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SYSTEM THEORY AND INDIVIDUAL RISK

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Abstract - The general system approach to risk in traffic and fundamental psychological theories leads to the frame of reference theory of risk. The reference-frame theory of risk integrates Wilde's risk-homeostasis theory and Fuller's threat-avoidance theory of risk by the simultaneous operation of underlying dimensions for arousal and fear associated with risk. The zero-risk model of Näätänen and Summala turns out to be a special case of the reference-frame theory. The theory is based on a system theoretical integration of adaptation-level theory, the aspiration-level concept and the approach-avoidance foundation of the unfolding theory of preference. Reference-frame theory states that individuals have a zero-valued indifference range on the risk-stimulation scale. Risk stimulation within that range below and above adaptation level has no immediate impact on behavioural adjustment. The valence of risk stimulation below and above that range is increasingly negative. Risk stimulation outside the indifference range causes adjustments by response-induced risk stimulation up to the outer values of the indifference range on the risk scale. Lasting changes in actual mean risk stimulation or changes in the sensation of arousal or fear by safety measures cause shifts of the indifference range on the risk scale and thereby gradually change the norms for individual risk acceptance. The theory postulates an adaptive downward shift of risk-indifference ranges of road users by successive safety measures and on an aggregated level predicts a gradual and lagged reduction of casualty rate. The theory also enables one to predict the direction and order of magnitude of behavioural adjustments to the otherwise expected risk reduction of safety measures.

1. Incentive values and behavioural control

In scientific psychological theories the measurement of subjective scales and valence functions of subjective or 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-value functions 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 1 serves as a crude summarization of some relevant concepts and system dynamics of behaviour. We explain Figure 1 in general, postponing its application to risk in traffic in a system-theoretical context.

