A general system approach to collective and individual risk in road safety

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Chapter 1 is an abridged version of chapter 2 of Koornstra (1988) and chapter 2 is a summary of the other chapters of that paper; the mathematically interested reader is referred to that publication for a complete analysis.

ABSTRACT

The framework of general system theory can be applied to traffic and traffic safety in a very useful way. A distinction between input-controlled and self-organizing systems is made; the former directs feedback to manipulation of input for a given system of the operational system, the latter directs feedback to change of the operational system for a given input (or throughput). The evolution of traffic safety can be described as a collective adaptation of a self-organizing system consisting of physical, human and social components. It is argued that variability in the system and selective action by individuals and more substantially by collective bodies, is responsible for the reduction of risk. Risk, as a conditional probability or rate of road accidents (not as utility), may be influenced by individual and collective actions in opposite ways. Combining Helson's adaptation-level theory and general systems theory, phenomena like (partial) risk compensation on the individual level and risk reduction on the collective level are formulated in a consistent way.

The structure of the concept 'road safety' in this approach is multivariate and time-ordered. It also reveals the structure of traffic-safety actions as an ordered cumulation of additive components which have constant or monotonically increasing effects along the ordering. The complexity of the system can be structured into a relational and semi-hierarchical network of subsystems interacting in the system as a whole in a conditional and time-dependent way. The characteristics of individual behaviour, its variability and limitations, are in this system stucture the driving forces for collective safety actions.

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1. GENERAL SYSTEMS APPROACH

At an aggregate level and over a long period of time one may view traffic and traffic safety as long-term changes in system structure and output. Renewal of vehicles, enlargement and reconstruction of roads, enlargement and renewal of the population of licensed drivers, changing legislation and enforcement practices and last but not least changing social norms in industrial societies are complex phenomena in a multi-faceted and interconnected changing network of subsystems within a total traffic system. The steadily decreasing fatality rate can be viewed as adaptation of the system as a whole to accommodate and evade the negative outcomes.

1.1. Evolutionary systems

The above-mentioned characterization of the system can be compared with evolutionary systems, known as self-organizing systems (Jantsch, 1980) in the framework of general-systems theory (Laszlo et al., 1974) .
There are striking parallels between the growth of traffic and the growth of a population of a new species. In Figure 1 we picture the main elements of such an evolutionary system in population biology.

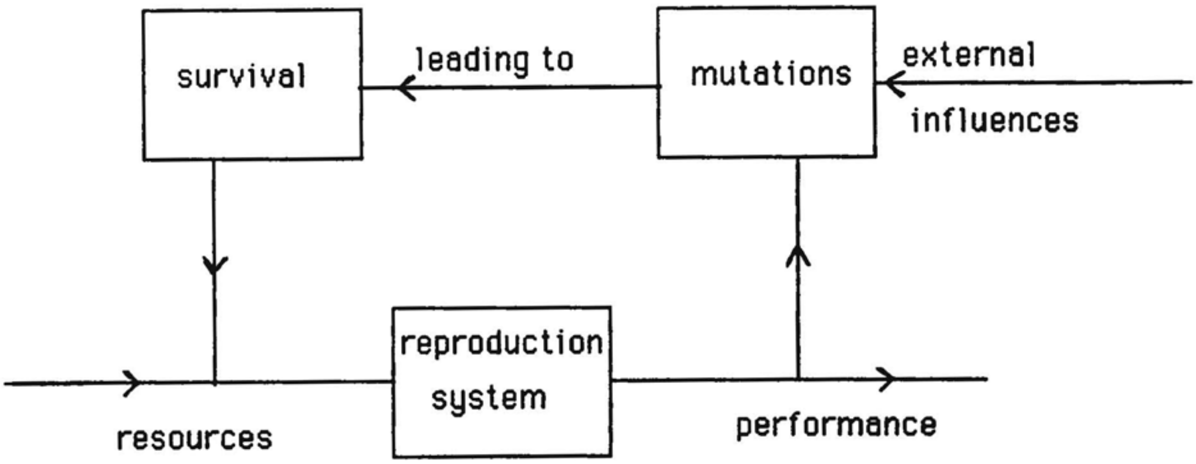

Figure 1. A model of a biological system.

Mutations are the basis for the formation of new aspects of functioning in specimen of an existing species. The survival process by selection of the fittest, leads to a reproduction process of those elements which are well adapted to the environment. The result is an emerging population of the new type of the species. The process of selection and reproduction guarantees that only those members who survive the premature period, will produce new offspring. The selection process leads to a growing birth rate as well as to a reduction of probability of non-survival before the mature reproductive life period. The resulting growth of a population and the development of the number of premature non-survivors is pictured in Figure 2.

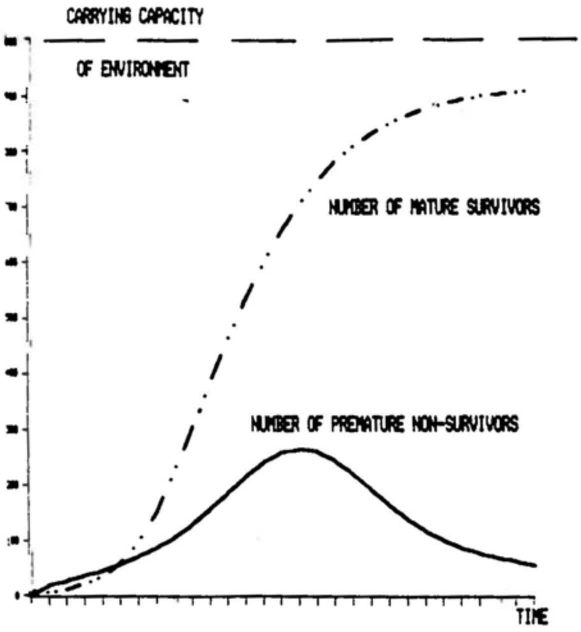

Figure 2. Evolution of a population.

Our main interest in this process is the rise and fall of the number of premature non-survivors. The growth of new-born members in the population follows a lower S-shaped sigmoid curve similar to the growth of the population. In combination with a steadily decreasing probability of death before mature age, this results in the bell-shaped curve of the number of premature non-survivors. Under suitable mathematical expressions, used in population biology (Maynard Smith, 1968) such as logistic equations, this bell-shaped curve can be mathematically described as proportional to the derivative of the growth equation. The generalized assumption of this notion could be formulated as follows:

- the development of the number of negative (self-threatening) outcomes of a self-organizing adaptive system is related in a simple mathematical way to the development of increase for positive outcomes-.

Looking upon the traffic system as a self-organizing adaptive system it is tempting to translate this conjecture as:

- the development of the number of fatal traffic accidents per year is in a simple mathematical way related to the yearly increment in traffic growth-.

1.2. Open and closed systems

The differences between open input-output controlled systems and closed self-organizing adaptive system, however, must be well understood in order to judge the validity of such analogy from biological systems to social, technical or economic systems. In Figure 3 a diagram of an open management system (taken from Jenkins, 1979) is given.

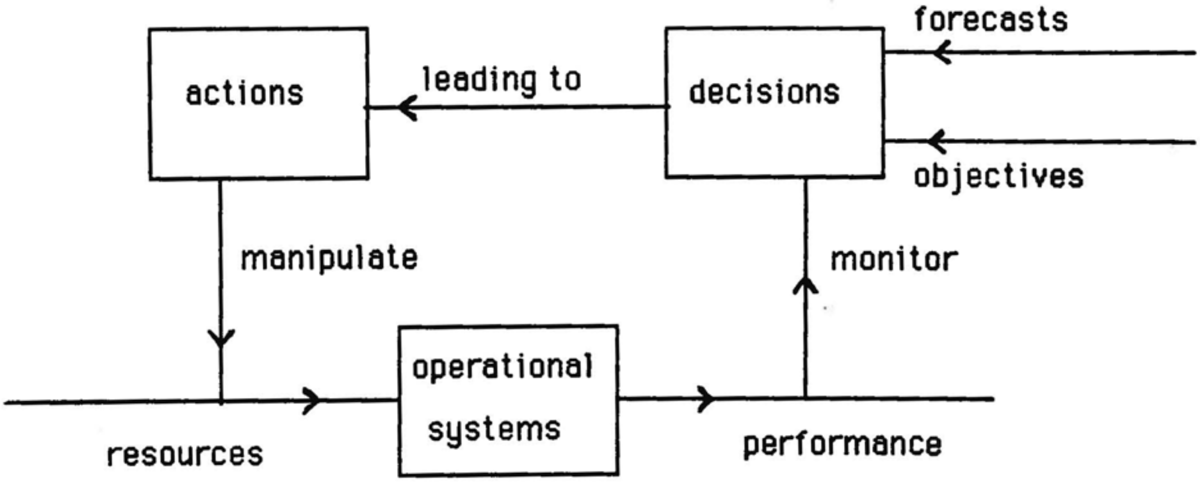

Figure 3. A model of an open system of management.

In such open systems feedback goes from output to input through a comparator based on extrapolations and objectives. Unlike biological systems, here this process is not governed by an automatic or blind mechanism like mutation, but by actions of a deliberate decision-making body. The control is directed to manipulation of the input resources by actions of individuals, collective bodies or even other subsystems of a more or less physical nature. The system is called an open system, since the feedback is a recursive relation between output to and input from the environment, while the inner operational production subsystem itself is unchanged.

In contrast to such an open system, we may picture an even more relevant "closed" system of management as is given in Figure 4.

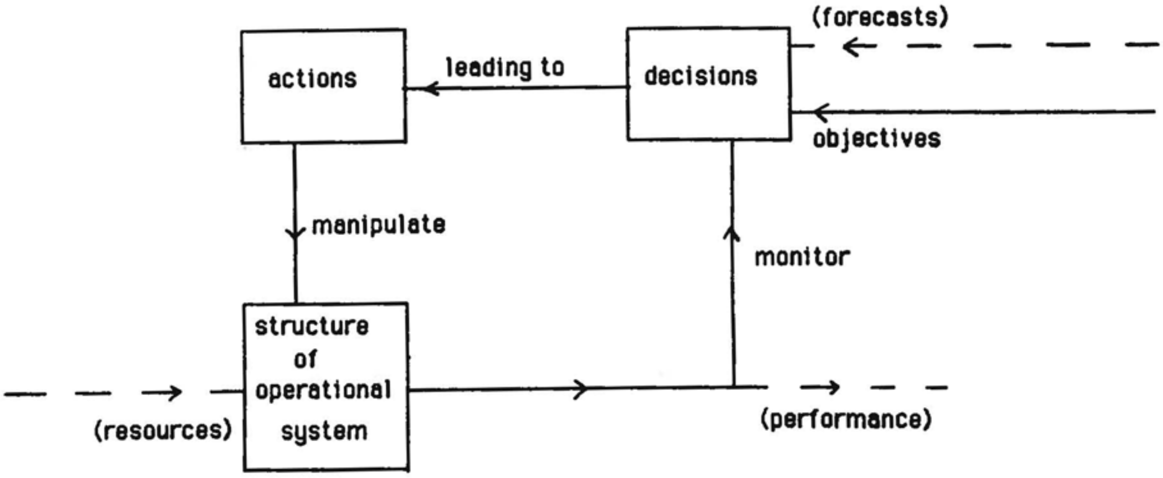

Figure 4. A model of a "closed" system of management.

Here the recursive loop in the system is hardly based on input-output relations. Again the comparator is a decision-making body. It compares intermediate output with given objectives, but now the action leaves the input unchanged as a given set of resources and changes the structure of the operational production process in order to bring the output performance in accordance with the objectives. The system is called a closed system since it operates within the system by changes in the substructure of itself. It takes the outside world from which the input comes as given and does not control the input. The effects of output are mainly viewed as intermediate and directed to the inner parts of the system.

The close resemblance to the biological system of Figure 1 is apparent. Now instead of a blind mutation and selection process we have deliberate actions from a rational decision-making body, but the structure is more or less identical with respect to its closing. This closing is even stronger in the diagram of the closed management system. Resources or necessary energy use of the system are taken for granted, although the environment of the closed system is a crucial condition for the existence of such systems. But given the environmental boundary conditions for the system, its functioning can be analyzed as internal throughput production without regard to manipulation of the given input.

In classical open systems (Desoer, 1970) the aim of control is the maintenance of stability at a (desired) equilibrium level of output through manipulating the input. In closed systems the input is not manipulated, but the operational structure itself changes.

In general, closed systems are self-referencing systems where output becomes input. They are concerned with intermediate throughput instead of input and output, and generally handle development of throughput in non-equilibrium phases of the system. The development of throughput is foremost described by non-linear equations, like throughput equations in electrical circuits as a classical closed system or throughput equations in catalytic reaction cycles in modern chemical closed systems (see Nicolis & Prigogine, 1977). Except in cases of complete self-reference, so-called autopoietic systems (see Varela, 1979; Zeleny, 1980), the field of closed systems is far less developed.

However, for most social systems the relevance of closed systems is much larger, than open systems. Every change of law, every reorganization of a firm, every new machine in a factory is a change in the operational structure in order to enhance the quality and/or quantity of the performance, but cannot be analyzed by the classical control theory. Except the universe itself, a system is never closed, nor solely an open system, perhaps excluded man-made technical control systems. Most complex real-life systems must be described as both open and closed. Although such mixed systems are mathematically difficult, on a conceptual level they can easily be described simultaneously and as such are pictured in the diagram of Figure 5 (taken from Laszlo et al., 1974).

