........efficient decisions may not always appear to be efficient in retrospect. Here the inferiority of a chosen path is unknowable at the time a choice was made, but we later recognize that some alternative path would have yielded greater wealth. In such a situation, which we will call *second-degree path dependence*, sensitive dependence on initial conditions leads to outcomes that are regrettable and costly to change. They are not, however, inefficient in any meaningful sense, given the assumed limitations on knowledge.

Applied to the road transport system it means that safety was not considered as a major problem in the early days of road traffic. Thus it was possible to focus on the development of the efficiency of the system without taking the safety problem into consideration when designing and building the system. The magnitude of the safety problem was recognized much later but it was then too late to integrate safety into the system in an easy and cheap way.

But despite the difficulty in giving an entire picture of the development of the view on the safety problem there seem to be some common characteristics. Wegman (2002) has summarized them in Table 1.

| Period | Characteristic |
|---|---|
| 1900-1920 | Accident is a chance phenomenon |
| 1920-1950 | Accident caused by the accident-prone |
| 1940-1960 | Accidents are mono-causal |
| 1950-1980 | A combination of accidents fitting within a "system approach" |
| 1980-2000 | The person is the weak link; more behavioral influence |
| 2000- | - Better implementation of existing policies<br>- "Sustainibly Safe"; adapt the system to the human being |

Table 1. (Wegman, 2002)

Also Tingvall and Lie (2001) discuss the "accident-prone theory". Wegmann (2002) and Tingvall and Lie (2001) seem to be agreed on that this theory has its foundation in a legal view where the road-user has broken the law and therefore is both guilty and liable. This legal view is still valid and according to Tingvall and Lie (2001) it has, more or less characterized the road safety work up until today. Hale (1999) makes a broader categorization of the development of safety in general over time as three ages. The first two ages have been focused on technical and human failures respectively. The third age, which we are passing into, is characterized by a focus on socio-technical and safety management systems.

According to Wegmann (2002) a systems approach has been present 1950-1980. This approach is mainly based on the work of William Haddon Jr. Haddon (1972) proposes a nine cell matrix for road losses consisting of three rows; the pre-crash, crash and post-crash phase of an accident and three columns consisting of the elements of the road transport system; the human, the vehicle and the environment (both physical and socio-cultural). According to O'Neill (2002) the importance of Haddon's matrix is that it implies the significance of working with *both* loss reduction and crash prevention  and the significance of working with all elements of the system, not only the road-user, in order to identify causes and countermeasures. Wegman (2002) further states that the safety approach was then again focused on road-user behavior 1980-2000. In the end of the 1990´s there seems to be a change towards a more system-oriented view again in which the idea is that the system must be adapted to the human being and her limitations and imperfections. According to Wegman (2002) the question in traffic for decades has been if "man should adapt to traffic or traffic to man". This ambiguity is well reflected in Table 1 and the pendulum seems to have been oscillating between those extremes the last 50 years.

## *The Road-User Approach*

The road-user approach (RUA) to road safety is focused on human error as the main cause of road accidents and hence the individual road-user is solely responsible when crashes occur (WHO, 2004). This view is based on several studies, e.g. Treat et al., (1977) and Sabey and Taylor (1980), claiming that road-user factors are the sole or contributory factors in approximately 95% of all road accidents. According to Wegman (2002) international research groups still support the truth of these findings. One example that clearly shows the impact of those findings on road safety strategies is the Irish Government Strategy for Road Safety 1998-2002 quoted by Wegman (2002):

> Human action is a contributory factor in over 90% of road accidents. The principal emphasis of all road safety strategies must therefore be on improving road user behaviour. This behaviour needs to be informed, trained, and to be modified, so as to improve interaction between road users, to ensure consideration for others to reduce risk. In this way a culture of road use is created that is both precautionary and pro-active in relation to road safety.

Another important basis for the RUA is the legal view of road accidents (Wegman, 2002 and Tingvall and Lie, 2001). In all current road transport systems around the world, the road-user has almost total legal responsibility for safety (Tingvall & Haworth, 1999). In most countries, there are general rules that the road-user, in all situations, should behave in such a way that accidents do not occur. If an accident occurs, at least one road-user has, by definition, broken the general rule and the legal system can therefore act. Rollenhagen (2003) means that the human being has a deeply rooted tendency to burden individuals with guilt and that we often attribute ourselves a greater responsibility for accidents than other circumstances. According to Hollnagel (2004) and Orasanu and Martin (1998) there is also a belief that behind accidents with severe consequences lies proportionally severe, intentional errors or causes. Such belief supports the RUA and hence almost no legal responsibility is put upon the designers or administrators of the road transport system.

Dekker (2002) further claims that such an approach is based on our reactions to failure and shares the following features:

- **Retrospective.** Reactions arise from our ability to look back on a sequence of events, of which we know the outcome;
- **Proximal.** They focus on those people who were closest in time and space to causing or potentially prevent the mishap;
- **Counterfactual.** They lay out in detail what these people could have done to prevent the mishap;
- **Judgmental.** They say what people should have done, or failed to do, to prevent the mishap.

An important consequence of the RUA is a main focus on accident prevention and hence the countermeasures are mainly aimed at changing the behavior to adapt the road-user to the system. The road safety work has up until now heavily been relying on countermeasures such as regulating and surveillance of behavior, information and education in order to make the road-user to behave correctly so that accidents will not occur. Mackay and Tiwari (2005) claim that the historical view of remedies is “that road users through training, supervision and retribution can cope with the demands of traditional highways without causing accidents”. The responsibility of the society has mainly been to administrate this system by issuing new regulations, financing and carrying out surveillance, information campaigns and educational programs (C. Tingvall, personal communication, June, 2007). As mentioned above almost no legal responsibility has been put on the designers, administrators or professional users (e.g. haulers, bus- and taxi companies, local communities and other organizations and companies buying or selling transportation) of the system.