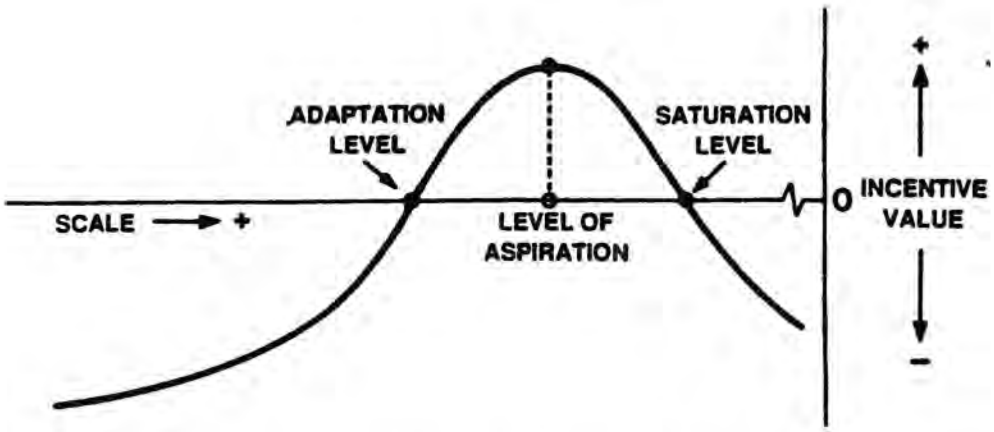

Figure 1. Graphical summary of scales and values for behaviour

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 functional relation between scale and incentive value. Inflexion points of the curve are named for explanation. Adaptation level stands for the mean overall level of input of the aspect measured by the scale to which an individual is exposed and habituated. 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 1, the level of aspiration is located on a higher scale value, it is assumed that the behaviour of the individual is directed towards obtaining higher scale values. Here the system dynamics of behavioural feedback, producing less or more objective stimulation and effects on subjective sensation or judgment of scale values and incentive values, come into play. Reactive behaviour that results in obtaining scale values moving from adaptation level to aspiration level is thought to be increasingly rewarding. Behaviour that results in obtaining scale values lower than adaptation level is experienced as punishment. Obtaining scale values above aspiration level is thought to be less rewarding up to saturation level. If a saturation level exists scale values higher than saturation level may even provoke disgust and have negative incentive values. Reward and punishment or expectations of reward and punishment explain approach and avoidance behaviour or preference. The system dynamics of this general picture become even more visible if one notices that continuing input of higher or lower scale values results in a upward or downward shift of the adaptation level. 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 ability 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 satiation may occur, but a saturation level will hardly exist; for scales of a more biological nature, like food or temperature, a saturation level is quite feasible. The logarithmic nature of the perceived scale implies that an amount of reduction of salary (objective scale value) has more negative incentive value than the positive incentive values for the same amount of rise in salary; moreover, it implies that effects of salary changes with the same objective amount are less for higher salaries. 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.

2. Frame of reference theory of risk in traffic

We may think of an objective and related subjective scale of risk based on cues or features in traffic associated with high frequencies of conflicts, accidents and casualties. The picture of Figure 1 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 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 arousal level has negative incentive value (Broadbent, 1971), which is explained by the neurophysiological nature of the saturation level of arousal. 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 this would shift the adaptation level also towards that level. In turn an accompanying shift of level of aspiration occurs. Since these shifts are bounded by the physiological nature of the saturation level of arousal, this would give rise to the maintenance of an optimal target level of risk at the level of saturation in the end. The end result would be negative incentive values above and below the merging reference levels for behavioural adjustments. Figure 2 illustrates this hypothetical evaluation of risk in traffic.

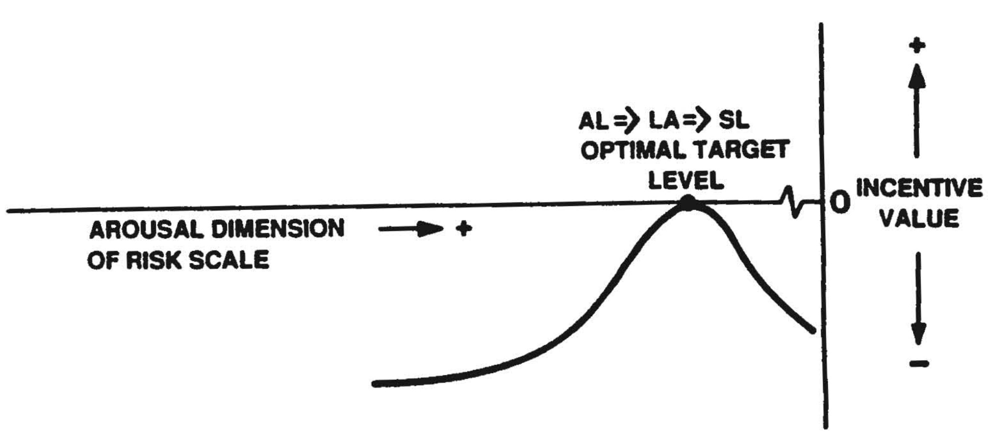

Figure 2. Graph of risk behaviour based on arousal

This unidimensional optimization of risk in traffic is also the hard core of Wilde's theory of risk homeostasis. We 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.

There is, however, also an other interpretation of risk associated with fear and social responsibility. 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 3 we picture the corresponding graphical relations.