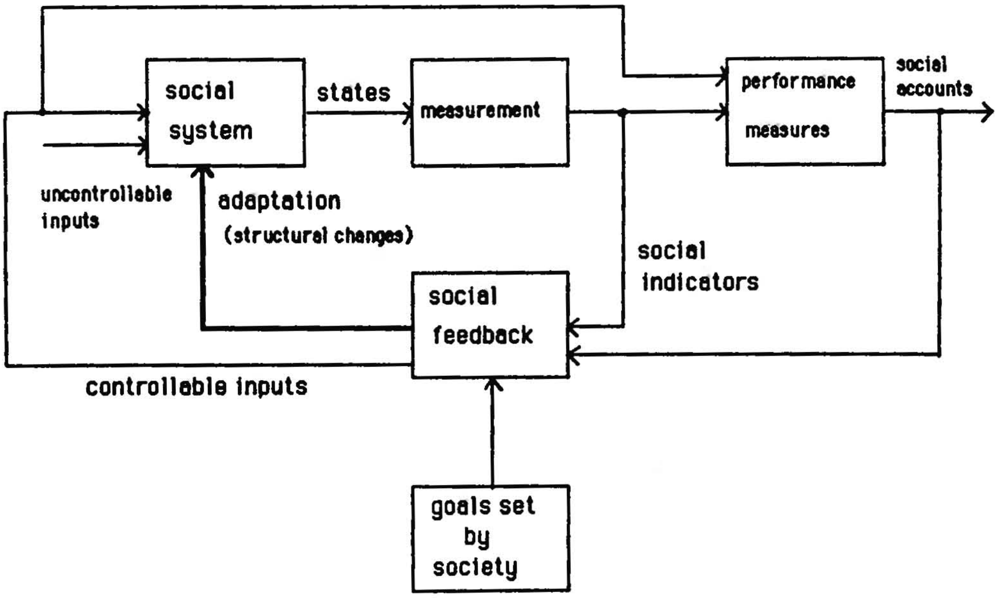

Figure 5. A model of an open and "closed" social system.

We apply this social-system description to the emergence of motorized traffic and traffic accidents. We concentrate on the inner closed feedback loop from measurement of performance through the feedback compartment to structural changes in the system as an adaptation process on a conceptual level. Subsequently the development of throughput in the system is analyzed quantitatively in the next chapter.

1.3. The "closed" traffic system

The emergence of traffic and traffic accidents can be described as a closed system in the following way. Society invents improvements and new ways of transport in order to fulfil the need of mobility of persons and the need of supply of goods. These needs and objectives are mainly met by the development and increasing use of cars and roads in modern industrial society.

This is done by

- building roads, enlarging and improving the network of roads,
- manufacturing cars and other motorized vehicles, improving the quality of vehicles and renewing them and enlarging the market of buyers of these vehicles,
- teaching a growing population of drivers to drive these cars or other motorized vehicles in a more controlled way for which laws are developed and enforcement and education practices are improved.

This growth and renewal can be quantified by numbers of car owners and license holders, by length of roads of different types and as a gross-result by the fast growing number of vehicle kilometers. We take vehicle kilometers as the main indicator of this growing motorization process of industrial society.

The negative aspect of this motorization is the emergence of traffic accidents; as an indicator we may take the number of fatalities. The adaptation process with regard to this negative aspect can be described as increasing safety per distance travelled, made possible by the enhanced safety of roads, cars, drivers and rules. Reconstructed and new roads are generally safer than existing roads, new vehicles are designed to be safer than existing vehicles, newly licensed drivers are supposed to be better educated than drivers in the past. Moreover, society creates and changes rules for traffic behaviour in order to improve the safety of the system. These renewal and growth processes of roads, vehicles, drivers and rules in the traffic system result in an adaptation of the system to a steadily safer system. In this view growth and renewal are inherently related to the safety of the system. Without growth and renewal there is hardly any enhancement of safety conceivable.

Growth of vehicle kilometers is not unlimited. The number of actual drivers is restricted by the number of the population and by time available for travelling. The main limitation, however, is the available length of road-lanes. This is not only restricted by economic factors, but has a limit by the limits of space, especially in densely populated areas. We conjecture therefore a still unknown saturation level for the number of vehicle kilometers, viz. a limit for growth of traffic. An interesting question we try to answer is, to which extent such a limit of growth also imposes, by its postulated inherence for safety, a limit to the attainable level of safety.

2. SYSTEM ADAPTATION AND COLLECTIVE RISK REDUCTION

2.1. Description of growth

From inspection of the curves for vehicle kilometers over a long period in many countries, it can be deduced that these growth curves in the starting phase are of an exponentional increasing nature. For some countries a decreasing growth seems apparent in the more recent periods, however not always. The theoretical notion of some unknown future saturation level or at least a notion of limits of growth for vehicle kilometers has strong face-validity. On the basis of these considerations we restrict ourselves to growth described by sigmoid curves. We concentrate on three types of sigmoid curves with time as the independent variable often used in sociometrics and econometrics, leaving other types used in ecology (May & Oster, 1976) aside. In the literature (Mertens, 1973; Johnston, 1963; Day, 1966) on econometrics and biometrics, these sigmoid growth curves are well documented. These three growth curves are named as the logistic curve based originally on the well-known Verhulst equation (Verhulst, 1844), the Gompertz curve originated by Gompertz (1825) and the log-reciprocal curve traditionally used in econometrics (Prais & Houthakker, 1955; Johnston, 1963). The mathematical aspects of these curves in the context of the system approach to traffic are extensively handled by Koornstra (1988). In Figure 6 we give an impression of the shape of these curves

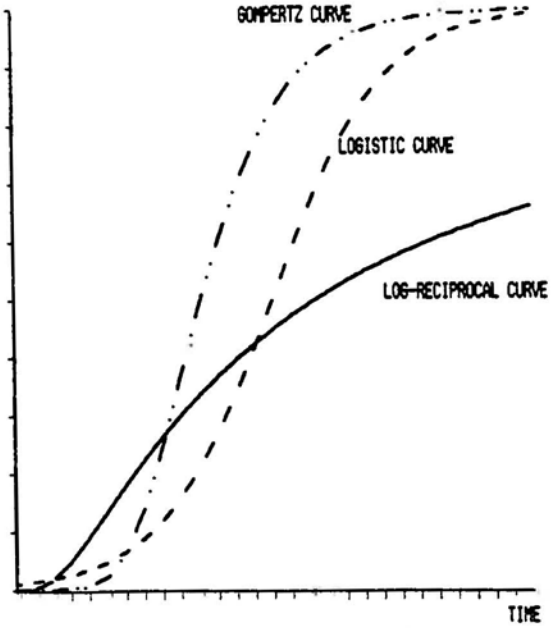

Figure 6. Curves of growth with saturation.

Since it is not so much vehicle kilometers that saturate, but density of traffic as a demand-supply relation between length of road lanes and distances travelled, a transformation from vehicle kilometers to density may be in place. Enlargement of length or road lanes in our system approach is a lagged reaction on the growth of vehicle kilometers. A transformation by a monotonic continuous reducing function of the vehicle kilometers themselves, therefore, may be an appropriate transformation. Such a transformation leads to a generalization of functions for growth. Assuming that the development of mean density of traffic over time can be expressed by a power-transformation of vehicle kilometers, the flexibility of these curves is enhanced by an increased stretching or shrinking of the vertical axes.
An other generalization is obtained by a similar monotonic transformation of the time axes. Since scale and origin of time are undetermined such a power-transformation is applied to a linear transformation of the time axes. The result of this generalization is a stretch or shrinkage of the horizontal axes around a particular point in time.

The increase of growth is mathematically described by the derivative of the functions for growth. It is shown by Koornstra (1988) on the basis of the derivatives of these generalized curves that Gompertz curve is a limit case of the time axes transformed log-reciprocal curve, as well as a limit case for the vertical axes (vehicle kilometers) transformed logistic curve. The generalized logistic curve and the generalized log-reciprocal curve therefore seems to span the space of possible sigmoid curves fairly well. In general, the log-reciprocal curve takes longer to level off than the logistic curve.
From a more phenomenal level it is also interesting to calculate the inflexion point of these curves, because inflexion points determine the maximum increase in vehicle kilometers with respect to time. For the non-generalized curves the maximum increase occurs at times where the achieved level is 50% (logistic curve), 36.8% (Gompertz curve) or 13.5% (log-reciprocal curve) of the hypothesized saturation level. These and the above mentioned considerations may also guide the choice of type of curve on a phenomenal level.

In Figure 7 we picture the development of the increase in vehicle kilometers as derivatives of the standard non-generalized curves in correspondence to Figure 6.

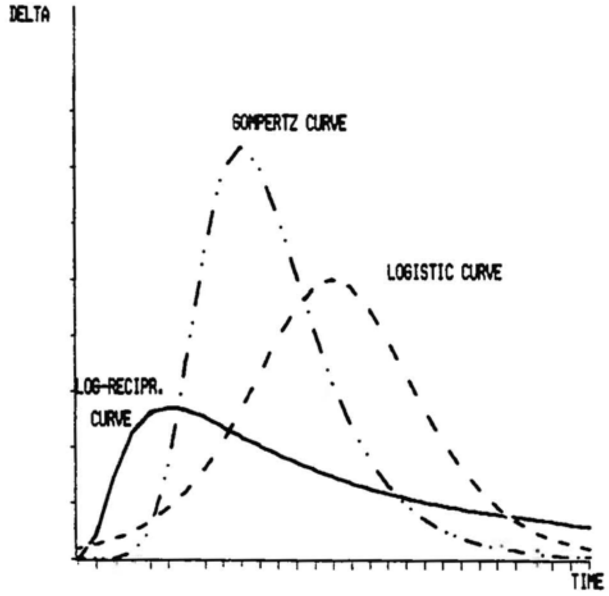

Figure 7. Curves of the increase of growth.

As shown by Koornstra (1988) all these sigmoid shaped curves are described by an increase of growth as the product of the growth achieved and (a transformation of) the growth still possible. This property leads to a very interesting aspect related to the mathematical description of adaptation since it enables one to write the rate of increase of these growth curves by monotonically decreasing functions of time.
In Figure 8 we show the corresponding curves for the rate of increase of growth for the three standard curves, named acceleration curves.

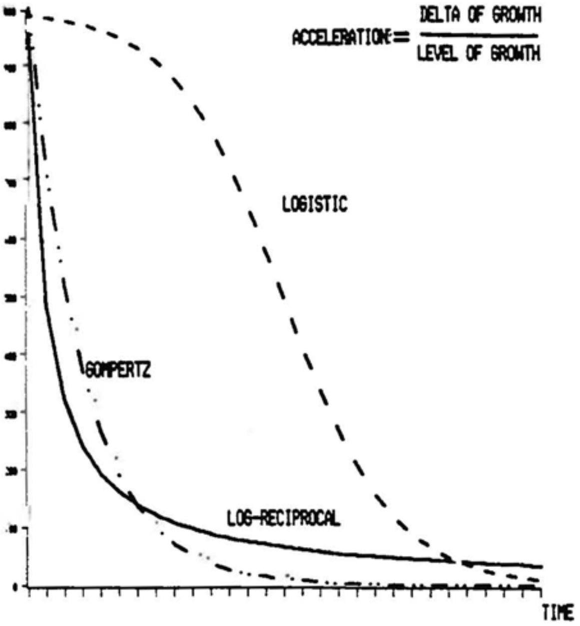

Figure 8. Curves for the acceleration of growth.

As can be seen from the graphs these acceleration curves are monotonicly decreasing curves and as such can be candidates for a description of adaptation in time.

2.2. Description of adaptation

The decreasing fatality rate has been interpreted by Koornstra (1987) and Minter (1987) as a community learning process. Their interpretations, however, differ. Minter stresses collective individual learning, where Koornstra points to a gradual learning process of society by enhancing safety through changes in road network, vehicles, rules and individual behaviour. Minter's interpretation is in accordance with stochastic learning theory (Sternberg, 1967), where learning is a function of the number of events. Koornstra's interpretation leads to community learning as a function of time. This last interpretation could be named "adaptation", since generally adaptation is a function of time.

Koornstra (in Oppe et al., 1988) rejects Minter's interpretation on two grounds. In the first place the fatality rate decreases more than the injury rate, which in Minter's interpretation means that individuals learn to discriminate and avoid fatal-accident situations better than less severe accident situations. This cannot be explained by individual cumulative experience. Secondly the mathematical learning curve functions described by Koornstra and Minter do fit the data much better as a function of time, than as a function of the cumulative experience, expressed by the sum of vehicle kilometers as Minter does.

On the other hand, transforming mathematical learning theory as functions of the number of relevant events (trials) to functions of time asks for strong assumptions. These assumptions are contained in our "closed" system interpretation of traffic and the adaptation theory of Helson (1964). The concept of adaptation as time-related adjustment to environmental conditions, must be brought in accordance to the event-related improvement described in learning theory.
Our "closed" self-organizing system interpretation points to the gradually safer conditions, while growth of traffic as such leads to more accidents. Growth of traffic, however, also implies safer renewal, enlargement of a safer road network, safer vehicles and better and coordinated rules. These effects are not immediate but generally will

lag in time. New laws, like belt laws, lead to belt-wearing percentages gradually growing in time. Reconstructions of black-spots are reactions of communities on a growing number of accidents leading to a reduction of accidents later. Traffic growth leads to building motorways, which after long periods of building-time attract traffic to these much safer roads.

As we will show lateron lagged counter-effects may sometimes also occur by risk compensation, such as present in gradually rising speeds of road traffic. These rising speeds are made possible by better roads and cars, but the cars are not only constructed for higher speeds; they are also inherently safer by crash zones, soft interior materials, better or semi-automatic breaking mechanism and so on. As Helson's adaptation theory (Helson, 1964) states, behavioural adaptation is the pooled effect of classes of stimuli, such as focal, contextual and internal stimuli. The fact that adaptation level is a pooling of different classes of stimuli implies that influence of one class may be counteracted by other classes of stimuli, but also that the influence of one class of stimuli may dominate over other classes of stimuli.
Taking into account the graduality of change in traffic environment, the lagged and over many years integrated safety effects and the eventually lagged counter-activity of human behaviour, we conjecture that adaptation to safer traffic is better described by a function of time, than as a function of cumulative traffic volume.

Referring to the incorporation of Helson's theory in the theory of social and learning systems (Hanken & Reuver, 1977) one possibility is to assume that the adaptation process reduces the probability of a fatal accident under equal exposure conditions by a constant factor per time-interval. Comparing this assumption with mathematical learning theory, we assume a model similar to Bush and Mosteller (1955) in their linear-operator learning theory or to the generalized and aggregated stimulus-sampling learning theory of Atkinson and Estes (Sternberg, 1967; Atkinson & Estes, 1967). The difference is that now time is the function variable, instead of n, the number of (passed) relevant learning events, since in the Bush-Mosteller or linear-operator learning model the probability of error is reduced by a constant factor at any learning event.

Sternberg (1967) compared the existing learning models and summarized that generally these models are based on a set of axioms, characterized by

- path independence of events
- commutativity of effects of events
- independence of irrelevant alternatives or arbitrariness of definition of classes of outcomes of events

while aggregation over individuals (mean learning curves) also postulates:

- valid approximation of mean-values of parameters or scales assuming distributions over individuals concentrated at its mean.