## ***The Vision Zero Approach***

In 1997, the Road Traffic Safety Bill founded on a strategy called the Vision Zero was passed by a large majority in the Swedish parliament. According to the Ministry of Transport and Communications (1997) the Vision Zero means that eventually no one will be killed or seriously injured within the road transport system. According to Tingvall and Haworth (1999) the Vision Zero "addresses fatalities and those injuries where the victim does not physically recover within a certain period of time. This means that common, but not long-term disabling injuries, and non-injury accidents are more or less outside the scope of the Vision". This is one of the cornerstones of the Vision Zero and leads to the important starting point that the biological tolerance of the human body against external forces should be the limiting factor when designing the road transport system.

The theory behind Vision Zero is summarized in Figure 1.

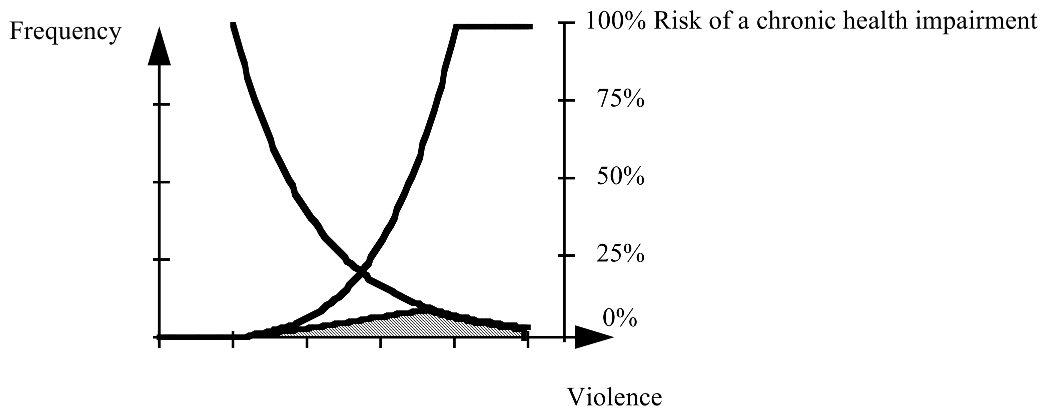



Figure 1. Schematic figure of the theory behind the Vision Zero (Belin, Johansson, Lindberg & Tingvall, 1997).

The left-hand curve schematically shows the relationship between the number of accidents (frequency) and the accident severity (violence). It points out that most road traffic accidents occur at a low level of severity. The right-hand curve schematically shows the relationship between the accident severity (violence) and the risk of chronic health impairment. The bottom curve describes the distribution of the number of persons seriously injured as a function of accident severity (violence) and risk. This curve represents the road safety problem, i.e. those cases where a serious loss of health occurs. According to Tingvall, Krafft, Kullgren and Lie (1999) there are three distinct strategies to minimize the number of fatal and serious injuries in car accidents; reduce the number of accidents, modify the accident so that the accident severity is lower and finally protect occupants of a vehicle so that a given accident severity is less hazardous. It is hence a question about taking measures that either individually or in combination serve both to prevent accidents, in order to move the left-hand curve in Figure 1 to the left, and to prevent injuries, in order to move the right-hand curve in Figure 1 to the right (Belin, Johansson, Lindberg & Tingvall, 1997). An example of the former is reducing drink driving, which mainly reduces the number of accidents, and an example of the latter is the use of seat belts, which reduces the likelihood of an injury (Tingvall, Krafft, Kullgren & Lie, 1999). But as Tingvall and Haworth (1999) state ”accident prevention and injury prevention become somewhat blurred” in this model since reduction in exposure to external violence ”can be achieved not only by avoiding accidents, but also by modifying it to fit into the human tolerance, sometimes filtered by protective systems”, e.g. a car crashing into a guardrail instead of a tree. This still is an accident but at a lower severity. Tingvall and Haworth (1999) emphasize that in the Vision Zero concept, ”it is assumed that accidents cannot be totally avoided. Hence the basis for this concept is built around the human tolerance for mechanical forces”.

From the theory in Figure 1 a model of safe road traffic is developed and forms the basis for a strategy for countermeasures which is shown in Figure 2.