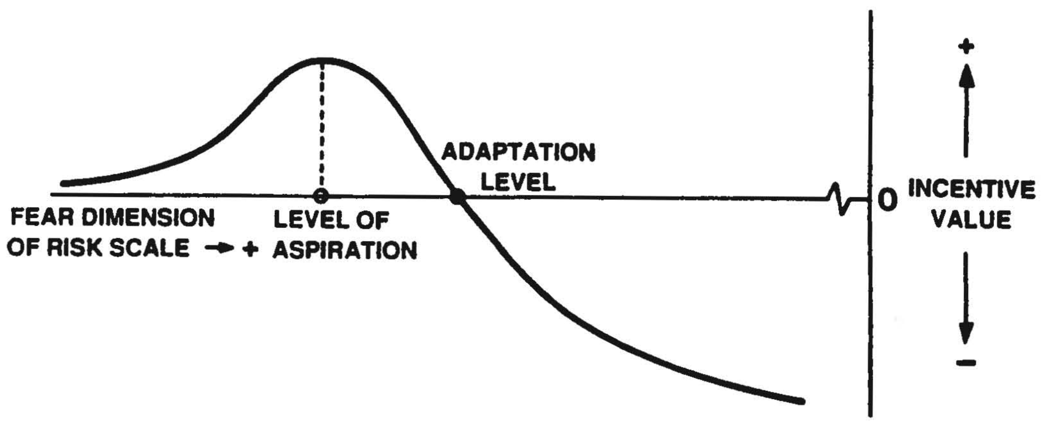

Figure 3. Scale and incentive values for fear of risk

In this presentation positive incentive values are obtained below adaptation level. Probably no saturation level exists beyond which negative incentive values are obtained, but shifts in level of aspiration are bounded by zero risk. Increasing negative incentive values are associated with higher scale values of risk. On such a dimension Fuller's threat-avoidance conceptualization of driving behaviour (Fuller, 1984) is in fact based. The control of danger approach of Hale and Glendon (1987) relates to the same dimension. If fear for risk would be the only operative dimension in risk behaviour, road users will behave as safe as possible. 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, behavioural feedback does not assure complete control over risk stimulation from the traffic environment. So, although downward shifts of levels by safer behaviour may occur, the distance between levels of adaptation and aspiration is not reduced to zero, unless zero risk becomes an aspect of one's traffic environment. We denote this risk hypothesis 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 a combination of the arousal and fear dimension of risk. If we assume symmetry of curves around adaptation level and equal weights for fear and arousal, we obtain the resulting curve presented in Figure 4.

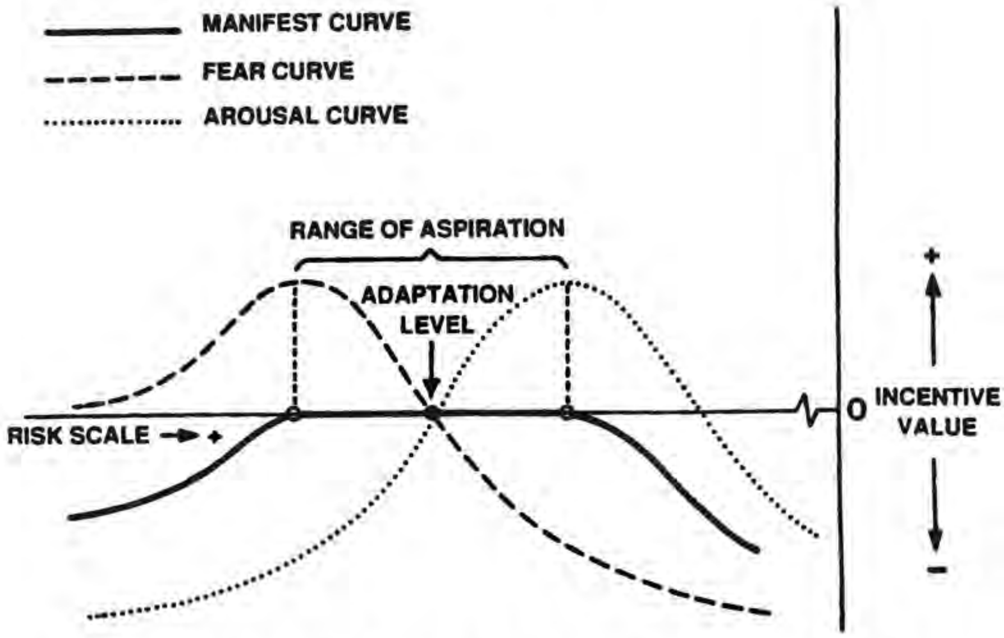

Figure 4. Graph for equal weighted dimensions of risk

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 accurate in the prediction of behaviour (Keeny & Raiffa, 1976; Dawes & Corrigan, 1974 and Dawes, 1979). For the description of the aggregated behaviour of individuals equal distributed weights and therefore equal mean weights is not an unreasonable assumption. Similar assumptions have shown to be valid for the prediction of decision making in other contexts (Einhorn & Hogarth, 1975).