On these assumption two other learning models have been developed, the so-called beta-model from Luce (1960) and the so-called urn-model from Audley & Jonckheere (1956). The urn-model has its roots in the earliest mathematical learning models of Thurstone (1930) and Gulliksen (1934). In the same way as for the linear-operator model these event-related models can be reformulated as time-related adaptation models.
Luce assumed the existence of a response-strength scale, in the tradition of Hullian learning theory (Hull, 1943), for particular types of reactions. Similar aggregation over response classes and individuals as for the linear-operator model, allows us to assume an aggregate safety scale for the community which changes according to our self-organizing description by a factor ß with time, leading to a time-related formulation of beta-model for adaptation.
One of the many possible time-related reformulations of the urn-model as described by Audley & Jonckheere (1956), in the spirit of our renewal and growth process of traffic, could be as follows.
The probability of a fatal accident in time interval t, is proportional to the ratio of situations liable to fatal accidents and the sum of situations liable to fatal accidents and all other safer situations together. Assuming that self-organization by growth (adding safe and dangerous situations) and renewal (partially turning dangerous situations into safe ones) leaves the number of situations liable to fatal accidents unchanged and increases the number of safer situations constantly in time, we obtain such a time-related urn-model; here safer situations corresponds to white balls in the urn and situations liable to fatal accidents to red balls in the urn.

It will be noted that time has no origin nor a unit of scale. Therefore linear transformation of time (generally with positive small scaling factor and large negative location displacement if t is taken in years A.D.) are permissible and do not change the general expressions for the functions of adaptation models with time. Taking the parameters of the time axes, denoted by X, in such a manner that P_t=0.25 and P_t=0.75 coincide for the three models, we picture in Figure 9 (monogram taken from Sternberg, 1967, p.51), the different behaviours of these models

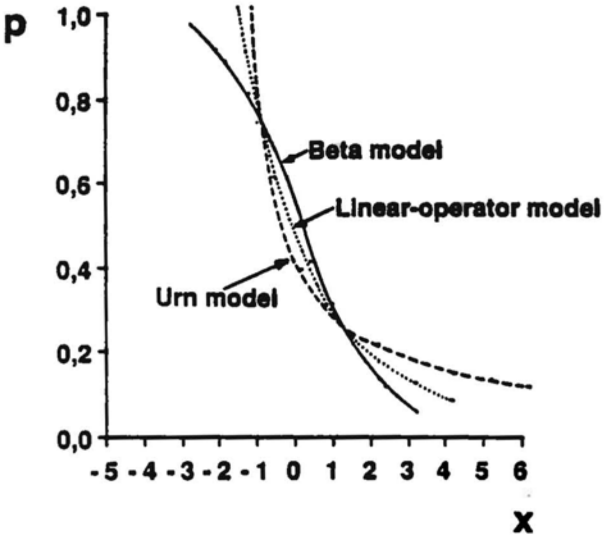

Figure 9. Nomogram for models of adaptation.

Just like the growth curves of the growth-models we may generalize our adaptation expressions by a similar power-transformation.
According to the mathematical descriptions of these models, the probability of a fatal accident will reduce to zero with time progressing infinitely. Along the lines of Bush and Mosteller (1955) we may also introduce imperfect adaptation to a non-zero level as another generalization. This results in readjustment (multiplication with (1-) and addition of) of the model expressions.
Koornstra (1987), Oppe (1987) and Haight (1988) used the linear-operator model for the fit of the fatality rate on the assumption of reduction to zero and of fatality rate as the probability of fatalities (P_t). They found a remarkable good fit for the data of time-series for the USA, Japan, FRG, The Netherlands, France and Great-Britain over periods ranging from 26 to 53 years.
Minter (1987) used Towill's learning model (Towill, 1973), which as Koornstra (in Oppe et al., 1988) proved, is essentially the beta-model under the condition that time as the independent variable is replaced by the cumulative sum of vehicle kilometers as an estimation of the collective number of past learning events.

The fatality ratio is defined as a probability. It is, however, by no means assured that the fatality rate is a probability measure. In order to be a probability the number of fatalities should not be related to traffic volume but to exposure as the expected number of possible encounters liable to fatalities.

Among others Koornstra (1973) and Smeed (1974) argued that exposure is quadraticly related to the density. The strict arguments for a quadratic relation are based on independence of vehicle movements. On theoretical grounds increasing dependence of vehicle movements in denser traffic is conjectured by Roszbach (in Oppe et al., 1988), stating that exposure will grow slower with increasing vehicle kilometers than assumed on growth of density without queue's and platoons. Since dependence increases with increasing density we assume that dependence reduces growth of exposure by a power-transformation of the squared density itself. Because of this reducing transformation of squared density and the estimation of density by a reducing power-transformation of vehicle kilometers, the power transformation of vehicle kilometers as an estimate of exposure may come close to power-parameter of unity; vehicle kilometers as such therefore may be a close approximation to the measure of exposure.

Since the probability of a fatality legitimately can be written as the ratio of the number of fatalities and exposure, the ratio of fatalities and exposure, approximated by vehicle kilometers (eventually power-transformed), is the probability measure for the adaptation models.

2.3. Relations between growth and adaptation

Instead of analyzing and fitting curves to observed data for the different models of growth and of adaptation separately, we concentrate on the conceptually postulated intimate relation between growth and adaptation. In the spirit of our system approach we directly express mathematical relations between acceleration and adaptation. We demonstrate that such a relation can be established in a fairly general way, more or less independent from the particular growth model or adaptation model. We regard the generality of this relation between adaptation and growth as the basic result from our theory.

In the paragraph on the description of growth curves we stated that the expressions for acceleration curves are monotonically decreasing curves and as such are candidates for the description of adaptation. Indeed, if we compare Figure 8 with graphs of the three models of growth and Figure 9 with the three adaptation curves we see, apart from differences in location and scale of time, identical shapes of curves for

logistic acceleration ~ beta-model adaptation
Gompertz acceleration ~ linear-operator model adaptation
log-reciprocal acceleration ~ urn-model adaptation

Koornstra (1988) compared the expressions for acceleration with the expressions for adaptation and proved the one to one correspondence between the above-mentioned pairs of curve expressions. This correspondence enables one to express adaptation as mathematical function of acceleration, which is in fact based on the same relation as in the ecological system between the number of mature survivors and immature non-survivors pictured in Figure 2.

As Koornstra (1988) showed the task is to relate time in the growth process in a meaningful way to time in the adaptation process. The relation is found by one parameter for difference of location of time and one parameter for ratio of scale-units of time.
The difference of location of time can be interpreted as a time-lag between the growth process and the adaptation process. In our closed-system description growth precedes adaptation, hence a time-lag for the time-scale of adaptation with respect to the time-scale of the growth process. The ratio of units of time-scales will be unity if the processes develop with the same speed in time. This seems most likely, but is not a necessary assumption; if the ratio is not equal to unity either growth or adaptation is a faster process. Within the closed adaptive self-organizing system interpretation, however, we are inclined to think of adaptation as a lagged process at approximately equal speeds, compared to the growth process.

Relating the acceleration curve expressions for the generalized growth curves to the expressions of the generalized adaptation models Koornstra (1988) proved that that the curves of acceleration for all models of saturating growth for positive outcomes are monotonically related to the curves of adaptation models for negative outcomes in the same system.

If we conjecture corresponding processes for growth and adaptation further simplifications are possible. The correspondence between models for growth and adaptation leads to the plausible simplification. Following the derivations of Koornstra (1988) one obtains the

basic assumption, which states that acceleration and adaptation are related by a proportional power-function and a zero or positive time-lag for adaptation.

Further simplifications are suggested in Koornstra (1988) by plausible approximations and correspondence of genaralization parameters. This leads to the so-called

specific assumption which states that fatalities and increase in vehicle kilometers are related by a proportional power-function.

The ultimate simplification results from the additional assumptions that exposure is well approximated by vehicle kilometers and that process speeds are equal. This leads to the so-called

simplified specific assumption as a proportional relation between fatalities and the increase in vehicle kilometers.

2.4. Empirical evidence

Although all these restrictions may seem to be based on rather strong assumptions, the data analyses for several countries by Oppe (1987) and by Koornstra (in Oppe et al., 1988) support such ultimately simple relations. This suggests at least that
- growth and adaptation can be conceived as closely related and that the mathematical theory has validity
- some strong simplifications in the theory are adequate
- the transformations to density and exposure is such that exposure is well approximated by vehicle kilometers.

The validity of the basic assumption can be investigated by the analyses of data from several countries. We do this by graphical presentations of fatalities and fatality rates, and of increase of vehicle kilometers and acceleration after calculation of interpolated differences from the data of vehicle kilometers. This is possible without curve fitting for growth or adaptation separately, since these variables can be calculated from or consist of observed time-series.

2.4.1. Federal Republic of Germany

In Figure 10 we present the developments of fatalities and of increments in vehicle kilometers for the FRG from 1953 to 1985. The figure reveals a remarkable overall resemblance in development.

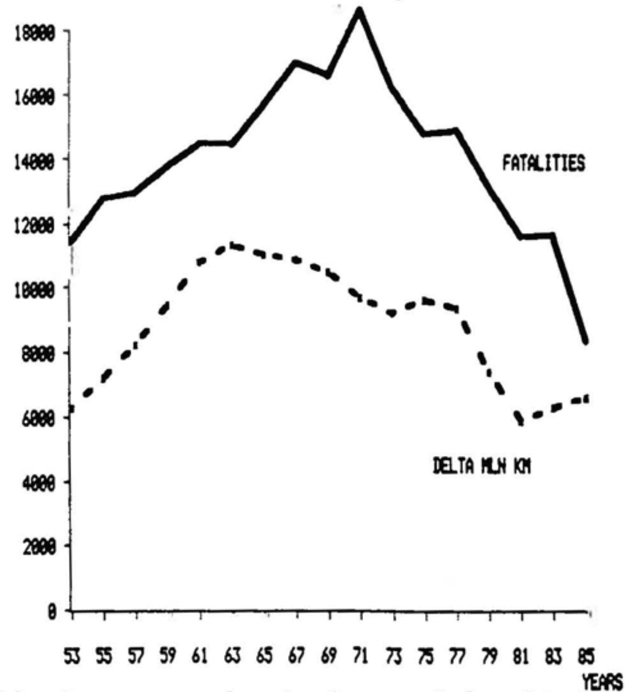

Figure 10. Increase of veh. km. and fatalities in the FRG.

As predicted from our adaptive system theory, the apparent shift for fatalities with respect to increment of vehicle kilometers, indicates a time-lag. The time-lag for fatalities seems to be about 9 years. The coinciding lagged development of fatalities and increase of vehicle kilometers seems to sustain the simplified specific assumption. This nearly proportional relation between fatalities and increments seems to sustain the hypothesis of equal speeds of growth and adaptation and the simplifications by the correspondence of models and parameters for growth and adaptation.

2.4.2. The Netherlands

For the Netherlands the same data from 1950 to 1986 are plotted in Figure 11 in the same way as before.
Figure 11 shows again a remarkable resemblance in the development of fatalities and increase of vehicle kilometers. There is an apparent time-lag of about 6 years.

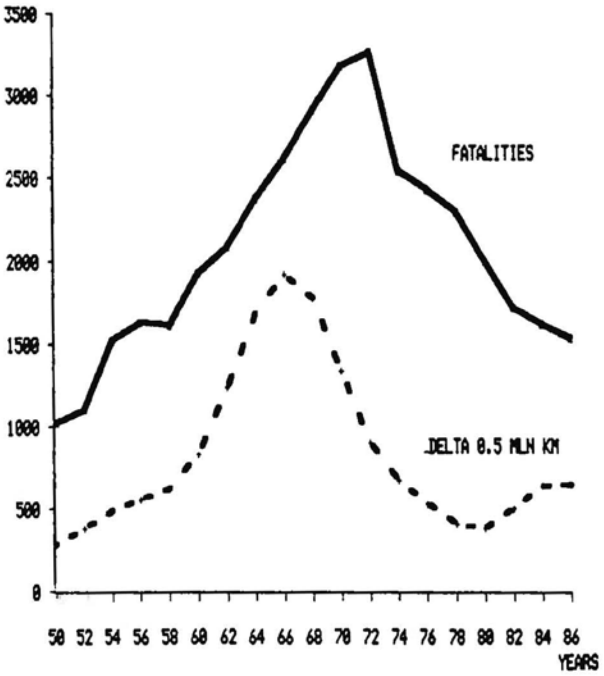

Figure 11. Increase of veh. km. and fatalities in the Netherlands

This second independent set of data strongly supports the applicability and possibly also the validity of conditions that lead to that simplified specific assumption.

2.4.3. France

The France data from 1960 to 1984 are plotted in the same way in Figure 12.

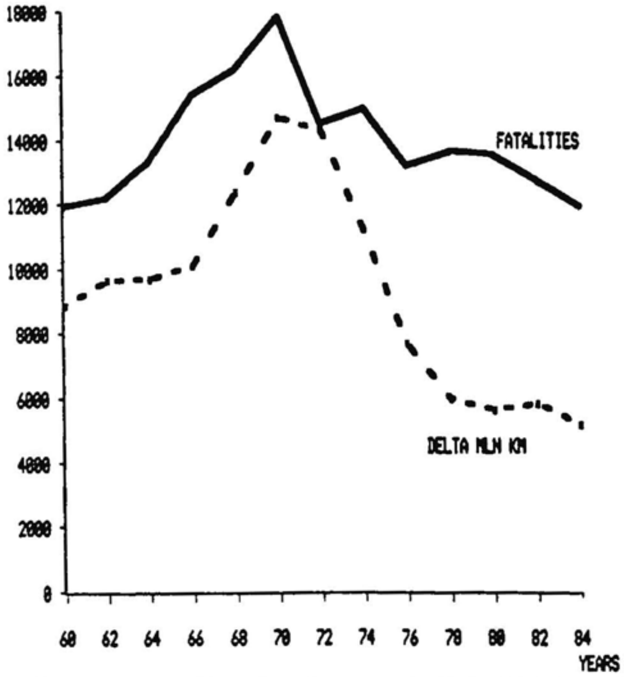

Figure 12. Increase of veh. km. and fatalities in France.