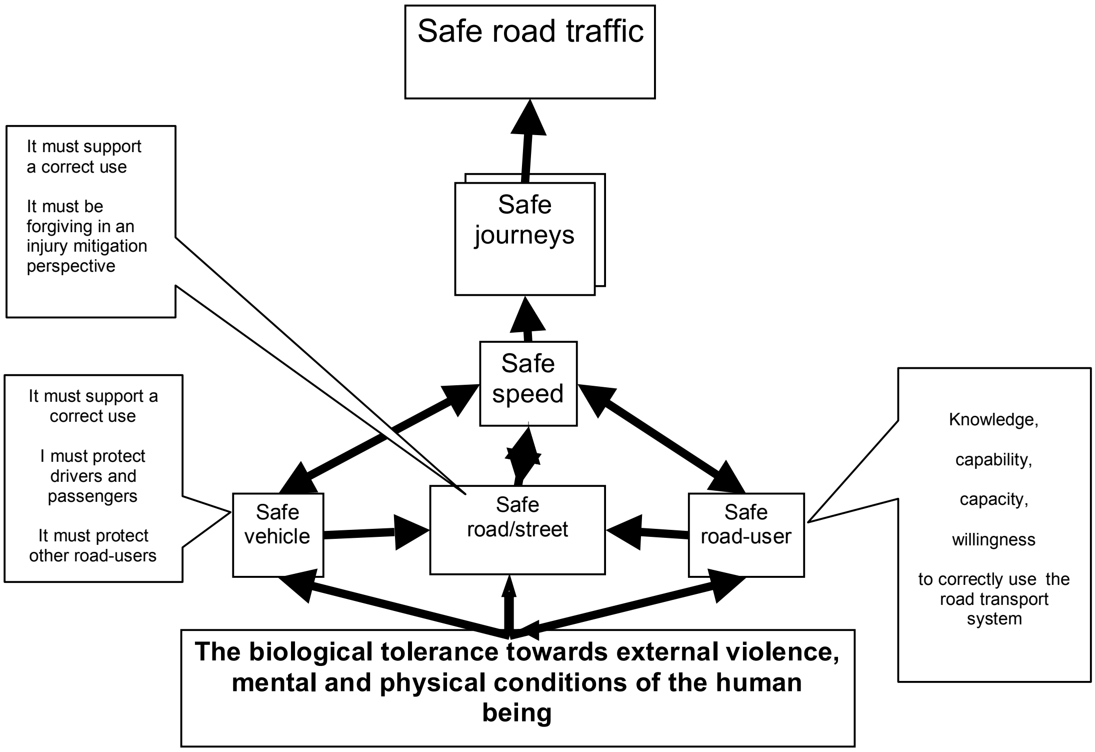



Figure 2. A model of safe road traffic for car occupants (C. Tingvall, personal communication, June, 2007).

The model describes, from a system perspective, the way a number of factors interact in order to achieve safe road traffic. The starting point for the model is the mental and physical conditions and limitations of the human being. The main limiting factor is her ability to withstand external violence, which can be considered given and constant. The passive safety, or injury mitigation capability of the system, is determined by the safety standard of the vehicles and the roads/streets added together. The total injury mitigation capacity of these components determines the safe speed of the system. Deficiencies in the system design must be compensated by a lower speed. According to Tingvall and Haworth (1999) the speed is the most important and regulating factor in the model. If the speed is lowered, the safety level of the vehicles and roads and/or streets can be lowered. Inversely the safety level of the vehicles and the roads and/or streets must increase if the speed increases. If the safety level of the vehicles decreases the safety level of the roads/streets must increase in order to maintain the speed. The speed level also influences the ability of the road-user to handle complex situations and hence the accident risk, mainly due to the increased stopping distance (Elvik, Christensen & Amundsen, 2004).

To be able to achieve a safe journey the road-users must follow the rules that the society and hence the system designers have drawn up for the safe use of the system e.g. obeying the speed rules, not driving under the influence of alcohol or other drugs and using the seatbelts. It is though important to identify what responsibility could be put on the road-user with his or her capacity as a basis. Different driver support systems in the vehicles and/or on the roads/in the streets may therefore be necessary (C. Tingvall, personal communication, June, 2007). According to Tingvall and Haworth (1999) the interfaces between the different components of the road transport system (humans, vehicles, roads) and their relation to speed become important. It is therefore important to define the parameters of the interfaces to make it clear what the limitation of a car is, as well as the road/street, in order to sort out the responsibility of the different components. In this sense the automotive industry and the designers of the infrastructure together will set the speed limits in the future (Tingvall & Haworth, 1999).

In contrast to the RUA the Vision Zero approach (VZA) explicitly states that the responsibility for road safety is shared by the designers, administrators and professional users of the road transport system and the road-user. This shared responsibility is expressed in the following way (Ministry of Transport and Communications, 1997):

1. The designers of the system are always ultimately responsible for the design, operation and use of the road transport system and thereby responsible for the level of safety within the entire system.

2. Road-users are responsible for following the rules for using the road transport system set by the system designers.

3. If road-users fail to obey these rules due to lack of knowledge, acceptance or ability, or if injuries occur, the system designers are required to take necessary further steps to counteract people being killed or seriously injured.

## Systems Theory

### *General Concept*

The systems theory approach began to emerge in the 1930´s and 1940´s as a response to the limitations of the classic analysis techniques and their possibilities to cope with the more and more complex systems being built (Checkland, 1981). Bertalanffy (1968) applied the approach to biology and also suggested that ideas emerging in other areas could be combined into a general theory of systems. The traditional scientific approach to systems had up until then been reductionistic (analytic reduction) (Pariès, 2006). The reductionistic approach argues that from scientific theories which explains phenomena on one level, explanations for a higher level can be deduced (Skyttner 2005). Or as Leveson (2002) expresses it:

> In the traditional scientific method referred as *divide and conquer* systems are broken into distinct parts so that the parts can be examined separately: Physical aspects of systems are decomposed into separate physical components while behaviour is decomposed into events over time.

Systems thinking is a response to the failure of mechanistic thinking to be able to explain social, socio-technical and biological phenomena (Skyttner, 2005). Skyttner further states that a system will lose its synergetic properties and cannot be understood if analytic reductionism is used to examine it. The system theory focuses on systems as a whole, not on the separate parts. Leveson (2002) states that:

> It assumes that some properties of a system can only be treated adequately in their entirety, taken into account all facets relating the social to the technical aspects. These system properties derive from the relationships between the parts of systems: how the parts interact and fit together.

## ***Systems Theory and Safety***

### *Safety as an Emergent Property*

Skyttner (2005) states that emergence is an important concept of systems theory and that it “results from the interaction of independent parts when they stop being independent and start to influence each other”. He argues that it is the relationships between the components of a system and not the nature of the components themselves that determines the properties and behavior of it. This is in line with both Leveson (2002) and Hollnagel (2004) who mean that accidents can be seen as emergent phenomena. Accidents occur when components of a system interact with each other and these interactions are not possible to foreseen because of their complexity (Hollnagel, 2004).

According to Leveson (2002) systems theory provides the theoretical foundation for systems engineering, which views each system as an integrated whole even if it is composed of diverse individual and specialized components. A basic and important assumption of systems engineering is according to Leveson (2002) “that optimization of individual components or subsystems will not in general lead to a system optimum; in fact improvement of a particular subsystem may actually worsen the overall system performance because of complex, non-linear actions among the components”. This means that safety can not be optimized through the optimization of the safety performance of the individual components and according to Leveson (2002) “attempts to improve long-term safety in complex systems by analyzing and changing individual components have often proven to be unsuccessful over the long term.” This leads to the important, general and basic principle for systems engineering that a system is more than the sum of it parts (Leveson, 2002).