Under these assumptions as Figure 4 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. 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, however, 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. The 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.

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

Table 1. Weights for the fear dimension

Misjudgment of one's own cognitive abilities and driving skills may also be a source of individual differences in weighting of the fear dimension. Especially overestimation of skills will reduce the weighting for fear. Individual differences in appreciation of arousal (Berlyne, 1960) 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). 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 level of aspiration and individual differences in the personality dimensions of neuroticism and extroversion 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 extroversion and stress.

The effects of individual differential weighting of the fear and arousal dimension in our frame of reference theory of risk in traffic leads to rather complex model dynamics. These model dynamics in sequential stages of the underlying process are described by Koornstra (1989a), but the results are as simple as in Figure 4. Due to shrinkage by adaptation and enlargement by deprivation of incentive amplitudes inverse to differential weighting, resulting incentive values of risk for differential weighting are also zero in a range of risk-scale values around one's adaptation level for mean risk. These resulting zero incentive values range from a shifted level of aspiration on one side to a shifted level of aspiration on the other side and increasing negative incentive values are obtained beyond these levels. The only effective difference of differential weighting with respect to manifest curve of Figure 4 is an asymmetric shift of levels.

Since any summation of individual graphs will result in a distribution of ranges of zero incentive values the curve of Figure 4 is also obtained without equal distributed weights. However, location and length 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). As seen from Figure 4 risk stimulation below or above adaption level within that range has no immediate impact on behavioural adjustment. Indifference within limits to traffic safety according to our reference-frame theory, therefore, is not only apparent in collective traffic behaviour, but is also inherent to actual individual behaviour in traffic. Beyond the range of zero values incentive value becomes increasingly negative. 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).
In our frame of reference theory of risk in traffic we take it for granted that zero weights for one of the two dimensions is exceptional. The theoretical exceptional case of a zero weight for fear reduces our theory to the risk-homeostasis theory of Wilde (1982a). Fuller's threat-avoidance model (Fuller, 1984) may be seen as the other special case of zero weight for arousal. The general reference-frame theory of risk reduces to an other special case if the level of aspiration for fear is located at zero risk. In this limiting case the indifference interval ranges from zero risk to the level of aspiration for arousal, above which increasing negative incentive values are obtained. This is equivalent to the zero-

risk model of Näätänen and Summala (1976) where a subjective risk monitor is activated above a particular threshold value of risk in order to reduce risk under this threshold level by future behaviour. In our terms, however, risk below threshold is not experienced as zero, but has zero incentive value.

Our reference-frame theory of risk in traffic is strongly motivated by the fundamental theory of single peakedness of utility functions in approach-avoidance situations in the unfolding theory of preference of Coombs (Coombs & Avrunin, 1977; Coombs, 1964) . The reference-frame theory of risk in traffic is also very much motivated by Siegel's translation (Siegel, 1957) of the classical concept of level of aspiration of Dembo, Lewin and Festinger (Lewin et al., 1944) in to the theory of decision making. As shown in the next section the crucial dynamics of our reference-frame theory of risk in traffic, which are in accordance with the dynamics of Siegel's theory, originate from Helson's adaptation-level theory (Helson, 1964). A cybernetic description of these dynamics is presented in Section 4 and is related to the theory of self-organizing systems. Some of the intriguing theoretical aspects of the integration of the foundations of Siegel, Helson and Coombs, the mathematical and system-theoretical aspects of such an extended theory will be presented in a forthcoming publication (Koornstra, 1989b).