Figure 12 shows a fair correspondence in curves; the fit for the correspondence in the last ten years can be improved by a power-transformation of increase in vehicle kilometers of a value just above unity. The France data therefore support the specific assumption instead of the simplified specific assumption, but does not show a time-lag. This absence of time-lag can be quite in agreement with the assumptions of the theory, especially if we assume that a disturbing increase in acceleration is immediately followed by an increase in fatality rate *), followed by a lagged drop in fatality rate.

In Figure 13 we plot fatality rate and acceleration against time.

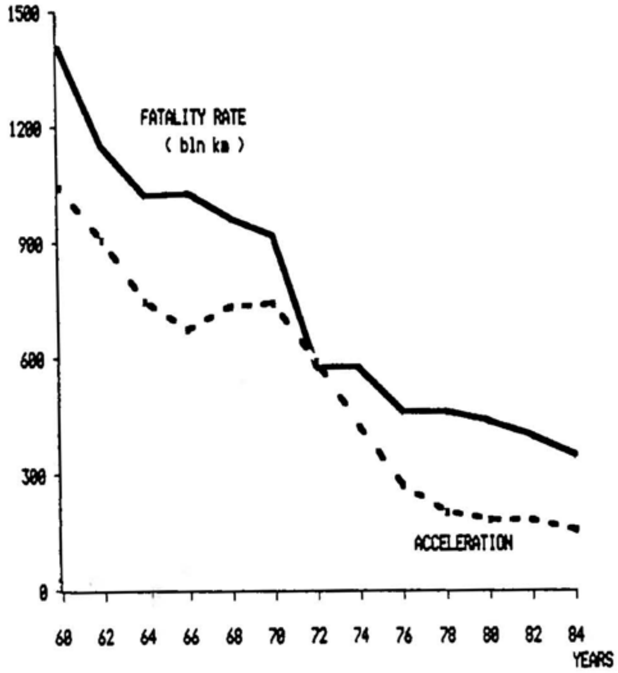

Figure 13. Fatality rate and acceleration in France.

The most striking aspect of Figure 13 is the marked divergence from the monotonically decreasing functions illustrated in Figures 8 and 9, while the correspondence between the plotted curves in Figure 13 remains apparently intact. This common departure seems to justify two conjectures. Firstly, that the relation between adaptation and growth expressed in the basic assumption will hold irrespective of the functions by which adaptation and growth are expressed. Secondly, that effects of a disturbing decrease in acceleration are immediate, while adaptive effects are lagged.

*) This assumption of immediate effects of disturbance in the decrease of acceleration was overlooked in Koornstra (1988). It forms an additional explanation for the absence of the hypothesized time-lag in the presence of a disturbance of decrease in acceleration.

2.4.4. United States of America

In Figure 14 we show the data on fatalities and increase in vehicle kilometers from 1948 to 1985 for the USA.

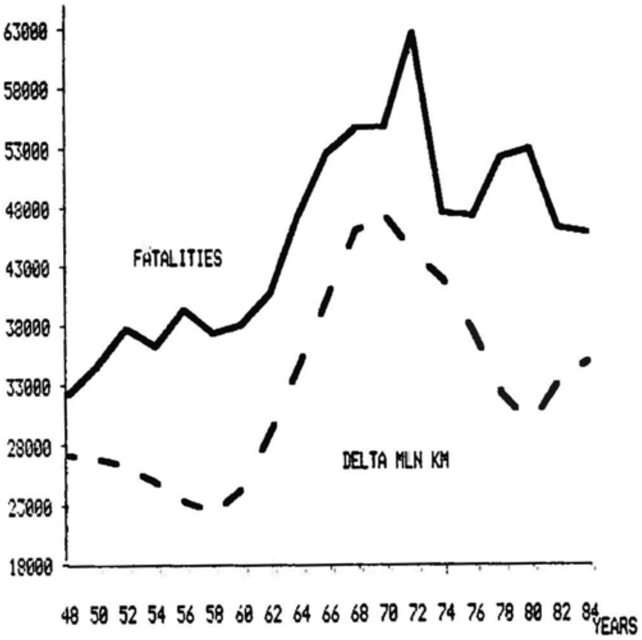

Figure 14. Increase of veh. km. and fatalities in the USA.

Again we see the predicted resemblance in the development of fatalities and increase of vehicle kilometers. There is no or only a small time-lag. This also suggests disturbing some immediate effects from non-decreasing acceleration. In Figure 15 we plot fatality rate and acceleration.

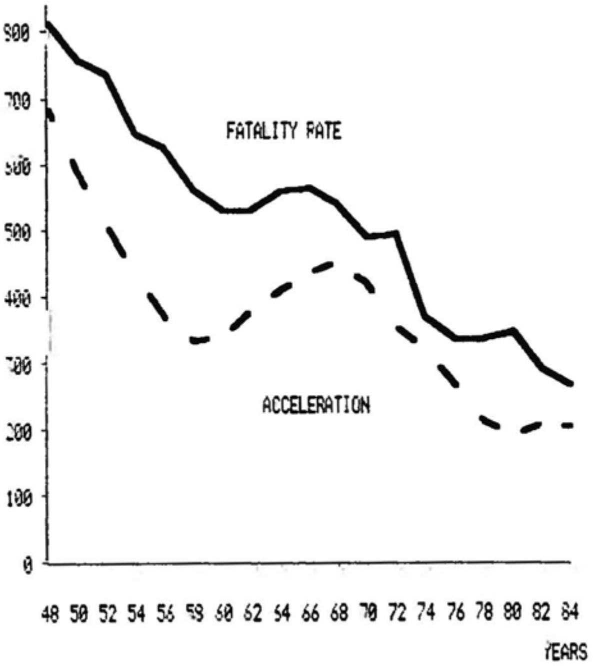

Figure 15. Fatality rate and acceleration in the USA.

Again we see a remarkable correspondence between both curves. This common curvature can even be improved by power-transformations of acceleration and of vehicle kilometers (as a better approximation of exposure) with equal parameters somewhat below unity. This flattens the acceleration curve somewhat more than the fatality rate. Thereby, we fall back on the specific assumption as the condition for this less simple assumption. As was already implied by the absence of a time-lag there is some disturbance of decreasing acceleration. We see from the fatality rate that the immediate effects of such a disturbance are quite appropriate.

In conclusion, we take the cases of the FRG, the Netherlands, France and the USA as an indication for the validity of our adaptation theory, since the basic assumption on the relation between acceleration of growth in vehicle kiolometers and probability of fatalities in traffic certainly holds. Moreover:

- a) simplification conditions which lead to the specific assumption are fulfilled for France and the USA, even under a non-monotonic decrease of acceleration;
- b) simplification conditions which lead to the simplified specific assumption are fulfilled for the FRG and the Netherlands.
- c) domimination of immediate effects of non-postulated increases in acceleration can mask the postulated adaptation time-lag.

3. SYSTEM THEORY AND INDIVIDUAL RISK

3.1. Incentive values and behavioural control

In scientific psychological theories the measurement of subjective scales and (interactive) operations on subjective and related objective scales play an important role. In the psychology of perception the transformation of objective, physical scales to subjective sensation scales is predominant. From the times of Weber and Fechner on, a logarithmic transformation of objective scales to the sensation of subjective magnitudes is basic in psychophysics. In theories on learning or choice the incentive values of sensations or features of tasks form the theoretical basis for the explanation of avoidance and approach behaviour or preferences. Incentive values of sensations or features, adaptation or habituation to perceptual and affective stimulation and behavioural feedback explains the dynamic properties of human sensation and behaviour. Uncertainty about outcomes and their values are incorporated in theories of judgment, choice and risk. Theories of cognition, attitudes and motivation are built on comparable concepts. It is not possible to give sufficient references to the voluminous relevant literature*) here. Figure 16 serves as a crude summarization of some relevant concepts and system dynamics of behaviour.

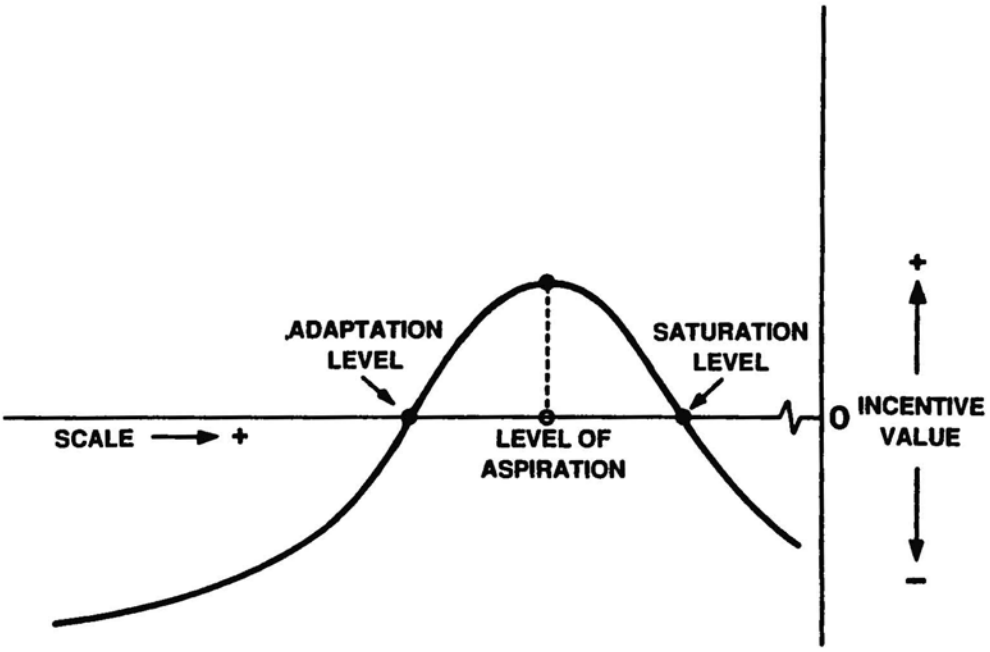

Figure 16. Graphical summary of scales and values for behaviour

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*) The reader is referred to general handbooks like Michon et al. (1979) for psychonomics, to Estes (1976) for learning and cognition, and to the literature mentioned in Section 3.2 to 3.4.

We explain Figure 16 in general, postponing its application to individual risk in traffic in a system-theoretic context. The horizontal line represents the logarithm of some objective measured scale of a psychological relevant feature. The vertical axis in this figure stands for the incentive value attached to the scale either innate or acquired by learning; its values are positive above the scale line and negative below that line. The curve represents the general nature of the relation between scale and incentive value. The inflexion points of the curve are named in order to explain the dynamics of behaviour. Adaptation level stands for the mean temporary or overall level of input of the aspect measured by the scale to which an individual is exposed and habituated. Generally, the adaptation level serves as a reference point for discriminative sensation and mental comparison. The level of aspiration or need level is defined by the subjective maximum incentive-value. If, as in Figure 16, the level of aspiration is located on a higher scale value, it is assumed that the behaviour of the individual is directed towards obtainance of higher scale values. Here the system dynanimics of behavioural feedback, producing less or more objective stimulation, and the effects on subjective sensation and judgment of scale values and incentive values come into play. Reactive behaviour that results in providing or obtaining scale values moving from adaptation level to aspiration level is thought to be increasingly rewarding or has increasing positive reinforcement. Behaviour that results in the obtainance of scale values lower than adaptation level has negative reinforcement or is experienced as punishment and it is assumed that such behaviour is avoided. Obtaining scale values above aspiration level is thought to be less rewarding up to the so-called saturation level. If a saturation level exists scale values higher than saturation level may even provoke disgust and have negative incentive values, which again lead to avoidance behaviour. Exposition to scale values with extreme negative reinforcement may lead to escape or resistance behaviour. The system dynamics of this general picture become even more visible if one notices that temporary or continuing input of higher or lower scale values results in a temporary or stable shift upward or downward of the adaptation level and with it generally also the level of aspiration shifts accordingly but less. The lagged adaptation to perceptual and affective stimulation, also denoted as habituation, guarantees that eventually adaptation level always coincides with mean scale value of stimulation and with mean zero value of incentives. As an illustrative example one may think of income as the relevant scale. The regular salary is the adaptation level; the level of aspiration, dependent on one's estimation of abillity and probability to earn more in the future, generally will exceed regular salary. A salary higher than a particular adaptation level is rewarding (positive incentive value). A salary higher than the level of aspiration is thought to be not so much rewarding, but that may change once the original level of aspiration is approached by a promotion to a higher income level due to one's good performances (behavioural feedback) in a job. Such a promotion to a higher salary will not only cause an upward shift in adaptation level but also an upward shift in level of aspiration. In the case of income as the scale a saturation level will hardly exist, but for scales of a more biological nature, like food or temperature, this is quite feasible. The logarithmic nature of the perceived scale implies that an amount of reduction of momentary objective scale value has more negative incentive value than the positive incentive values for the same amount in rise of objective scale value; moreover it implies that effects of scale changes with the same objective amount are less for higher adaptation levels. The maximum level of incentive value, defined here as incentive amplitude, depends on the level distance between adaptation and aspiration. This dependence follows from the stochastic nature of stimuli for scale feature and incentive, stimulus generalization, perceptive or mental adaptation and habituation to reward. The general concepts and dynamics of this frame of reference for behaviour can be applied to risk behaviour in traffic, since risk behaviour in traffic is based on the same processes of perception, learning, cognition, judgment, choice and motivation.

3.2. Frame of reference theory of risk in traffic

We may think of an objective and perceivable scale of risk based on cues and features in traffic associated with high frequencies of conflicts, accidents and casualties. Whether such a scale can be experienced or perceived in a consistent way will depend on the ability of the road user. We assume such to be the case for at least those modes of traffic in which the road user has actively participated for some years. Uncertainty in perception of risk, as studied in probabilistic judgment tasks (Cohen, 1972), needs not be of concern here, as long as there is a functional relation between objective and perceived risk.

