THE EVOLUTION OF MOBILITY AND ROAD SAFETY

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SUMMARY

It is shown that long term developments in mobility and safety can be related by an evolutionary model of growth and risk adaptation. The model is applied to historical data of several countries (JAPAN, USA, UK, GERMANY) over long periods of time. Growth of mobility can be described by sigmoid curves with a saturation level (taken from biology or econometrics) and risk in road traffic as the fatality rate follows a decreasing adaptation curve (taken from mathematical learning theory). A single peaked curve for the road fatalities per year, is a necessary result from saturating growth and steadily decreasing risk adaptation.

Such growth and risk adaptation curves are related. Deviations from these monotonic macro-developments in mobility and risk are also time dependent and related. Deviations from sigmoid mobility growth tend to be cyclic and seem to be reflected in delayed and reduced cycles of deviations from the steadily decreasing fatality rate curves as a growth-dependent safety adaptation. Relative less increases in mobility seem to be followed by a stagnated decrease or even an increase of fatality rate, as if the system becomes less well adapted. On the basis of these time-related evolutionary trends and cycles, long term predictions are given. It is argued that the momentary stagnation in safety improvements in some countries are temporary cyclical effects of the recent larger increase in motorized mobility and stagnated decrease of the fatality rate. In the long run the increase of mobility levels off to a saturation level for motorization. As a consequence of the model and its fit to data, the fatality rate seems to decrease to virtually zero as time proceeds to infinity, but the injury rate seems to stabilize on a non-zero level.

The impact of these new findings and of the underlying theory of evolution and adaptation are discussed. The relation between mobility growth and risk adaptation is seen as a result of the technological evolution of traffic in a self-organizing socio-economic system. The utility of motorized mobility leads to an increase of vehicle kilometers, which in turn asks for time-consuming plans, investments and realizations of road-network enlargements and improvements. Safety benefits from such enlarged and

improved infrastructures, as well as from the renewal of the national car fleet by safer cars, from revisions of traffic rules, from improved practices of enforcement and driver education and from the ever increasing collective driver experience. These sequences of replacements of subsystems enable the traffic system to grow and are also the cause a of lagged safety improvement.

The mathematics of the theory leads to process descriptions and predictions which are only a function of time. The validity of the theory and its predictions may only hold for motorization in democratic countries, since that democratic control seems to determine the socio-economic self-organization of the transport system and its lawful developments of growth and safety. Moreover, these predictions may only hold for our known traffic system, but could be bypassed by a yet unknown evolution of a new and safer transport technology.

CONTENT

1. INTRODUCTION

1.1. General

This paper deals with the understanding and prediction of traffic growth and safety. The origin of the analysis lies in the attempt to explain the observed rise and fall of the number of fatalities in road traffic before and after a turning point in the beginning seventies. How can we explain that development and how will the further development be? What is the meaning of the observed turning point and will the course of affairs be irreversible or not? Will there be a further decrease of road fatalities or will there be again a rising number like we observe in the last six years in Japan. This is displayed by a typical graph of fatalities (e.g. The Netherlands 1950-1990) in Figure 1.