3. <u>Adaptation-level theory and risk</u>

The crucial dynamics of the frame of reference theory of risk in traffic lean heavily on adaptation-level theory as originally formulated by Helson (1948, 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 that theory for cognitive, internally produced mediating stimulation. 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 collective traffic system as described by Koornstra (1988 and 1989a).

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)."
According to Helson's formulation the central aspects of adaptation-level theory are the frame of reference view that all judgments are relative, i.e. based on the scale difference of stimulation to prevailing adaptation

level of stimulation and the assumption that effects of stimulation are formed by a spatiotemporal configuration in which sequence order prevails. Utmost relevant to our frame of reference theory of risk is the evidence Helson (1964) gathered from many studies that subliminal stimuli influence adaptation level as well, albeit with less effect than supraliminal stimuli. The effect of such subliminal changes in risk will depend on the frequency of stimulation and their integration over time according to Bloch's law (Bloch, 1885; Di Lolo, 1980). Continuing unperceivable changes in risk, therefore, will have an effect on adaptation level of risk in the long run. Consequently, modify the zero-risk conception of Näätänen and Summala (1976); a mean change in level of low risks may be subliminal, but changes in low risk stimulation on the long run will have effects.

Adaptation-level theory has been very useful in the study of psycho-physical judgment, perception, learning, cognition and motivation (Helson, 1964; Appley, 1971).
Bevan and Gaylord (1978) showed that adaptation to perceptive stimulation must be the source for explanation for adaptation-level effects and not judgmental responses. 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) ingeniously showed how relativity and organization of visual judgment can be explained by adaptation-level theory.
Hilgard and Bower (1966) in chapters 14 and 15 of their classical book 'Theories of Learning' conclude that adaptation-level theory - "... implies a relativistic view of reinforcement ... is a conception that makes contact also with the economists' notion of utility and even more obviously with the cognitive theorists' notion of expectancy. The effect on behavior of a given outcome is seen as dependent upon its relation to an internal norm derived via a pooling process from series of prior outcomes encountered in a given situation (p. 418) ... may be applied to both positive and negative reinforcement (p. 518) ... nicely integrates parts of the 'relational' and 'specific' stimulus theories (p. 527)".
Adaptation-level theory also 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 (1971).
In studies on choice and risk or judgment under uncertainty the concepts of adaptation level and level of aspiration are often undistinguished (Siegel, 1957; Payne et al., 1980; Hogarth, 1987). Two types of bias from heuristics for judgment under uncertainty (Kahneman et al., 1982) e.g. bias by anchoring and adjustments and bias by availability, however, are in fact phenomena explained by adaptation-level theory. 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 ... The second characteristic is 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 ... 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 with mental simulation as stimulation.

Based on the generality of adaptation-level theory for all kinds of behaviour and especially its relevance in the study of perception, judgment of risk and motivation, we have no doubt about the justification of its application in risk behaviour in traffic.
The adaptation-level concept is sometimes equated with the functional maintenance of an equilibrium. This may lead to erroneous insight. The attainment of a fixed level 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 riskiness of risks in traffic.

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. Every non-motivational traffic-safety measure, according to risk-homeostasis theory will not enhance safety since such measures 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 unidimensional theory of risk based on the arousal dimension for risk as described in Section 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) and Evans (1985, 1986) for empirical arguments. In reply to Slovic 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 the target level of risk and gives suggestions for influencing the utility of risk in order to achieve that.

We accommodate the theory of risk homeostasis in the light of our frame of reference theory of risk in traffic. The target level of risk in the system model of Wilde must be replaced by 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 adjustments for changes in risk within the range of aspiration. In case risk deviates from adaptation level outside the range of aspiration, behavioural adjustments lead to risk

compensation up 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 outside 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 results in a change of risk behaviour.