The picture of Figure 16 can be seen as a sketch of such a risk scale, provided a risk scale exists for which the aspiration level can be conceived to be higher than momentary risk. Higher risks in traffic are associated with more arousal and higher speeds. In psychological theory the maintenance of a level of arousal (optimal activation level) has been hypothesized and demonstrated (Berlyne, 1960), while higher speed shortens travel time and therefore has positive utility. As a matter of fact Wilde's theory of risk homeostasis (Wilde, 1982a, 1982b) is based on these notions. A rather high level of arousal has negative incentive value (Broadbent, 1971), which is explained by the neurophysiological nature of the saturation level of arousal (Hebb, 1955). Human abilities in traffic are able to produce more and less arousal to nearly any degree. The control over arousal by response produced stimulation in traffic therefore is assumed to be complete. This would lead to a behaviour that brings the level of risk to the aspiration level. By lagged adaptation to risk sensation this in turn would shift the adaptation level also to that level. An accompanying shift of level of aspiration is bounded by the physiological nature of the saturation level of arousal. Although the positive utility of reduction of travel time may be unbounded, cost of speed and the correlation of speed with arousal, would give rise to the maintenance of an optimal target level of risk. By adaptation to incentive stimulation positive incentive values would reduce to zero in the end, leaving a level with negative incentive values above and below as the only reference level for behavioural adjustments. Figure 17 illustrates this hypothetical evaluation of risk in traffic.

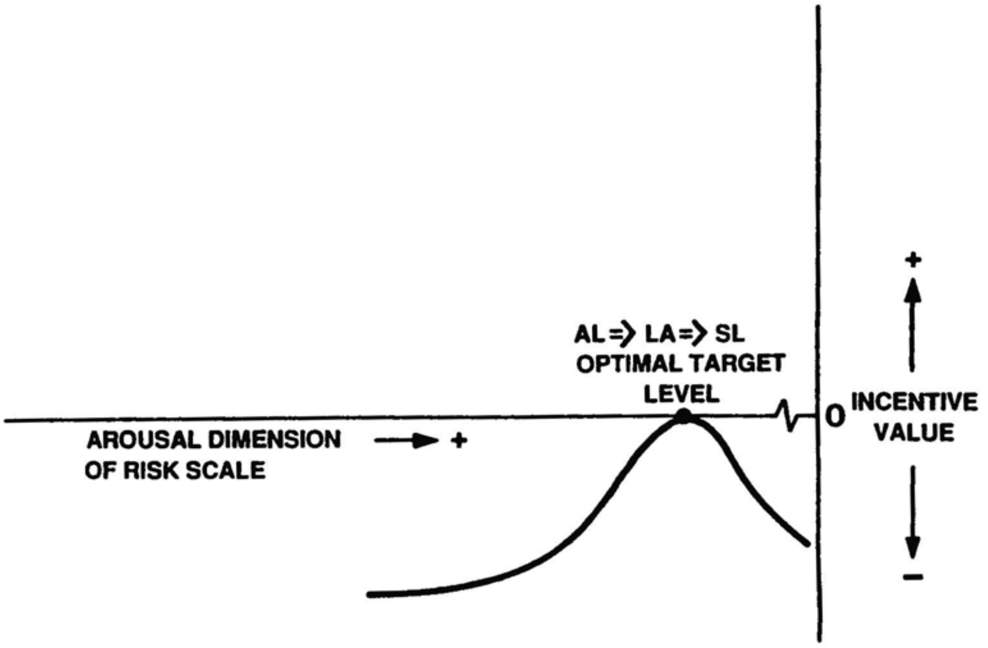

Figure 17. Graph of risk behaviour based on arousal

This unidimensional optimization of risk in traffic is also the hard core of Wilde's theory of risk homeostasis. We will denote the above risk interpretation as the arousal dimension of risk or risk-approach dimension, since generally this would lead to higher risk in traffic than human abilities to behave safe can achieve.

In general, the theory states that in case of complete control over stimulation by behavioural feedback to the situation from which stimulation generates, the distance between level of aspiration and adaptation is reduced to zero if a fixed saturation level exists. By adaptation to per-ceptive and incentive stimulation, stimulation below and above the resulting target level has only negative incentive value. It will be noted that without a fixed saturation level, there always remains a distance between the upward shifting level of aspiration and adaptation level and, thereby, room for positive incentive values.

There is, however, also an other interpretation of risk associated with fear and social responsability. Here the objective risk scale is associated with perception of danger, the probability of accidents and possible negative outcomes of accidents for oneself and others. The level of aspiration on this risk scale is certainly located below the adaptation level, which reverses the outlook of the picture without changing the basic concepts and system dynamics. In Figure 18 we picture the corresponding graphical relations.

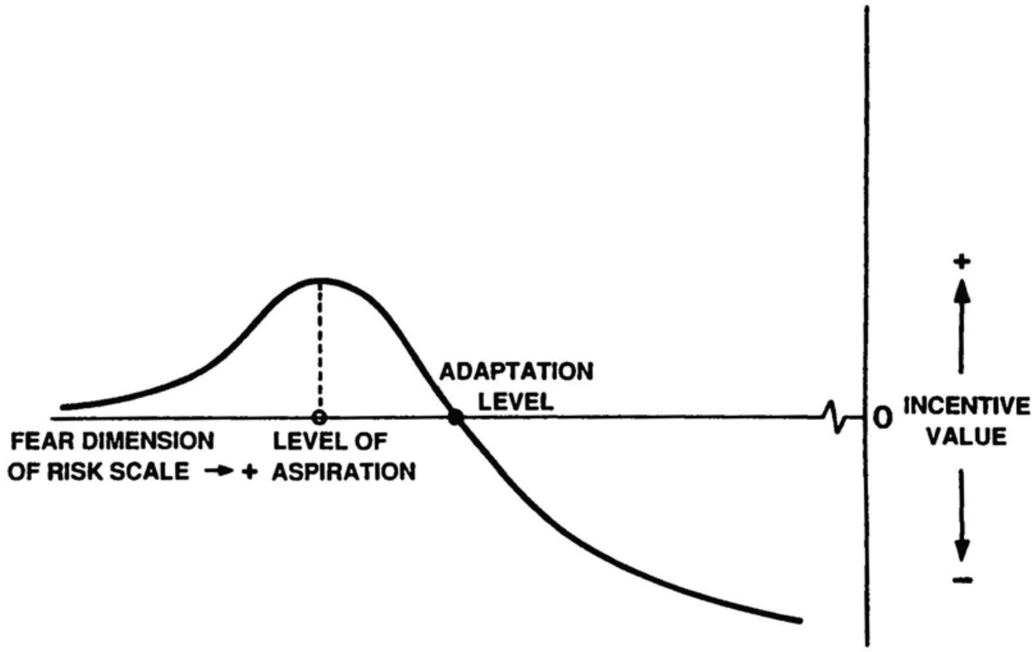

Figure 18. Scale and incentive values for fear of risk

In this presentation positive incentive values are obtained below the adaptation level. There probably does not exist a saturation level beyond which negative incentive values are obtained, but shifts in level of aspiration are bounded by zero risk. Increasing negative incentive values are to be expected for higher scale values of risk, even up to a level where extreme escape or resistance behaviour may result. Apart from plausibility, the existence of such a scale of risk as fear for risk and the possibility of extreme behaviour is illustrated by the sometimes observed, long lasting psychotraumatic reaction after the experience of an accident. (Such a change in behaviour is psychologically explained by the bias in information acquisition due to overweighting of recent, vivid and concrete information (Hogarth, 1987 and references there) in human judgment.) On such a fear dimension Fuller's threat-avoidance conceptualization of driving behaviour (Fuller, 1984) is in fact based.
If fear for risk would be the only operative dimension in risk behaviour, road users will behave as safe as their ability allows them to be. A downward shift in adaptation level accompanied by a probably somewhat smaller shift in level of aspiration would be the result of safer behaviour. However, since behavioural feedback generally does not assure complete control over the stimulation from the traffic environment on the fear dimension of risk, this will not result in a continuing risk stimulation as low as the shifting level of aspiration. So, although some approaching downward shifts of levels by safe behaviour may occur, the level distance between adaptation and aspiration is not reduced to zero, unless zero risk becomes an aspect of the traffic system itself. We denote this fear associated scale of risk as the fear dimension of risk or risk avoidance dimension.

Our frame of reference theory of risk in traffic states that risk in traffic can be explained by the weighted combination of the arousal and fear dimension of risk. Additivity in case of simultaneously aroused approach and avoidance is a classical assumption in motivational views of risk taking behaviour (Atkinson, 1957). In the study of choice behaviour and judgment linear weighting models in multi-attribute tasks has proved to be robust. Deviations from the underlying assumptions (for example independence of dimensions) do not hamper an accurate prediction of behaviour (Dawes & Corrigan, 1974 and Dawes, 1979). If we assume symmetry around adaptation level in curves on the arousal and fear dimension of risk and equal weights to fear and arousal, we obtain the result presented in Figure 19. For the description of the aggregated behaviour of individuals of a nation this is not an unreasonable assumption. Similar assumptions have shown to be valid for the prediction of decision making in other contexts (Einhorn & Hogarth, 1975).

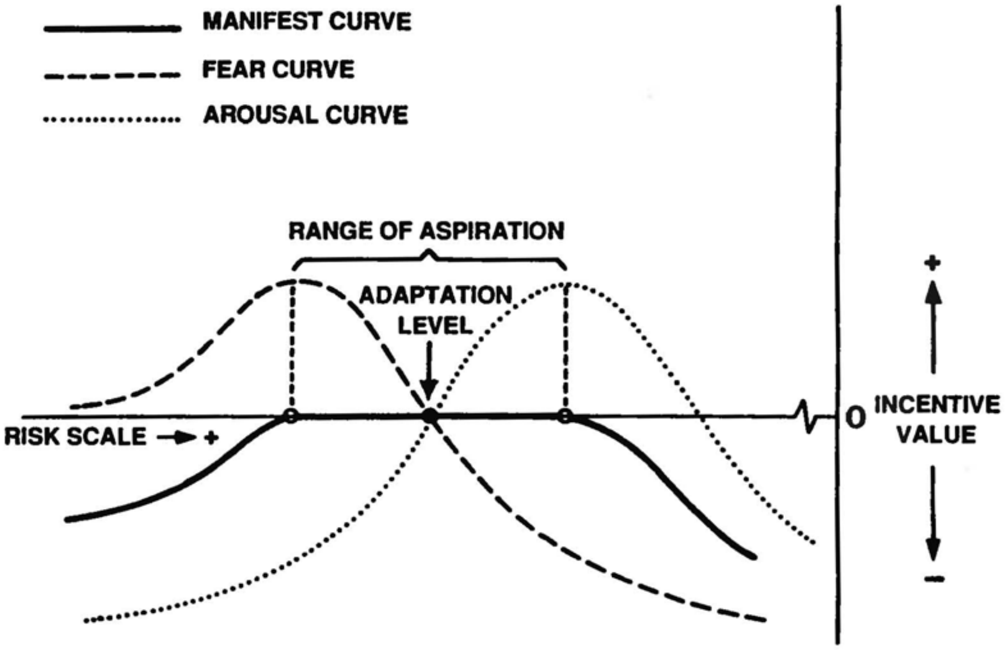

Figure 19. Graph for equal weighted dimensions of risk

Under these assumptions as Figure 19 shows, we obtain no particular scale value for risk with a positive maximum incentive-value, but a whole range of risk-scale values with maximum incentive-value of zero. Instead of a unique determined level of aspiration at maximum incentive-value we obtain an incentive value of zero for an aspiration range between the two underlying original levels of aspiration for the fear and arousal dimensions. This explains nicely the often noticed indifference to road safety of the collectivity of road users in their collective behaviour.

Behaviour of individual road users may better be described by individual differential weights of the arousal and fear dimensions. Doing so, we integrate Wilde's risk-homeostasis theory (Wilde, 1982a, 1982b) and Fuller's threat-avoidance theory (Fuller, 1984) of risk in traffic. Apart from momentary influences of the set of the driving task or influences of different traffic contexts, the weight for the fear dimension is probably dependent on more stable or slowly changing individual cognitive abilities and skills. The somewhat complex, but plausible way in which weights for the fear dimension of risk are dependent on one's cognitive ability of risk anticipation (to foresee and to discriminate between high and low risk situations) and on one's estimation of skills to reduce risk in traffic effectively by one's own behaviour (for a particular vehicle), is tentatively given in Table 1.

		Estimation of skills	
		high	low
Cognitive ability of risk anticipation	high	medium	high
	low	low	ambiguous

Table 1. Weights for the fear dimension

Individual differences in misjudgment of one's own cognitive abilities and driving skills may also be a source of individual differences in weighting the fear dimension. Especially overestimation of skills will reduce the weighting of the fear dimension.

Individual differences in appreciation of arousal (Berlyne, 1960) or need for arousal (Hebb, 1955) may introduce differences in weights of the arousal dimension. Individual differences along the personality dimension of extrovert-introvert are found to be related to low-high arousal satisfaction by medium or low stimulation (Eysenck, 1967; Orlebeke, 1972). Extroverts are also less susceptible to punishment (Gray, 1972) and may weight the fear dimension less. Differences in emotionality and anxiety as personality dimensions will correlate positively with differences in the weighting of the fear dimension, but may also be related to the arousal dimension (Orlebeke & Frey, 1979; Olst et al., 1980). The complex relations between individual differences in distances for the level of aspiration, individual differences in the personality dimension of neuroticism and in the dimension of extrovert-introvert are discussed by Inglis (1961). High scores on neuroticism seem to be correlated with high levels of aspiration and low performance control, but are also dependent on the extrovert-introvert dimension and stress. The compensatory effects of individual weighting of the fear and arousal dimension in our frame of reference theory of risk in traffic leads to rather complex model dynamics, but the results are rather simple. The model dynamics in sequential stages of the underlying process is described as follows:

- Due to the differential weighting of the two dimensions the weighted curve first flattens the curves of Figure 16 for arousal-dominated weighting and of Figure 17 for fear-dominated weighting, but still shows lower peaks at the original aspiration level of the dominating scale.

- Next, by the dynamics of behavioural feedback the stimulation of risk will shift the adaptation level towards the level of aspiration of the dominating scale. This shift is accompanied by a smaller shift of the two original aspiration levels.
- In the third phase the incentive amplitude will increase on one side and decrease on the other side of adaptation level accordingly with change in level distance. For example, in case of an arousal-dominated weighting, the shifting adaptation level will gradually approach the less upward shifting aspiration level of arousal, while the distance to the also less upward shifted aspiration level of fear is enlarged. Because of adaptation to incentive value at adaptation level of risk the incentive value of the level of aspiration for arousal decreases (habituation to reward and stimulus generalization), while the original incentive value of the level of aspiration for fear increases (strengthening by deprivation).
- The last stage consists of the same differential weighting of these altered underlying curves. The resulting curve shows a range of zero incentive values from the shifted aspiration level on one side to the shifted level of aspiration on the other side and increasing negative incentive values beyond these levels.