*System and Component Performance is Variable*

Hollnagel (2004) conducts a line of arguments that socio-technical systems in the modern society tend to increase in complexity. By complex systems Hollnagel (2004) means systems which “consist of multiple parts that depend on each other, and there is only a limited possibility of delaying processes or in carrying out actions”. This notion is in line with Perrow (1984) but who also underlines that in a complex system there are unexpected interactions between the components of the system that are not obvious and anticipated. Hollnagel (2004) further reasons that performance in any complex system is necessarily variable. This is due to both the performance variability of the components of the system, and to the complexity of their interactions. Under these conditions accidents will occur if the performance variability is not under control and/or barriers are introduced. This is in line with Skyttner (2005) who states that in a network of coupled variables each variable has a highest and lowest threshold. Within this limits the system can function normally but if the thresholds are exceeded disorder and finally collapse will occur. In the case of technical components in a system the performance variability is due to imperfections of manufacturing and operation. But the variability is also partly due to the design of the system in which working conditions and combinations of input which were not, or could not, be foreseen when the system was designed (Hollnagel, 2004). In the case of humans and social systems, performance is variable for many different reasons. The human tendency to adjust performance to current conditions and lack of constancy of perceptual and cognitive functions are the most important sources for this kind of variability (Hollnagel, 2004). Hollnagel (2004) underlines that these performance variabilities are not inherently bad. Instead they are necessary for system users and operators to learn and for a system to develop. He further argues that:

> Human performance must be variable and approximate because of the complexity of the socio-technical environment, and that it is the variability of performance rather than the complexity of systems as such that is the main reason for accidents. The variability is furthermore not the same as “human error”, and should not be considered

> as such. On the contrary, the variability is a necessary condition for the proper functioning of systems even moderate complexity and without that they would not work.

The strategy for prevention is either by introducing barriers or by performance variability management. Hollnagel (2004) though states that “barriers are valuable because they are effective against a specific type of disturbance even if the cause or origin of that disturbance is unknown”. This is in line with Haddon (1980) who argues that “.... reductions in desirable end results can often be achieved without exhaustive knowledge of their exact causes”. Hollnagel (2004) further claims that multiple barriers are needed to prevent undesired events from taking place.

*Systems as Hierarchical Structures*

According to Leveson (2002) accidents can be viewed as a control problem. A systems theory approach treats safety as an emergent property. Such property can be controlled by a set of constraints related to the behavior of the components of the system. According to the systems approach accidents occur when the components interact and those interactions violate the constraints (Leveson, 2002). Such violations can be component failures, external disturbances and/or dysfunctional interactions among system components which are not adequately handled by the control system. According to Leveson (2002) such control is imposed on many levels from the operational to the managerial. She further states that “socio-technical systems can be modeled as hierarchy of levels of organization with control processes operating at the interfaces between levels to control processes at the lower levels”. Leveson (2002) proposes a generic socio-technical control model with one hierarchical control structure for system development and one for system operation with interactions between them. The model is shown in Figure 3.