The range of aspiration as an indifference interval for risk with zero incentive value is, therefore, better described as the risk-acceptance band or risk-tolerance region.
The change in risk behaviour for an externally induced change of risk stimulation is fourfold. We describe 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:

- risk stimulation below the downward shifting indifference interval results in less strong compensation by riskier behaviour;
- risk stimulation in the downward shifted but below the unshifted indifference interval is no longer compensated by riskier behaviour;
- risk stimulation above the downward shifted but in the unshifted indifference interval is now compensated by safer behaviour;
- risk stimulation above the unshifted indifference interval is more strongly compensated by safer behaviour.

In our frame of reference theory changes in risk behaviour are not only possible as a result of changes in risk stimulation directly operating on adaptation level. According to our reference-frame theory we can distinguish between four types of changes in the frame of reference, which are conceptually independent:

- changes in risk-scale stimulation influencing adaptation level;
- changes in weights for the underlying compensatory incentives for risk;
- changes in the amplitude of associated incentive values of dimensions;
- changes in distances of aspiration levels relative to adaptation level.

Since the first three are related to location of the risk-tolerance region and the last only to the width of that region, the first three are probably more effective in changing risk behaviour. We may relate these four ways of changing risk behaviour to the aspects of more formal theories in the psychology of motivation (Atkinson, 1964; Beck, 1978; Berlyne & Madsen, 1973). Translated in terms of our theory, these aspects are:

- probability of actually obtaining a scale value together with an incentive associated to that scale value (the expectancy aspect);
- weights as strength of association between scale dimensions and incentive dimensions (the strength of motive aspect);
- amplitude of incentive value for motives (the strength of incentive aspect);

- direction and distance of level of aspiration with respect to adaptation level (the goal-setting aspects).

In these formalized theories of motivation, however, the distance aspect is less mentioned; thereby implicitly sustaining the redundancy of distances and weights in our theory. (In our mathematical theory (Koornstra, 1989b) distances of the levels of aspiration with respect to adaptation level are reciprocally related to weights.)

The first way of changing risk behaviour by actually changing the risk stimulation is discussed before.

The second way of 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 directly, 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. Since weight reduction for the fear dimension may shift the tolerance region more upward than the downward shift of the ceteris-paribus effect of the new device, an actual increase in accident rate can be obtained. We believe that the reported effects of safety measures with perverse consequences (Evans, 1985) are not so much based on compensatory feedback as on anticipatory changed weights resulting in an upward shift of the risk-tolerance region. In contrast 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. 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 asphalt 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.

A third way of inducing downward shifts in tolerance region, which is conceptually independent, is obtained by a relative decrease in the amplitude of incentive for arousal with respect to the amplitude of incentive for fear. These types of measures are the utility influencing measures suggested by Wilde (1982a, 1982b) and in Wilde's view 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. 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.

Our revision of the risk-homeostasis theory, although still homeostatic in design, is no longer only characterized by equilibrium maintenance but by maintenance of lawful lagged changing levels and lagged gradual change of risk-tolerance region. In terms of general system theory as described by Koornstra (1988; 1989a) the risk-homeostasis theory is an input controlled and open system, in contrast to self-referencing closed systems. As Koornstra remarked 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 a man-made technical homeostatic model. Wilde's transition to human behaviour does not take the self-referencing aspects of human information processing into account. On the basis of our reference-frame theory we add a self-referencing feedback for risks influencing the evaluation of risks. Amending the system structure of Wilde's homeostasis model by an extra self-referencing connection from the box for accident rate to the box labelled by target level, but now representing the risk-tolerance region we show the influence of adaptation to risk on the tolerance region. This self-referencing adaptive loop and the risk-tolerance region form the essential amendments of the risk-homeostasis model. Thereby, we design a mixed open and closed system of human risk behaviour, capable of adaptation which is a vital aspect of man. In Figure 5 the amended system for our frame of reference theory of risk in traffic is pictured.