In Figure 20 the latent underlying resulting curves for fear and arousal and the resulting weighted manifest curve in case of a fear dominated differential weighting of dimensions are shown.

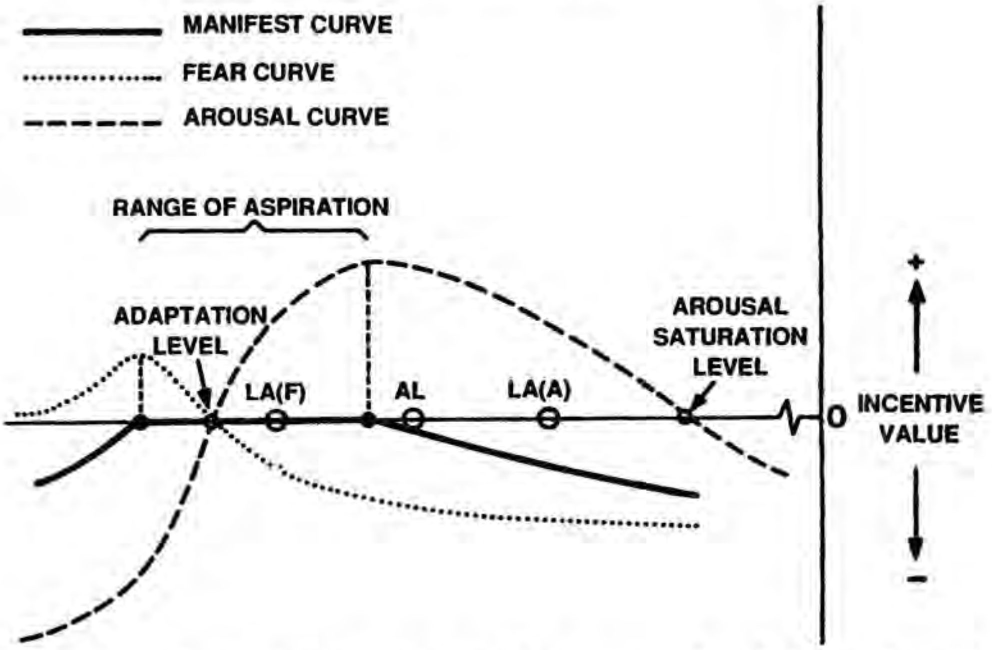

Figure 20. Latent curves and manifest curve for fear-dominated risk

It will be noted that resulting asymmetry in graphs of the underlying fear and arousal dimension can also be mimicked by asymmetric shifts of levels and equal weighting of the original unaltered curves. A higher weighting of an original curve mimics larger distances from adaption level on the horizontal axis for the scale of risk and larger amplitudes on the vertical axis for incentive value. The resulting relative increasing vertical and horizontal distances for arousal in case of fear-dominated weighting, therefore can also be represented by an inversely increase of the lower and an inversely decrease of the higher weight for the respective underlying dimensions of fear and arousal. The result is mimicked by equal weights of the unaltered curves and an asymmetric upward shift in levels. The end result of a range of aspiration of zero incentive values, similar to a shifted range in Figure 19 is not surprising after all.
A resulting curve for extremely fear-dominated weighting is similar to a reversed graph of Figure 17, if control by behavioural feedback is able to push the adaptation level near to the shifting level of aspiration for fear. But now zero incentive values range from zero risk to the extremely downward shifted level of aspiration for arousal. However, if control of risk stimulation by behavioural feedback is incomplete, the adaptation level will never shift close enough to the downward shifting aspiration level for fear. Complete control is unlikely, since the ability to reduce risk stimulation by one's own behaviour is limited; this in contrast to the ability to match optimal arousal by risk-behaviour adjustments.

As seen from these figures varying risk stimulation around adaption level has no impact on behavioural adjustment. The curve of Figure 19 can therefore also be obtained without equal distributed weights, since any summation of individual graphs will result in a distribution of ranges of zero incentive values. Indifference within limits to traffic safety according to our frame of reference theory is not only apparent in actual collective traffic behaviour, but is also inherent to actual individual behaviour in traffic. However, location and lenght of the indifference interval on the risk scale may differ for individuals. This would relate our theory to the individual differences between 'sharpeners' and 'levelers' in perception and cognitive control (Gardner et al., 1959). Since negative and positive aspects of stimulation, are present in many situations our theory could be generalized to other contexts of behavioural control. This would relate our theory to the discussions on the single peakedness of utility functions in approach-avoidance situations in choice theory (Coombs & Avrunin, 1977). Some of these intriguing aspects of this generalization, the mathematical and system-theoretical aspects of this theory will be presented in a forthcoming publication (Koornstra, 1989).

According to the compensatory dimensions in our frame of reference theory of risk in traffic the resulting weighted incentive value of risk of an individual is zero in a broad interval of risk-scale values around one's mean adaptation level for risk and beyond that interval increasingly negative. Two exceptions are theoretically possible. One exception is a reduction of the interval to a unique risk-scale value with zero incentive value at the level of aspiration for arousal in case of extremely arousal dominated weighting. In that exceptional case, made possible by the complete behavioural control of response produced-arousal stimulation, the adaptation level approaches the level of aspiration for arousal, which in turn is shifted to the level of saturation as was shown in Figure 17. An extremely fear-dominated weighting does not lead to such a reversed graph, since complete behavioural control of response-produced zero risk is not feasible. The other exception is formed by virtually zero weighting of the arousal dimension, as shown by Figure 18. In our frame of reference theory of risk in traffic we take it for granted that zero weights for one of the two dimensions can be excluded. The aggregated graph of Figure 19 therefore will also be obtained by summation of distributed weights and levels; individual mean adaptation levels deviating from the collective mean adaptation level are accompanied by asymmetrical mean shifted levels of aspiration for arousal and fear.

3.3. Adaptation-level theory and risk

The crucial dynamics of the frame of reference theory of risk in traffic lean heavily on adaptation-level theory as originally formulated by Helson (1938, 1949, 1964) and on its application in a general system approach. One may question our assertion of the validity of the application to risk in traffic, especially since perception of risk in traffic may be viewed as impossible, because of its rather hidden nature and the very low probabilities of real danger. A view that is shared by Näätänen and Summala (1976) in their zero-risk model of traffic behaviour. Moreover, habituation to incentive values and adaptation to perception are not always conceptualized as common and simultaneous processes. Adaptation-level theory applied to cognition, judgment and risk asks for the validity of the theory for cognitive, internally produced mediating stimulation. Although imaginary internal stimulation is a common concept in cognitive psychology, an explicit reference to adaptation-level theory is seldom. We therefore examine the evidence for adaptation-level theory in the context of risk in traffic more closely. This is also necessary in order to understand the influence of externally produced changes of risk in traffic and their effects on the human system as a subsystem of the system described in Section 2.

Dark adaptation is a perceptual adaptation we are all aware of. It takes time and extends over an amazing range of illumination. The sensitivity of the dark-adapted eye compared with the light-adapted is about 100,000 to 1. The concept of adaptation is, however, much richer than adaptation as desensitizing to increased stimulation on one dimension. It not only sensitizes (adaptation to red makes us more sensitive to blue-green), it is also a multidimensional simultaneous process. We can do no better than cite Helson's book from 1964, which contains the evidence since its first formulation in 1938, and add more recent crucial evidence in order to illustrate the relevance of adaptation-level theory for our theory of risk behaviour in traffic.

- " Even the simplest sensory experiences are more or less complex, containing focal, contextual, and organic components (p. 37). The level of adaptation is the pooled effect of three classes of stimuli: (1) focal stimuli; (2) background or contextual stimuli; and (3) residual stimuli (p. 58). Adaptation level is defined as a weighted geometric mean of all stimuli impinging upon the organism from without and all stimuli affecting behaviour from within (p. 59). Action (and enjoyment) comes not from situations giving rise to neutral states of the organism but rather from disparity between stimulation and prevailing adaptation level. Magnitude of response depends upon this difference from level, not only in perceptual phenomena but in emotional and motivational states as well (p. 49). The division into three classes (focal, background and residual) is largely a matter of convenience and depends upon the 'sense' of the experimental situation (p. 59). The weighted logarithmic mean ... is affected by both range and density of a set of values ... increases less rapidly ... incorparates the law of diminishing return ... is a first good approximation to the relation between stimulus intensity and magnitude of sensation or response (Fechner's law) ... an easy and convienient base with which to start (p. 60). Adaptation level as a weighted mean immediately implies that every stimulus displaces level more or less in its own direction, providing that counteracting residuals are not operative. If a stimulus is above level, the level is displaced upward; if below level downward; and if it coincides, it does not change level. ...especially repeated stimulation, negates itself to some degree by reducing its distance from level. The fact that adaptation level is a weighted mean of external and internal stimuli implies that influence of one class of stimuli may be counteracted by sufficient emphasis on other classes of stimuli (p. 61). Organisms are space-time averaging mechanisms in which all dimensions of objects and events contribute differentially to the formation of levels. Among the more obvious and important weighting factors are area, intensity, frequency, nearness, recency, order of stimulation, and affective quality. Less obvious but often important in fixing levels are task, instructions, self-instructions, organic states, cognitive systems, and genetic factors. Cognitive acts, sensori-motor responses, skills, and learning are differentially affected by focal, background, and residual stimuli and hence are functions of prevailing level no less than perception and judgement. Similar considerations apply to affective and emotional bahaviour. Just as individual levels are established with respect to prevailing conditions, so group levels, conceived as weighted means of individual levels, are established (p. 63). ....internal sources of stimulation are often more important than external sources in determining adaptation levels .... pre-existing affective levels and cognitive systems have greater weight than do stimulus dimensions in the determination of many responses ... usually they are neither manipulated as independent variables nor evaluated as dependent variables....(p. 93)." -

In our frame of reference theory of risk behaviour, we incorporated innate or acquired incentive values and aspiration level. Helson, referring to relevant research results on task errors of Payne and Hauty (1955a;1955b) and himself (Helson, 1949), states: - "The concepts of par or tolerance for error has certain points in common with the concept of level of aspiration. In so far as explicitly formulated standards are concerned, the two concepts seem to be identical. But in addition we stress implicit standards that are established more or less automatically. Consciously formulated aspirations constitute only one class of determinants of intra-organismic norms. ... Level of aspiration according to this view goes into the pool of factors affecting behavior and, in turn, is affected by prevailing adaptations (Helson, 1964, p. 118)."

Central to adaptation-level theory is the frame of reference view that all judgments are relative, i.e. based on the scale difference of stimulation to prevailing adaptation level and the assumption that effects of stimulation form a spatiotemporal configuration in which order prevails.

Relevant to our frame of reference theory of risk is the evidence Helson (1964) gathered from many studies that subliminal stumuli influence adaptation level as well, albeit with less effect than supraliminal stimuli. Perceptibility is therefore not a criterion for the application of adaptation-level theory; subliminal stimuli along with supraliminal stimuli are incorporated in the formation of norms underlying judgment. Unperceived changes in risk can therefore influence the adaptation level for risk. The effect of such small changes in risk will depend on the frequency of stimulation and therefore continuing unperceivable changes in risk will have an effect on adaptation level of risk in the long run. Therefore, we do reject the zero-risk conception of Näätänen and Summala (1976); a mean change in level of varying low risks may be subliminal or nearly so, but we deny that changes in low risk associated stimulation on the long run cannot have effects.

Adaptation-level theory has been very useful in the study of psychophysical judgment. It simplified Steven's power law (Corso,1970), it explained many judgment phenomena, like hysteresis, assimilation and contrast effects first differently conceived, reciprocity of frequency and magnitude, effects of series and order (Helson, 1964, Appley, 1970). These last effects nicely illustrate the basic idea of adaptation level; for example, a weight of 500 grammes lifted after a series of 300, 400, 500, and 600 grammes is judged to be heavier than after a series of 400, 500, 600, and 700 grammes.

In the study of perception adaptation-level theory explains phenomena of after effects, colour conversion, size and form distorsions, illusions, figure ground reversals, formation of Gestalt properties, over and under estimation in perception of distances and duration (Helson, 1964; Appley

1970) as well as in perception of velocity and motion (Drösler, 1978). It even explains parts of selective perception in speech and vision by the sensitizing aspect for neighbouring non-adapted stimulation ranges (Eimas & Miller, 1978) and cross-modality matching and judgment effects by similarity in distance from adaptation level (Howard, 1978; Bower, 1970). Many phenomena of adaptation in visual space perception were thought to be changes in judgment or response, but Bevan and Gaylord (1978) showed that perceptive adaptation must be the source for explanation. Relevant for traffic behaviour is the older work of Bevan and students (Bevan et al. 1967; Hardesty & Bevan, 1965) on vigilance as modelled by adaptation-level theory for expectancy and arousal. Restle (1978) ingeneously showed how relativity and organization of visual judgment are explained by adaptation-level theory.

Phenomena in learning as stimulus generalization, transposition, transposition reversal of learned responses, effectivity of reinforcers and contrast, and transfer and cross-dimensional transfer of responses are explained successfully by adaptation-level theory. Hilgard and Bower, in chapter 15 of their classical book 'Theories of Learning', conclude that adaptation-level theory may be applied to both positive and negative reinforcement and that 'relational' and 'specific' stimulus learning theories are nicely integrated by adaptation-level theory.

Adaptation-level theory coincides with habituation in motivation theory (Nuttin, 1980; Berlyne & Madsen, 1973). McClelland and Clark (McClelland et al., 1953) have formulated an adaptation-level theory of motivation. Anderson's theory of attitude change as integration of existing and new information (Anderson, 1981) is a multidimensional adaptation-level theory. Adaptation-level theory in the study of affective values is reviewed by Helson (1973). The relevance of adaptation-level theory for societal values has been discussed by Brickman and Campbell (1970).