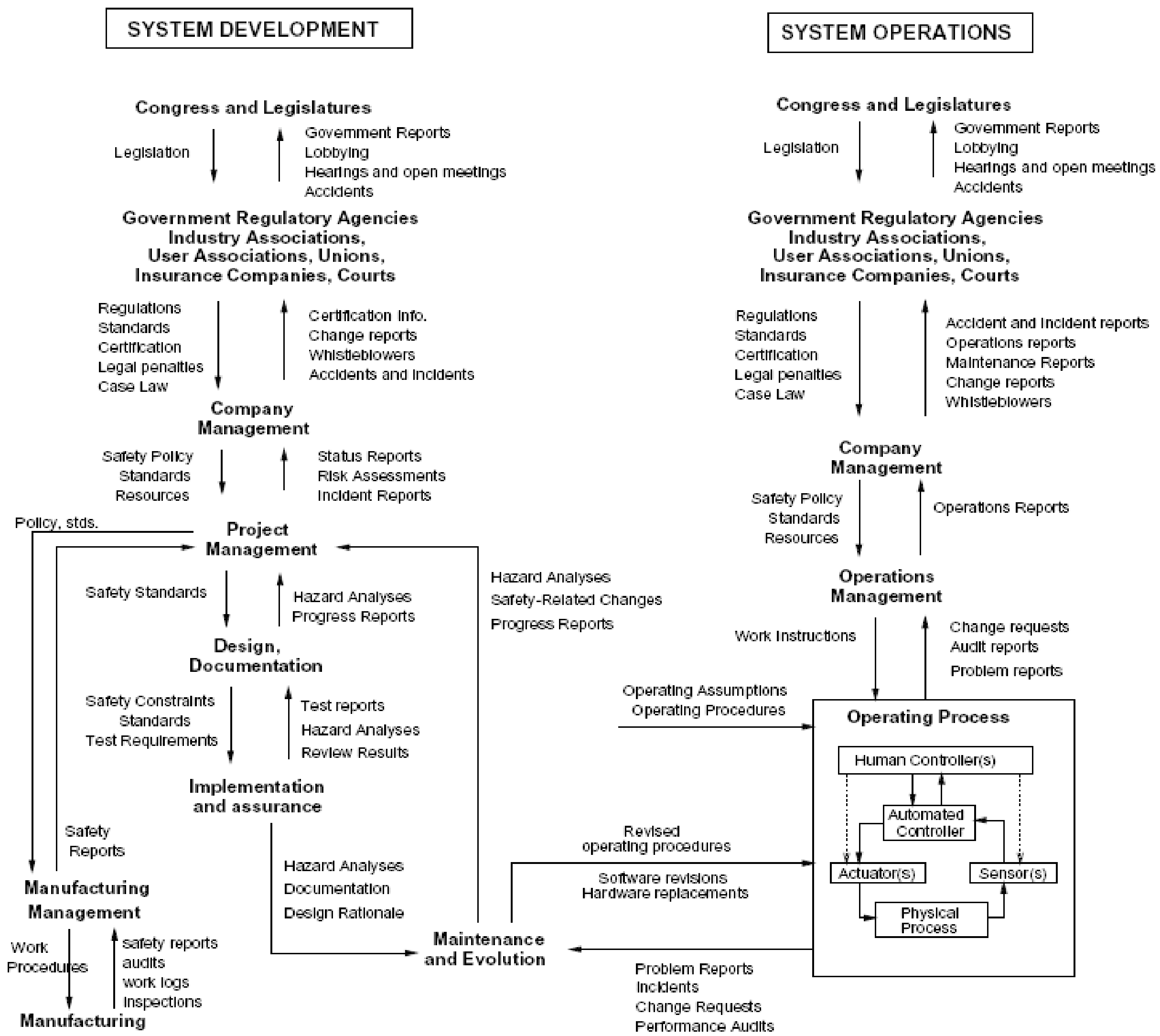



Figure 3. Generic model of socio-technical control (Leveson, 2002).

She consequently concludes that “while much of engineering is based on technology and science, systems engineering is equally concerned with overall management of the engineering process”.  Leveson (2004) also claims that “the most important factor in the occurrence of accidents is management commitment to safety and the basic safety culture in the organization or industry”.

### ***Systems Theory and Road Safety***

There are very few references to systems theory and road safety found when a literature research is carried out. Van Emmerik (2001) though concludes that the traditional, reductionalist approach to road safety has limitations and a systems approach could overcome some of these limitations. Also Zein and Navin (2003) conclude that the "simplistic representations of traffic safety disregard the dynamic interactions among the road environment, the vehicle, and the road-user". According to them these simplistic representations are a result of police reports that attribute more than 90% of all road traffic accidents to driver error. This leads to the incorrect conclusion that improving driver behavior is the only effective road safety strategy. They further claim that a systems approach in road safety acknowledges the more complex nature of road traffic accidents where multiple factors interact resulting in an accident.

## Analysis

### ***Method***

The method used to identify the differences between a systems theory approach on one hand and the RUA and the VZA on the other is divided into three steps.

1. From the literature on systems theory, summarized in the previous section of the thesis, important features of systems theory with regard to safety will be identified.
2. An analysis is carried out in order to judge if these features are applicable to the road transport system.
3. The RUA and the VZA are then compared to the identified features of systems theory in order to identify differences which may influence the effectiveness of the identification of road safety countermeasures and their implementation.

### ***Important Features of Systems Theory With Regard to Safety***

The following important features of systems theory with regard to safety can be identified from the literature.

- *Applicable to systems.* Systems theory is applicable to different kinds of systems. Skyttner (2005) especially points out social and biological systems while Hollnagel (2004) and Leveson (2002) apply the theory to socio-technical systems.

- *Safety as an emergent property.* Systems theory views safety as an emergent property due to the complex relationships and interactions between the components of the system.

- *System and component performance is variable.* Performance in any complex system is variable due to the performance variability of the system components and the complexity of their interactions. As a consequence accidents can be seen as a result of the performance variabilities among the components of a system and the complex relationships between them.

- *Systems as hierarchical structures.* According to Leveson (2002) socio-technical systems can be seen or modelled as a hierarchy of levels of organization with control processes operating at the interfaces between levels to control processes at the lower levels (Fig 3). To be able to control the system, constraints for these processes must be set, communicated, measured, controlled and enforced at each level.

### ***Applicability to the Road Transport System***

As mentioned above systems theory is applicable to systems. According to Skyttner (2005) there are many different definitions of systems depending on which scientific school one represent.  He refers to an often used common sense definition: ”A system is a set of interacting units or elements that form an integrated whole intended to perform some function”. From this definition it is possible to draw the conclusion that the road transport system really is a system since it consists of road-users, vehicles and road components that interact with each other in order to ”produce” transports of people and cargo.

In the literature on systems theory complexity is often mentioned as an important feature of systems which increases the unanticipated connections between components or subsystems. According to Skyttner (2005) complex systems are characterized by for example:

- a large number of elements,
- many interactions between the elements,
- attributes of the elements are not predetermined,
- interaction between elements is loosely organized,
- the system is subject to behavioural influences,
- the system is largely open to the environment.

Skyttner (2005) further states that complex systems often behave in an unexpected manner where the relationships between cause and effect often are difficult to understand. The road transport system consists of a large number of components in the form of road-users, vehicles and road components that each day interact many million times. The vehicle and road-user constitute a sub-system in which humans and technology interact. The vehicle and road components is also a subsystem where technology interact. The safety of the whole system is largely subject to the behaviour of road-users and the system is not only open to the environment; the environment could be seen as a part of the system. The attributes of the components are partly predetermined and the interaction between the components is highly random even though there are rules governing road traffic. Consequently the road transport system in many aspects corresponds with the characteristics of a complex system.

According to Wikipedia (2007) the term socio-technical systems refers to the ”interaction between society’s complex infrastructure and human behaviour. In this sense, society itself, and most of its sub-structures, are complex socio-technical systems”. The road transport system is a complex infrastructure of the society and is almost a prerequisite of the modern society. The humans must take part of and interact with the system in order to be able to live a normal life. From this definition the road transport system can be seen as a socio-technical system. The analysis in this section supports the conclusion that the road transport system can be seen as a complex socio-technical system and consequently systems theory is applicable to it.

## ***The Road-User Approach and Systems Theory***

### *Safety as an Emergent Property*

The RUA to road safety is focused on human error as the main cause of road accidents and consequently the countermeasures are mainly aimed at changing the behaviour of the road-user in order to adapt him/her to the road transport system. This approach emanate from the view that the system itself is flawless, were it not for the erratic behaviour of unreliable people in it (Dekker, 2002). In that respect the RUA differs from systems theory where safety is viewed as an emergent property due to the complex relationships and interactions among all components of the system. The RUA more or less omit the influence of the other components of the system. This is especially valid from an injury mitigation point of view. From an accident risk reduction point of view the RUA partly have included the vehicle and the road components but only in order to assess their contribution to the behaviour of the road-users (C. Tingvall, personal communication, September, 2007).