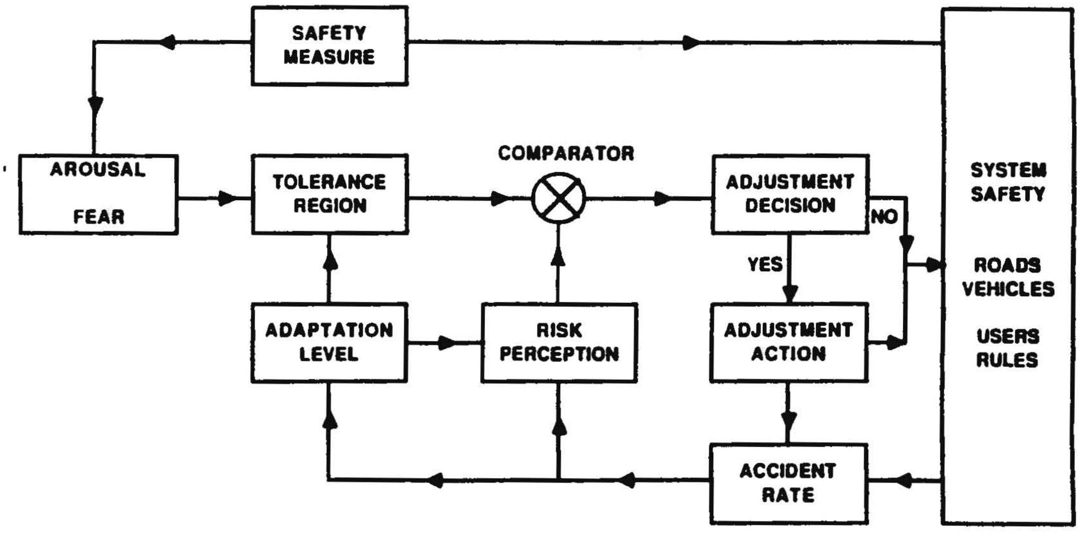

Figure 5. System structure for frame of reference theory of risk

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). The two compatible concepts of cybernetics and adaptation level lend themselves to the development of a cohesive theory. Our proposed system theory of individual risk is based on identical concepts and structure as Capehart's stimulus-equivalence theory. One may wonder why researchers 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.

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 rates. Our frame of reference theory of risk in traffic predicts an aggregated gradual decrease of risk by safety measures. Analysis of fatality-rate time-series (Koornstra, 1987; Koornstra, 1988; Oppe, 1989) confirms this prediction. This is due to small autonomic behavioural downward shifts of the risk-tolerance

region for small measures and for big measures to maximum bounded partial and lagged behavioural compensation towards the also lagged downward shifting risk-tolerance region.
The confirmation of the prediction of a lagged partial compensation for a rather large risk-reduction measure up to a gradual downward shifting risk level is shown in Figure 6 by a fatality-rate time-series taken from Evans (1989). The measure, which induced the change, is the behaviourally accepted reduction of speed-limit from 70 to 55 mph for the Interstate highway system of the USA since the oil-crisis of 1974.