In studies on choice and risk or judgment under uncertainty explicit reference to adaptation-level theory is seldomly made. Sometimes effects of adaptation level are merged with effects of aspiration level into target-level effects (i.e. Payne & Laughhunn, 1980). However, two types of bias from heuristics for judgment under uncertainty (Kahneman et al., 1982) are in fact phenomena explained by adaptation-level theory. Bias by anchoring and adjustments can directly be described as adaptation-level effects. For instance, a presentation of 3 red and 7 white balls followed by 7 white balls and 3 red balls or reversed giving systematic under-, respectively overestimation of 50 % in the urn. Bias by availability can also be explained by adaptation-level effects on self-produced internal cognitive stimulation. For example, the question whether there are more English words beginning with a 'k' or with a 'k' in third position is incorrectly answered with the judgment of a beginning 'k'. In this example the judgment is explained if the distance from level is thought to be formed by the frequency of inner stimulation by relevant words gathered from memory. The prospect theory of Kahneman and Tversky (1979) and its extension in the ambiguity theory of Einhorn and Hogarth (1985) of decision making under uncertainty are based on identical concepts as adaptation-level theory. Hogarth (1987) formulates (p. 99-101): - "First, people are assumed to encode outcomes as deviations from a reference point ... by definition deviations only exist in reference to some norm, e.g. as potential increases or decreases from the status quo ...it is necessary to know how specific reference points are established ... a person's status quo often provides a natural reference point ... The second characteristic of the value function is that its shape captures the notion that people are more sensitive to differences between outcomes the closer they are to the reference point ... The third characteristic of the value function is that it is steeper for losses than for gains. This translates the notion that people experience losses and gains with different levels of intensity. ... people are assumed to assess ambiguous probabilities by first anchoring on some value of the probability and then adjusting this figure by mentally simulating or imagining other values the probability could take. The net effect of this simulation process is then aggregated with the anchor to reach an estimate." - It will be clear that this psychology of decision is an adaptation-level theory for judgment and risk with mental simulation as a source of cognitive stimulation.

Based on the generality of adaptation-level theory for all kinds of behaviour and especially its relevance in the study of perception and judgment of risk, we have no doubt about the justification of its application in risk behaviour in traffic. Two important, sometimes misconceived aspects of adaptation-level theory, however, are still to be discussed.

First, adaptation is often conceived as establishing only momentary levels. This need not be the case; watchmakers feel weights to be heavier

than weightlifters and actors attribute causes less to dispositions of persons than the watchers of plays. Longlasting effects of experimentally induced adaptation levels (for example in sensory deprivation studies) are also obtained.
Secondly, adaptation-level concepts are often equated with the functional maintenance of an equilibrium. This may lead to erroneous insight. The attainment of fixed levels must not be confused with the theory of adaptation-level formation. The adaptation levels are dynamic because of the ongoing changing nature of the processes in the individual and the give-and-take of responses to and stimulation from the environment. As Helson remarked (Helson, 1964, p. 54): "adaptation-level theory differs from the principle of homeostasis because it stresses changing levels." Adaptation-level theory concerns perceptions influencing perception of perceptions and affections influencing affectivity of affections. As such, adaptation-level theory belongs to the class of dynamic self-organizing systems of dissipative and evolutionary processes. Our theory of risks in traffic uses adaptation-level theory by showing how risks in traffic influence the risk of risks in traffic.

3.4. Risk-homeostasis theory revisited

The theory of risk homeostasis has been put forward by Wilde (1982a, 1982b), who illustrates the plausibility of his theory by many examples. Wilde states: - "road users adjust their behavior such that the level of perceived risk will match the level of target risk. .... As a consequence of the postulated tendency of drivers to adjust their behavior such that the time-average level of experienced risk remains constant ... the accident rate per time unit of driver exposure is invariant." - Every non-motivational traffic-safety measure, according to risk-homeostasis theory will not influence target level since it will be compensated by behavioural adjustment in such a way that the time-averaged risk remain individually and thus collectively constant.

This theory is exactly the result of a onedimensional theory of risk based on the arousal dimension for risk as described in section 3.2. Wilde explicitly confirms this by referring to the occurrence of road accidents as a consequence for the sake of reaching or maintaining an optimal arousal level. Many authors have objected to this view and questioned the evidence brought forward by Wilde. To name a few: Slovic and Fischoff

(1982) for risk-decision arguments, McKenna (1985) for psychological arguments and Evans (1985, 1986) for empirical arguments. In reply to Slovic's and Fischoff's argument that homeostatic equilibrium may break down when people adapt to new levels of risk, Wilde only notes that such changes must be brought about or one must wait for the desirable social change to come along "spontaneously". Wilde assumes that only motivational changes can influence safety by a change in target level and gives suggestions for influencing the utility of risk in order to achieve that.

Figure 21 taken from Wilde illustrates the system control by human behavioural adjustment in risk-homeostasis theory.

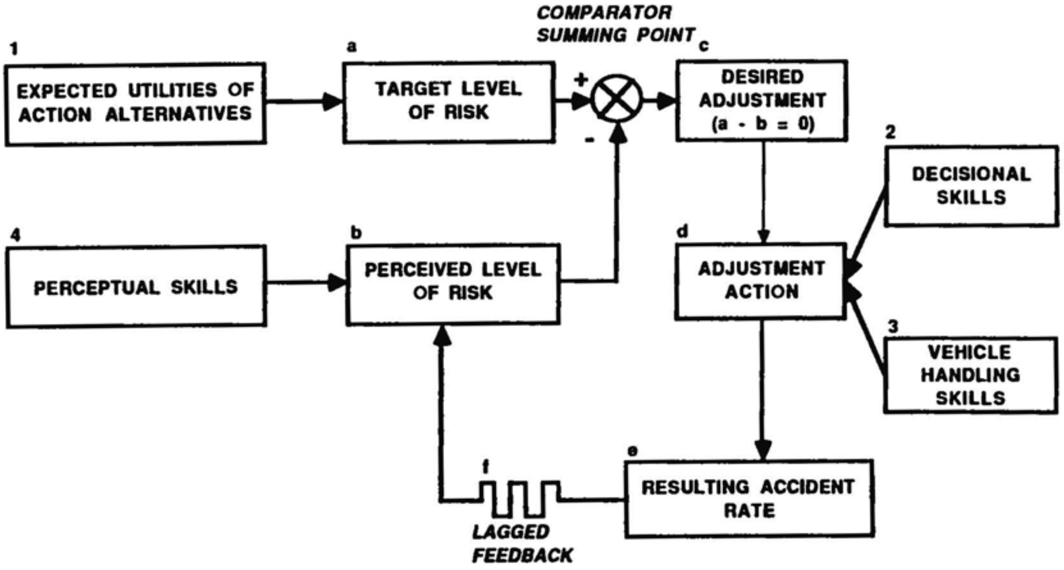

Figure 21. Wilde's homeostatic model of risk behaviour

We accommodate the theory of risk homeostasis in the light of our frame of reference theory of risk in traffic. The resulting system theory of individual risk predicts changes or (partial) compensations or overcompensations in risk, dependent on the aspects of a given safety measure. These aspects can be evaluated before implementation of a safety measure.

With respect to our frame of reference theory of risk the target level in the system model of Wilde must be considered to be the range of aspiration. The implication is that there is no determined value for the optimal level of risk, but a whole range of optimal risk values of zero incentive value. This has important consequences for the dynamics of the system, since changes in risk do not result in desired adjustments for changes in risk within the range of aspiration. Adjustment actions are nil for risk deviations from the adaptation level of risk, as long as these deviations remain in the range of aspiration. In case risk deviations from adaptation level result in risks outside the range of aspiration, behavioural adjustments lead to risk compensation to the outer scale values of the range of aspiration. Therefore we distinguish between within-range changes and changes outside that range in the description of the resulting system dynamics.

The system dynamics of the changes are phased as follows:

- an externally induced change in risk within the range of aspiration will not be compensated by behavioural adjustment and therefore results in a probably small, but comparable change of accident rate;
- an externally induced change in risk causing risks ouside the range of aspiration is compensated by behavioural adjustments up to the adjacent outer range value and therefore results in a comparatively reduced, but maximal obtainable change in accident rate;
- a maximum or comparable change in accident rate, perceived or subliminal, will result in a lagged maximum or comparable change of the adaptation-level for risk;
- a comparable or maximum change in adaptation level is followed by a reduced comparable or maximum shift of the range of aspiration;
- a reduced comparable or reduced maximum shift of the range of aspiration or indifference interval results in a change of risk behaviour.

The range of aspiration as an indifference interval for risk with zero incentive value is better described as the risk-acceptance or risk-tolerance region. The validity of risk decisions in traffic as based on evaluation of negative aspects only, is also sustained by evidence on decision making under time pressure and moderate distraction (Wright, 1974).

The change in risk behaviour for an externally induced change of risk stimulation is fourfold. We discribe the four aspects of effects in case of some safety measure that shifts the risk-tolerance region downward, under the hereafter discussed condition that the measure does not change the dimensional weights and incentive values as such:

- momentary risk stimulation below the unshifted and shifted indifference interval results in less strong compensation by riskier behaviour;
- momentary risk stimulation in the shifted but below the unshifted indif-

ference interval is no longer compensated by riskier behaviour;
- momentary risk stimulation above the shifted but in the unshifted indifdifference interval is now compensated by safer behaviour;
- momentary risk stimulation above the shifted and unshifted indifference interval is more strongly compensated by safer behaviour.

According to our frame of reference theory changes in risk behaviour are not only possible as a result of effects of externally induced changes of risks directly operating on adaptation level. Changes in risk-tolerance region can also be obtained, independent from direct risk-scale stimulation, by changing weights for the postulated underlying fear and arousal dimensions of risk. Changing weights may be obtained by methods directly aimed at the formation of weights, such as exposure to new information (Anderson, 1981, 1982), other instruction methods (affect and mastery oriented education) and socially induced changes in attitude (McGuirie, 1985). Safety measures, however, also can influence the differential weighting, and thereby reinforce or mitigate their actual safety benefits. New devices for the active safety of cars for example may enhance the estimation of the skills of the driver-car unit, which may lead to less weight for the fear dimension of risk. If weight reduction for the fear dimension shifts the tolerance region more upward than the ceteris-paribus effect of the new device, an actual increase in accident rate may be obtained. We believe that the reported so-called overcompensation of safety measures (Evans, 1985) with perverse consequences are not so much based on compensatory feedback as on anticipatory changed weights resulting in an upward shift of the risk-tolerance region. In general measures which stress the fear dimension or relaxes the arousal dimension or both will as such enhance road safety more than the possible ceteris-paribus effect of the measures would predict. Such planned measures may change weights in advance and can have foreshadowed effects before actual implimentation, which render evaluative before-after studies with relative short periods even more inconclusive. Such foreshadowed effects are found in the time-series analyses of accident rates by Wegman (1989). Measures with reversed effects on the dimensional weights will show partial or even adverse safety results. One can easily think of an 'a priori' evaluation of measures with respect to weight effects; porous asfalt for example will increase the need for arousal and decrease fear on wet roads and the application of rib-reflex road marking will do the reverse.

An other indirect way of inducing shifts in tolerance region, which is conceptually independent (however, mathematically (Koornstra, 1989) confounded with changes of weights mimicking the same within an individual but not so interindividually), is obtained by a relative decrease in incentive value for the arousal dimension with respect to the incentive value for the fear dimension. These types of measures are the utility influencing measures suggested by Wilde (1982a, 1982b) and in risk-homeostasis theory they are the only effective type of measures.

The last conceptually independent way of changing the risk-tolerance region would be a change in location of underlying aspiration levels of fear and arousal relative to adaptation level. In our mathematical theory (Koornstra, 1989) distances to adaptation level, however, are reciprocally related to weights. This would lead us into the area of the formation and change of the location of achievement targets of individuals on motivation associated scale dimensions. In achievement motivation (Dweck & Elliot, 1983) goal setting is shown to be dependent on (changes in) skills and estimation of competence in relation to the estimated difficulty of tasks. In the project theory of motivation of Nuttin (1980) the goal setting is dependent on one's expectation of the possibilities in the future.

More formal theories in the psychology of motivation (Atkinson, 1964; Beck, 1978; Berlyne & Madsen, 1973), translated in terms of our theory, distinguish between:

- a) probability of actually obtaining a scale value of the incentive associated scale dimension (the expectancy aspect);
- b) weights as strenghts of association between scale dimensions and incentive dimensions (the strenght of motive aspect);
- c) amplitude of incentive value for motives (the strenght of incentive aspect);
- d) direction and distance of level of aspiration with respect to adaptation level on the incentive associated scale dimension (the goal-setting aspects).

In the formal theory of motivation, however, the distance aspect is not explicit; thereby confirming the redundancy in the reciprocal relation of distances and weights. Accordingly our frame of reference theory of risk in traffic distinguishes four types of influencing risk behaviour by changing the frame of reference in four conceptually independent ways. Changes in risk-scale stimulation, changes in weights for the underlying compensatory dimensions of risk, changes in the incentive values associated with the underlying dimensions and changes in underlying levels of aspiration relative to aspiration level. Since the first three are related to shifts of the risk-tolerance region and the last only to the width of the indifference interval for the risk-tolerance region, the first three are probably more effective in changing risk behaviour.

Our revision of the risk-homeostasis theory, although still homeostatic in design, is no longer characterized by equilibrium maintenance but by maintenance of lawful lagged changing levels and risk-tolerance region and by prediction of legged gradual change of that region. The picture of the system as given in Figure 21 has to be amended. An arrow from outside to the accident-rate box, symbolizing the external safety influences, is to be added. An extra connection from the box for accident rate to the box labelled by target level, but now representing the range of aspiration and perhaps beter labelled as risk-acceptance or risk-tolerance region, will show the influence on adaptation level and the tolerance region. This self-referencing adaptive loop and the risk-tolerance region, as the indifference interval for the range of aspiration of risk-scale values, form the essential amendments of the risk-homeostasis model.
In Figure 22 the amended system for our frame of reference theory of risk in traffic is pictured.