*System and Component Performance is Variable*

According to the RUA the countermeasures have preferably been focused on regulating and surveillance of behaviour, education and information in order to decrease the performance variability of the road-user. These countermeasures have been judged successful since the variability in attitudes towards e.g. alcohol and road traffic and the behaviour in connection to that has decreased (C. Tingvall, personal communication, September, 2007).

The variability of the other components of the system have been taken into consideration but mostly from an accident risk reduction point of view. The development of countermeasures to reduce this kind of variability has mostly been introduced in isolation from the other components of the system and consequently has not been able to take the complex interactions into consideration (C. Tingvall, personal communication, September, 2007).

*Systems as Hierarchical Structures*

According to the RUA society has the responsibility for road safety. This responsibility is focused on issuing constraints for the road-user in the form of regulations. These constraints are then communicated, controlled and enforced by the society. One important reason for this procedure is that society puts the responsibility for road safety on the individual road-user. Few constraints are put on the designers and professional users (e.g. haulers, bus- and taxi companies, local communities and other organizations and companies buying or selling transportation). According to figure 3 a systems theory approach to safety emphasize the constraints and control processes at the interfaces between the different levels in order to control processes at lower levels. These control processes are more or less non-existing in the road transport system except for the process between the regulatory agencies and the operating process.

## *The Vision Zero Approach and Systems Theory*

### *Safety as an Emergent Property*

As stated earlier in this thesis safety is an emergent property due to the complex interactions between the components of a system. Figure 2 shows a model of safe road traffic for passenger cars. The model describes the way the three main components of the road transport system (the road-user, the vehicle and the road) interact with each other together with the speed. Figure 1 together with figure 2 implies that this interaction could be seen both from an accident risk reduction and injury mitigation point of view. Tingvall and Haworth (1999) and Tingvall, Krafft, Kullgren and Lie (1999) also underlines the importance of defining the interfaces between the different components of the system in order to better understand and control the complex interactions between them. The VZA consequently see road safety as determined by the complex relationships between the components of the road transport system. But the interfaces between the components are not clearly defined and operationalized.

### *System and Component Performance is Variable*

According to Hollnagel (2004) accidents occur due to the unpredictable aggregation of variability. The strategy for prevention is to introduce barriers and/or to control and manage performance variability among all components of a system. From the literature it is not clear how the VZA views performance variability in the road transport system. The model in figure 2 implies that there is a focus on road-user performance variability. This variability is due to different levels of mental and physical conditions and biological tolerance. It can be compensated or controlled by a vehicle and/or a road that supports a correct use in order to avoid accidents or the vehicle and/or the road must be protective in order to mitigate injuries. As a consequence it seems that the road, the vehicle and/or the speed are used as barriers to manage the performance variability of the road-user. But according to the functional resonance model proposed by Hollnagel (2004) the safety of the system could also be increased if the performance variability of the vehicles and road components is decreased. It is also still unclear which level of variability of the road-user that should be addressed. The model further implies that there must be a certain level of inherent injury mitigation properties of the joint vehicle-road system to determine a speed limit in relation to it in order not to exceed the human tolerance of external violence. But these levels are not clearly defined. In reality there are different types of vehicles e.g. passenger cars, lorries and motorcycles with varying safety levels in the system. The road environment differs a lot, from small roads with tight curves and trees, rocks etc. in close proximity to the road to wide, straight motorways with forgiving side areas and/or different types of guardrails. In this aspect the model of safe road traffic is not clear. Should the least safe component in the road-vehicle system govern the output (speed) from the system? Consequently the VZA seems to be more focused on barriers than performance variability management.

*Systems as Hierarchical Structures*

As mentioned earlier in the thesis the VZA emphasizes the shared responsibility between the designers and professional users of the road transport system. It is however clear that this shared responsibility has not been operationalized further. The hierarchical levels according to Fig 3 are quite well known but the control processes operating in the interface between them has not fully been mapped (C. Tingvall, personal communication, September, 2007). For that reason constraints for these processes have not been able to be set, communicated, measured, controlled and enforced to any larger extent.

## Conclusions

Systems theory has become an important foundation for modern safety work in different complex socio-technical systems in the society. The road transport system is such a system and for that reason systems theory is applicable to it from a safety point of view.

It is further clear that the important features of system theory with regard to safety; safety seen as an emergent property, the variability of system performance due to component variability and the hierarchical structure of a socio-technical system, cannot be found in the RUA. The VZA is clearly a step forward towards a system theory approach since road safety is seen as an emergent property due to the complex relationships between the main components of the road transport system (the road-user, the vehicle and the road). However it is not quite clear how the VZA views and handles performance variability. This must be further scrutinized. One important feature of the VZA is the shared responsibility between road-users, system designers and professional users of the system. This indicates that the road transport system is viewed as a hierarchical system in the VZA but the control processes between the different levels and their constraints have not yet been clearly defined and operationalized.

## Discussion

### *Implications for the Road Safety Work*

*Safety as an Emergent Property*

Since safety is seen as an emergent property, one of the most important conclusions that can be drawn from a road safety point of view is consequently that optimization of individual components or subsystems will not generally lead to a system optimum and hence a safety optimum (Leveson, 2002). As a consequence an effective road safety work cannot focus on one component at a time trying to optimize the safety features of that component. An example of this is the car industry claiming that there is a marginal potential to put a lot of effort into further enhancing the injury mitigation properties of passenger cars. Kopf (2002) claims that it is ”evident that the fatality reducing potential of passive safety measures is almost exhausted”. This is maybe true if you only look at injury mitigation properties of the vehicle component in isolation from the road component. Figure 4 shows the schematic relationship between the fatality risk and level of impact severity for a car occupant. The impact severity is proportional to the travelling speed. In many car crashes the impact severity lies on the far right end of the curve (e.g. a side impact against a rigid pole). Consequently an increase in the injury mitigation properties, which means a lower impact severity given the same travelling speed, will result in a marginal decrease of the fatality risk. But if the injury mitigation properties of the road components are developed to absorb some of the energy (e.g. a deformable pole) the impact severity will be starting to reach the steep part of the curve where a small increase in the properties of the car will give a greater decrease in fatality risk. For that reason it is important that the car industry and the road authorities co-operate in order to understand and identify the complex interactions between the car and the road.