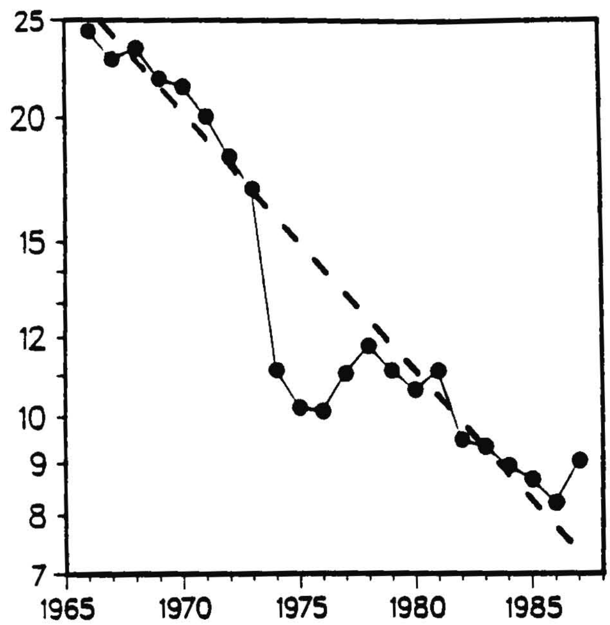

Figure 6. Fatality rate (log scale) on the USA Interstate system

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 log-linear regression line of the decreasing fatality-rate, as is shown by the data from 1978 to 1986. Thereafter the speed-limit was raised again to 65 mph. The picture of Figure 6 reveals that the time-lag lasted about two years before the compensation process for this large risk change started, while the partial 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 after integration over time of risk stimulations on such a low level of risk, risk change becomes effective. From our reference-frame theory, therefore, we predict a return to the decreasing fatality rate after the increase of risk in 1987 about 1991 or 1992 for the USA Interstate highway system.
The apperant lagged partial compensation can not be explained by risk-homeostasis theory, nor by the zero-risk model or the threat-avoidance model. The above results, however, confirms 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 strength of incentive values through safety measures are harder to obtain. Such will be less clear because of the many possible interpretations of

effects. The accident rate differences between age and sex groups, however, may be not only explained by differences in ability to avoid risk but by differences in risk acceptance as well. Different weights or strengths are age 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 age dependence of experience, psychophysiological functioning and abilities is evident. The need for arousal will decrease with age due to psychophysiological and life-style changes. The sex-typed differences in life-styles of adolescents may imply a higher mean weight for fear and a lower mean weight for arousal for young women compared with young men. The relative actual accident rates for these groups are identical with the differences in expected risk acceptance regions. 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 result of the analysis shown in Table 2 is certainly more convincing.

Type of measure	Source	Number of studies	Evaluation 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/-	+
anti-locking 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 2. Prediction of extra effects by expected changes in weights and evaluation with respect to ceteris paribus expectation.

In this 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 evaluation scoring is taken from these publications and is based on differences of actual effects and the expected effects 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 multiple reported results for one measure we took the median evaluation as the scoring for Table 2. The estimation of implicit effects on weights for the postulated fear and arousal dimension is ours. Again we took the median as the score. From our frame of reference theory of risk the resulting extra effects on the otherwise expected effects are predicted on the basis of the fear and arousal scoring. In Table 3 we present the significant high correlation between evaluation and prediction for the 22 measures. Although there may be some bias in the determination of weights (the reader is invited to check Table 2), we regard Table 3 as firm evidence for the frame of reference theory of risk.

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

Table 3. Number of measures for evaluated and predicted extra effects

The evidence of Table 3 not only confirms our postulated underlying dimensions for fear and arousal, but also the hypothesized role of differential weighting 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."-

6. Summary and conclusions

- The frame of reference theory of risk in traffic is a partial self-organizing system theory based on an integration of adaptation-level theory, the aspiration concept in decision and motivation theory and the approach-avoidance foundation of the unfolding theory of preference.

- The three major models of risk in traffic, e.g. Wilde's risk-homeostasis model, Fuller's threat-avoidance model and the zero-risk model of Näätänen and Summala, generate from exceptional limit conditions in the reference-frame theory.

- The reference-frame theory distinguishes four conceptually independent ways of changing risk behaviour by changes in:
  - adaptation level on the risk scale;

- weights for the underlying compensatory incentives for risk;
- amplitudes of incentives for risk;
- distance of aspiration levels relative to adaptation level.

- Individual differences in risk behaviour are explained by differences in the risk-tolerance region related to psychophysiological age and sex characteristics, skills, cognitive abilities of risk perception and the personality dimensions of extroversion and anxiety

- The theory predicts gradually downward shifting norms of individual risk acceptance by changed risk stimulation or changed risk-associated stimulation induced by successive physical and behavioural safety measures. On an aggregated level this results in a gradual and lagged reduction of the fatality rate.

- The theory is able to predict the direction and order of magnitude of behavioural adjustments to the otherwise expected risk reduction of safety measures.

- The predictions from the reference-frame theory are in accordance with or verified by evaluative studies of risk change in traffic, which are unexplained by or even contradict the other major risk models.

7. Literature

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