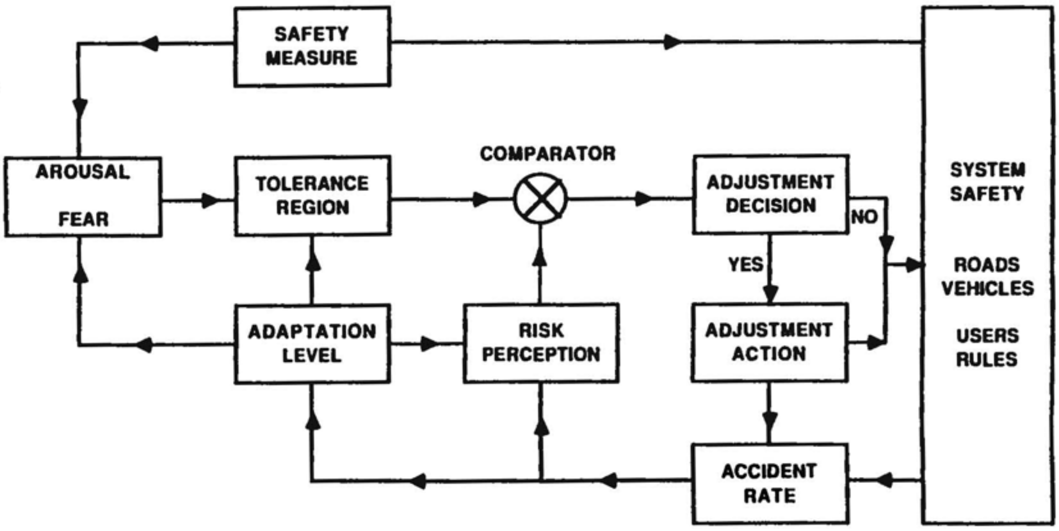

Figure 22. System structure for frame of reference theory of risk

Such a marriage of cybernetic feedback and adaptation level led already as early as 1969 to a theory of stimulus equivalence in psychology (Capehart et al., 1969). It is instructive to cite from this work:- "The theory is based on two concepts, the TOTE (test-operate-test-exit) unit (Miller, Galanter, & Pribaum, 1960) and adaptation level (Helson, 1964). TOTE can be viewed as an information-processing mechanism, while AL appears to be able to account for context or frame of reference effects. In addition, TOTE and AL are two compatible concepts and seem to lend themselves to the development of a cohesive theory. In this theory AL is viewed as a 'stored referent' or 'template' to which inputs are compared. The TOTE unit, which is basically a cybernetic feedback loop, consists of two parts: a test phase and operation phase. The test phase can be thought of as an incongruity-sensitive mechanism. Whether the test consists of a match or a detection of incongruity between input an the referent depends on the information available .... Based on the test, operations are performed. .... Such operations provide feedback to the test. ... The stored referent serves as a standard against which an incoming stimulus is judged. If Helson's concept of AL and stored referent are equated, an important link between TOTE and AL is made. ... AL is conceived of as being an internal reference point, but it can be operationalized as a value or region on the physical stimulus dimension. ... Thus, the stored referent or AL is said to change with change in incoming stimulation. Rather than a static isomorphic representation of a given stimulus value, the stored referent is a dynamic reference point that is sensitive to changes in stimulation (Capehart et al., 1969, p. 407-408)." - It is evident that our proposed system theory of individual risk is based on identical concepts and structure. One may wonder why psychologists in criticizing Wilde's risk-homeostasis theory did not follow a more constructive approach by adjusting the theoretical system. Instead of bringing the theory in accordance with conflicting data, only the validity of the predictions were questioned or denied.

In terms of general system theory as described in Section 1.1 the risk-homeostasis theory is an input controlled and open system, in contrast to self-referencing closed systems. As we remarked there, a system is never closed, nor solely an open system, perhaps excluded man-made technical control systems. And indeed Wilde (1982a) explicitly copied the system structure from the man-made technical homeostatic model relating room temperature to heating system activity. This transition to human behaviour does not take the self-referencing aspects of human information processing into account. Even human control of temperature is adaptive: after lower room temperatures we adapt our senses for differences in temperature to a lower level and our feedback action to the heating system in the house is no longer static, although bounded in change by rather narrow saturation levels for human temperature. Our frame of reference theory led to an accomodation of the solely open system by adding a self-referencing feedback for risks influencing the evaluation of risks. Thereby, we designed a mixed open and closed system of human risk behaviour, capable of adaptation which is a vital aspect of man.

3.5. Empirical evidence

In criticizing the risk-homeostasis theory Evans (1986) showed that the main prediction of this theory (Wilde, 1982b), e.g. constant accident rate as accidents per unit of travel time, is beyond reasonable doubt invalidated by the apparent decrease of accident rates. Our frame of reference theory of risk in traffic predicts an aggregated gradual decrease of risk reduction by physical safety measures. This is due to partial and lagged behavioural compensation towards the lagged maximum bounded downward shift of the risk-tolerance region for big measures and to small autonomic behavioural downward shifts of the risk-tolerance region for small measures. Analysis of fatality-rate time-series, based on the linear operator model for collective adaptation of Section 2.2 confirms this prediction. Figure 23 shows four fitted fatality-rate curves, taken from Koornstra (1987), for this model.

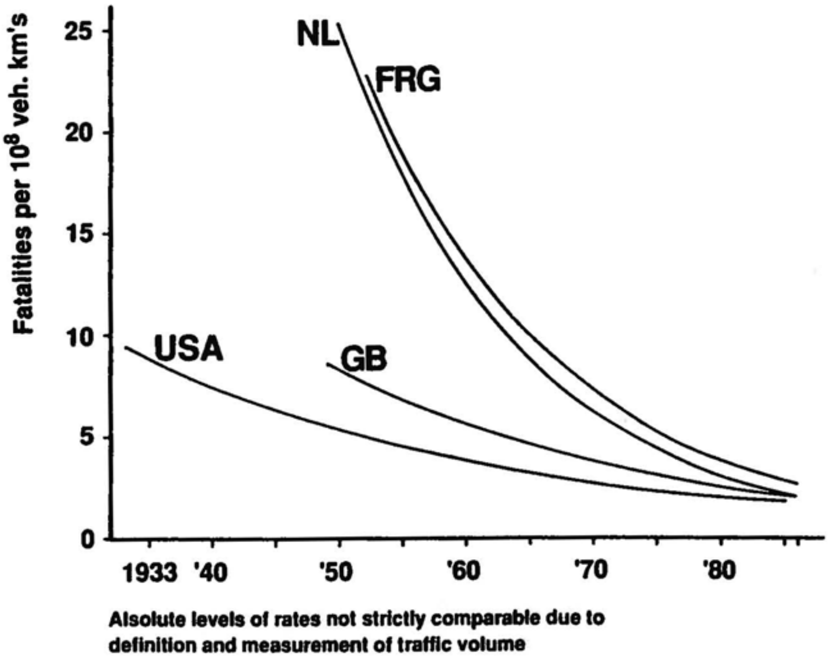

Figure 23. Fitted fatality-rate curves for four countries

The prediction of a lagged partial compensation for a rather large reduction of risk up to a gradual lower shifting accident rate is confirmed by a fatality-rate time-series presented by Evans (1989) and shown in Figure 24. The measure, which induced the change, is the behaviourally accepted reduction of speed-limit from 65 to 55 m/h for the interstate highway system of the USA since the oil-crisis of 1974.

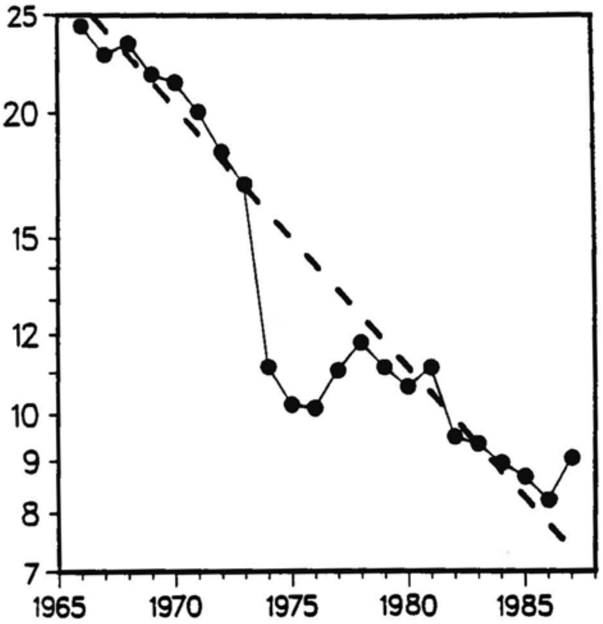

Figure 24. Fatality rate (log scale) on the USA Interstate System

The predicted time lag is confirmed by the decrease from the fitted trend in 1974/75 and the predicted partial compensation by the increase relative to the trend from 1976 to 1978. The increase is not obtained by higher speeds (low mean speed remained), but undoubtedly by other compensating riskier behaviour on the otherwise unaltered interstate system. Compensation is not complete, since it stops as predicted at the gradually in time downward shifting fatality-rate curve, as is shown by the data from 1978 to 1986. Thereafter the speed-limit was raised again to 65 m/h. The picture of Figure 24 reveals that the time-lag lasted about two years before the compensation process for this large risk change started, while the compensation process took a period of four years. This confirms our hypothesis of low perceptibility or subliminal nature of changes on low risk level. Only by integration over time of stimulations on such a low level of the risk scale, risk change becomes perceivable. From our frame of reference theory of risk, therefore, we predict a return to the, perhaps less, decreasing fatality rate after the increase of risk in 1987, induced by the raise in speed-limit to 65 m/h, about 1991 or 1992 for the

USA interstate highway system. We take the above results as clear evidence for the hypothesized adaptation-level effects of the frame of reference theory of risk in traffic.

Evidence for effects of changing weights or for effects of changed incentive values through safety measures are harder to obtain. It will be less clear because of the many possible interpretations of effects. The accident rate differences between age and sex groups, however, may very well be explained by differences in ability to avoid risk and in risk acceptance. Differences in risk acceptance under equal exposure to risk stimulation must be due to different weighting or different incentive strengths of the postulated underlying fear and arousal dimension. Different weights or strengths and age are correlated by accumulation of experience, psychophysiological and life-style changes. We refer to Table 1 for the evaluation of the weights on the fear dimension as a function of cognitive ability to anticipate and of driving skills. The relation of the age-dependent accumulation of experience and psychophysiological functioning with skills and abilities is evident. The need for arousal will decrease with age due to psychophysiological and life-style changes. The sex-typed life-style difference of adolescents may be associated with less arousal need and higher sensitivity to fear for adolescent women. This implies a higher mean weight for fear and a lower mean weight for arousal for young women compared with young men. In Table 2 we summarize the tentative effects of differential weighting of fear and arousal and abilities for sex and age groups.

	Adolescents		Middle age	Old age
	man	woman		
Developmental and life-style effects:				
weight for fear	-	0	0	+
weight for arousal	++	+	0	-
Driving skills	0/-	0/-	+	0/-
Cogn. anticipation	-	-	+	+
Effects according to Table 1 on weight for fear	?	?	0	+
Ability to avoid risk	low	low	high	moderate
Fear-arousal determination of risk-tolerance region	very high	high	medium	low
Expected resulting risk	very high	high	low	moderate

Table 2. Risk as a funtion of risk-tolerance regions and abilities

The relative actual accident rates for these groups are identical with the expected risk levels. Whether this is to be taken as evidence for our theory or not, depends on the evaluation of the amount of circularity in our reasoning. Anyhow, consistency of theory and facts is beyond doubt. The results of the analyses shown in Table 3 are certainly convincing. In that table we present the evaluation of 22 measures which are judged to have certain effects on traffic safety, based on the studies of Evans (1985) and the OECD (1989) on behavioural risk compensation. The scored evalution is based on differences of actual effects and the expected effects of experts under the absence of behavioural compensation. The scoring is simple :(++) means safety increased contrary to expectation; (+) means safety increased more than expected; (0) means safety result was as expected; (-) means safety increase was less (or nil) than expected; and (--) means a safety decrease where an increase was expected. In case of more than one reported result for the same measure we took the median evaluation as the scoring for Table 3.

type of measure	source	number of studies	evalution expected result	weight of fear	weight of arousal	prediction expected result
publicity campaigns	O	>6	0/-	+/0	0	+/0
education/training	O/E	>6	-	-	0	-
legisl. enforcement	O	>6	0	+/0	0	+/0
daytime running lights	O	3	+	+/0	0/-	+
high breaking lights	O	5	+	+/0	0/-	+
antilocking system	O	2	-	-	0	-
seatbelt wearing	O/E	>6	0/-	0/-	0	0/-
speed limit 55 m/h	E	1	0	-/0	0/+	-
studded tires	O/E	2	-	-	0/-	0/-
higher veh. accel.	E	1	-	-	0	-
vehicle pass. safety	E	2	-	-/0	0/+	-
new traffic signals	E	2	--	0	-	-
pedestrian cross-walk	E	1	--	-	0	-
motorcycl. helmet	E	2	--	-	+	--
* small cars	E	2	++	+	-/0	++
* Sweden left->right	E	1	++	+	-	++
* anti prolonged driv.	E	2	0	0	0	0
* bad weather effects	E	1?	++	+	-	++
* monocular vision	E	1	0	+	+	0
* larger cars	E	2	-	-	+/o	--
* reduced breaking cap.	E	1	-	+	0	-
* driver distractions	E	1	-	-	-	0

-* Measures not aimed at safety effects but having associated effects
Source of review and evaluation: E = Evans (1985); O = OECD (1989).

Table 3. Prediction of extra effects by expected changes in weights and evalution with respect to ceteris paribus expectation of experts.

The evaluation scoring is taken from the publications of Evans and the OECD. The estimation of implicit effects on weights for the postulated fear and arousal dimension is ours. (After interviewing some experts and laymen. We explained to them the meaning of the dimensions and the relation with skills and asked them their opinion on the change of strength per dimension and measure, but did not inform them about the evaluation or purpose of the inquiry. Again we took the median as the reported score.) From our frame of reference theory of risk the resulting extra effects on the expected effects are predicted on the basis of the fear and arousal scoring. In Table 4 we present the significant high correlation between evaluation and prediction for the 22 measures.

		Prediction of extra effect				
		(++)	(+)	(+/0,0,0/-)	(-)	(--)
Evaluation of extra effect	(++)	3	-	-	-	-
	(+)	-	1	-	-	-
	(0,0/-)	-	-	5	1	-
	(-)	-	-	2	5	1
	(--)	-	-	-	2	1

Table 4. Number of measures for evaluated and predicted extra effects

Although there may be some bias in the the determination of weights (the reader is invited to check Table 3), due to the knowledge of evaluation the experts may have, we regard Table 4 as firm evidence for the frame of reference theory of risk. The evidence of Table 4 not only confirms our postulated underlying dimensions for fear and arousal, but also the hypothesized role of differential weighting or differential incentive strength of these dimensions in determining the risk-tolerance region and the predicted effects of actual risk behaviour in traffic. We do not know of any other theory capable of consistent prediction of the above effects of measures. Perhaps our theory is not simple, but as Wilde and Evans (1986), we quote Einstein again: -" Everything should be made as simple as possible, but not simpler."-