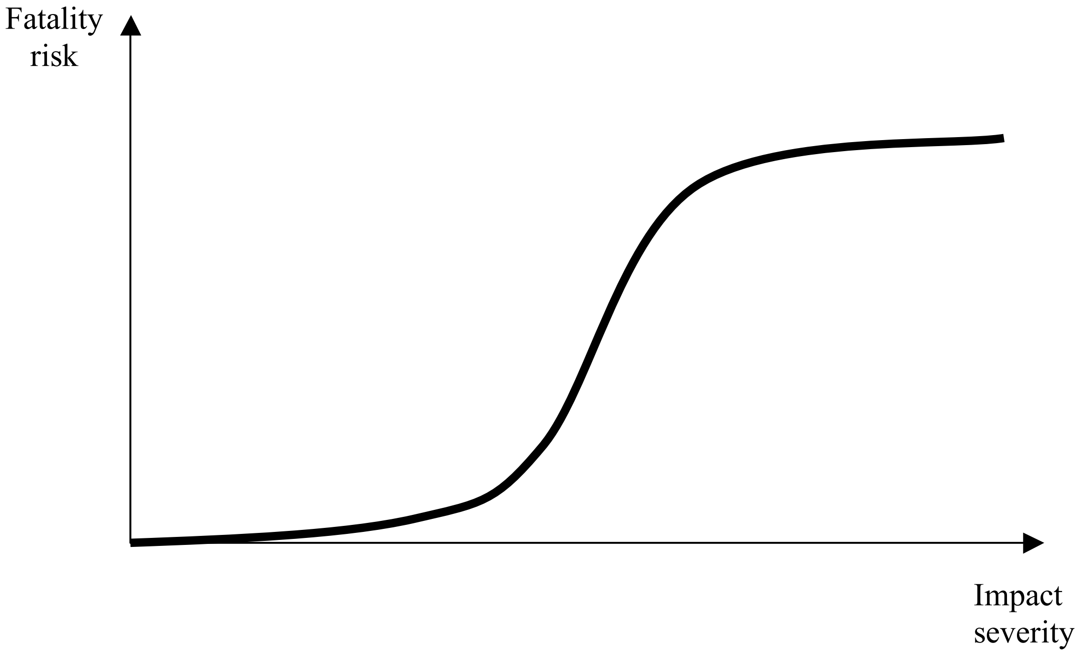


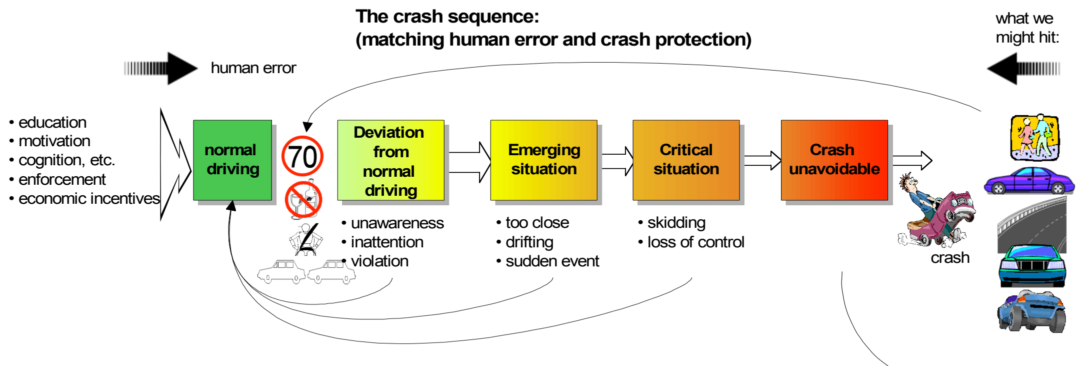

Fig 4. Schematic relationship between fatality risk and impact severity for a car occupant, (Tingvall, Krafft, Kullgren & Lie, 1999)

Another example is different Advanced Driver Assistance Systems (ADAS) in cars (e.g. night vision systems and driver alert systems) which are claimed to have ”an enormous road safety potential” (e-Safety Support, 2007). The development of these systems has up until today been highly technology-driven. There is however a phenomenon described in the scientific literature called risk compensation or behavioral adaptation (e.g. Adams, 1995). It occurs when individuals adjust their behavior in response to perceived changes in risk. Drivers may, for example, increase the driving speed, pay less attention to the driving task, become more reckless and exhibit poorer control to such an extent that the safety margins created by the ADAS are cancelled out (Kovordányi, Ohlsson & Alm, 2004). If ADAS are developed without the understanding and control of these complex interactions between the road-user and technology there is an obvious risk that the real safety benefits of a system will be lower or even negative.

*System and Component Performance is Variable*

According to Hollnagel (2004) performance variability of the components of a system is normal. The normal variability of one component in isolation is consequently not the source for a system to collapse; it is the unforeseen aggregation of normal variability of two or more components that is. When road traffic accidents are investigated there are in many cases not possible to find the defective or erroneous component which ”caused” the accident. The deeply rooted human character to always find a cause and someone to blame, leads many investigations to conclude that the road-user was inattentive, careless etc. Instead the conclusion in many cases could be that the components worked within their normal and accepted variability limits but there were no or too weak barriers. The countermeasures must hence be aimed at decreasing and controlling the variability of the components, not only the variability of the road-user, and/or introducing new barriers or strengthening existing ones. It is however unclear how the notion variability is defined. Hollnagel (2004) talks about variability as something normal and necessary in a system. In the road transport system variability is of two types; violations and errors. Intentional violations like speeding and driving under the influence of alcohol, can not be seen as normal and necessary. There are however different opinions what should be seen as violations and what should be seen as errors in the road transport system. The promoters of the RUA are more prone to see all errors as violations while the promoters of the VZA aim at a clearer distinction between the two types of variability. They hence advocate that variability through violations must be lowered substantially while errors must be allowed if they are dealt with by the designers of the system.

There is often a criticism from the promoters of the RUA that the VZA is too much focused on technical and physical barriers in order to mitigate injuries. It would be better if accidents did not occur at all. However the theoretical foundation of the VZA clearly shows that it embrace both views. The starting point is the human performance variability both from a physical and behavioural point of view and that it should be the most important guideline for the design of the road transport system. This is further supported by the model in Figure 5 which is a development of the VZA.




| | • access to road transport system | • comfort • economy • social conformity | • warning system • supporting system | • intervention in driving | • immediate correction | • preparation for crash | crash protection |
|---|---|---|---|---|---|---|---|
| Vehicle | | promote normal driving | (ISA, SBR, alcohol interlock) | (AICC, LDW) | (ESC, LDA, AICC2) | (pre-safe, emergency braking) | (seat belts, airbag, whiplash protection, pedestrian protection) |
| Infrastructure | | promote normal driving | (speed warning, tactile warning, humps) | tactile edge lines | high friction surface | | barrier design, roundabouts |
| Others | | promote normal driving | • enforcement • insurance • contracts | | | | • emergency service |

Figure 5. Schematic model of the crash sequence and the possible barriers. (C. Tingvall, personal communication, September, 2007).

Figure 5 shows that it is possible to employ barriers in the whole crash sequence, from the access to the road transport system to the emergency service, in order to prevent the accident or mitigate injuries. But in reality the focus has been on injury prevention countermeasures e.g. median barriers, "forgiving" side areas and increased injury mitigation properties of private cars since the VZA was introduced. This may be an important basis for the criticism directed towards the VZA. But the promoters of the VZA claim that much effort has historically been put into decreasing the performance variability of the road-user with quite a successful result. Hence the cost-effectiveness of injury mitigation countermeasures so far is considerably higher compared to accident prevention measures since the former has not been explored and utilized to the same degree as the latter. They instead acknowledge that it impossible to decrease the performance variability of the road-user to zero (people will always make mistakes) and consequently physical barriers like guardrails are effective countermeasures to manage this variability. It should also be underlined that the performance variability of the road-users will still be great since the society almost sees the driving license as a human right, even for professional drivers. This is in sharp contrast to e.g. aviation where there are much higher demands on pilots, especially pilots in commercial aviation. This leads to a lower performance variability of the system operators but still there are more and tougher barriers compared to the road transport system.

*Systems as Hierarchical Structures*

It is more or less an unspoken truth within the road safety community that there is a big difference between the road transport system and other socio-technical systems. As a result the safety strategies in those systems cannot be applied to the road transport system. One of the major arguments is that the road transport system is an ”open” system where an almost unlimited number of companies, organizations, private persons etc. can operate. As a consequence it is not possible to apply the model of socio-technical control (Fig 3) to the road transport system. In my opinion the road transport system is not more ”open” than other systems e.g. aviation and shipping. Both systems are also open for private operators but the biggest difference is the number of professional users. In the other transportation modes there is a clearer distribution of responsibility compared to the road transport system. As a consequence the model in fig 3 with its hierarchical levels and control processes operating between them is easier to apply. The VZA clearly states the importance of shared responsibility for road safety. So even if the number of professional actors is much larger it should be possible to apply the model for socio-technical control to the road transport system.

### *Haddon´s Matrix*

In the road safety community and in the literature it is often claimed that Haddon's matrix is a model for an integrated systems approach to road safety. In my opinion it is a valuable tool for sorting the road safety problem into different categories. Evans (1991) points out that there are complex interactions between the components of the road transport system which the matrix does not account for. Therefore it seems that Haddon´s matrix can not be seen as a systems theory approach. The major importance of Haddon's matrix is that it implies the significance of working with *both* loss reduction and crash prevention and the significance of working with all elements of the system, not only the road-user, in order to identify causes and countermeasures (O'Neill, 2002).

### *Different Views on Road Safety in the Society*

In the thesis two fundamental approaches to road safety have been described and contrasted with a systems theory approach. In reality none of the two approaches is totally predominant. It seems however like the pendulum has been oscillating between the two ”extremes” for the last ten years. It seems that the view you defend is dependent on which role you have in society. People in common often have a lot of everyday experience from the road transport system and hence they have a very clear opinion of what kind of measures that is effective. It is enough to study the letters-to-the-editor column in a newspaper for a short period to understand that ”if only people behaved” there would be less safety problems in road traffic. Education, information and other types of lecturing are hence important in their view. Politicians are often in favour of cheap and easy solutions. If they admitted that the system had fundamental deficiencies and consequently must be changed completely it would lead to high costs and/or inconveniences through restrictions in the personal freedom in the short term. As a consequence they are often in favour of behavioural solutions. In the road safety scientific community there is though a tendency towards the recognition of the need for a system approach to road safety. But the change is slow and lined with disagreements between the promoters of the different approaches especially when it comes to the battle between accident reduction through behavioural measures and injury mitigation through technical measures.

The road transport system is a complex socio-technical system where humans and technology interact in complex and unpredictable ways. There is not time to argue whether the road safety work should focus on humans or technology. From my thesis work it is clear that both perspectives are needed. But they must be integrated in an approach where it is acknowledged that the human is a part of, and interacts with a socio-technical system. This system creates the conditions of the human to act safely and her possibilities to survive. The VZA is a step in the right direction but it must be further operationalized. It can also still learn from a systems theory approach to safety and hence a lot from safety strategies in other hazardous socio-technical systems in society.

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