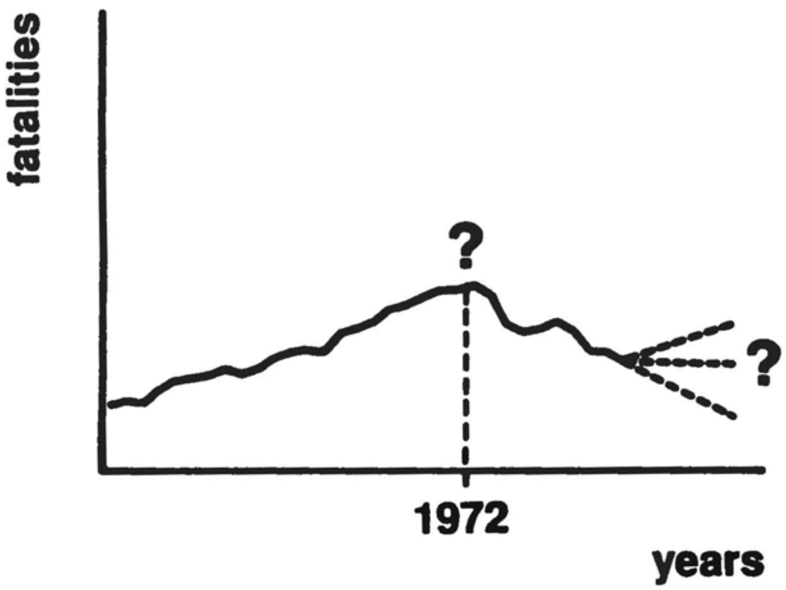

Figure 1. Fatality curve for motorized countries

The history of safety measure gives no particular explanation for the marked fatality decrease after the beginning or mid seventies. Numerous effective safety measures are taken before and after, while the oil-crisis of 1974 only had temporary effects. If we express the number of fatalities per motorized vehicle kilometers per year, we observe in all industrialized countries a gradual decrease of the fatality rate (Koornstra, 1987). It seems that per unit of production, like the decreasing failure rate for units of increasing production in many factories (Towill, 1973), the quality of the growing production is increased. In Figure 2 we illustrate how the long term development can be decomposed in monotonic trends for growth and risk (again actual curves for the past 40 years in The Netherlands).

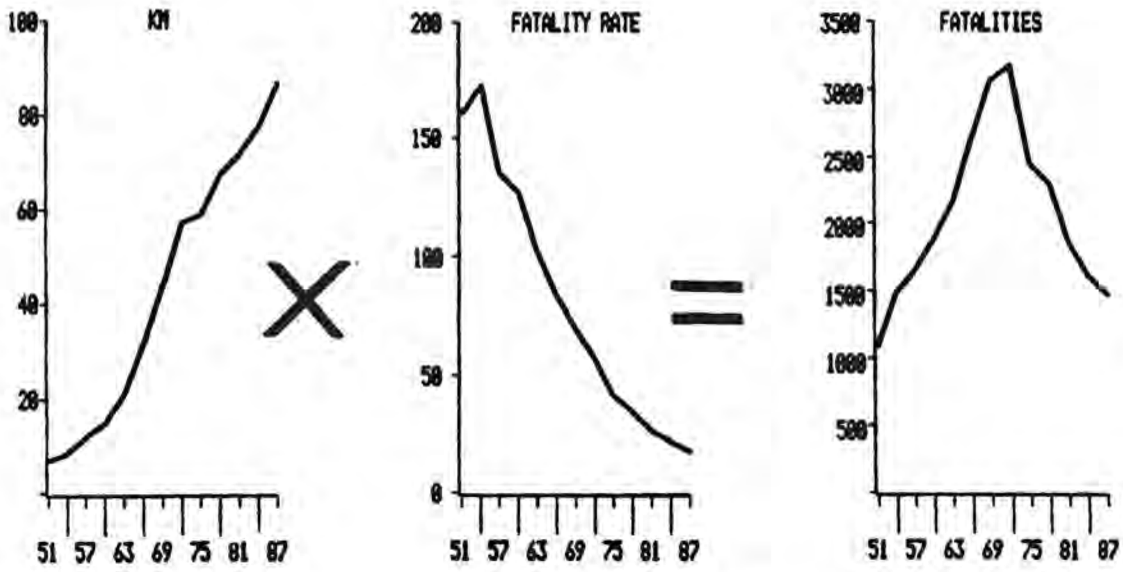

Figure 2. Fatalities = veh. km. x fatality rate

The figure shows how gradual increasing traffic and a gradual decreasing fatality rate result in a peaked development of the absolute number of fatalities. A peaked absolute number always will result as long as the percentage of increase in vehicle kilometers is greater than the percentage of decrease in the fatality rate in the beginning, while later on the percentage of increase in traffic volume becomes smaller then the percentage of decrease in the fatality rate.

These gradual trends in the emerging traffic and decreasing risk with the resulting safety development will be studied as a technological evolution of a self-organizing system with its (partial) inherent adverse consequences. If we apply evolutionary general systems theory to traffic, we can describe saturating growth by sigmoid shaped curves, borrowed from population biology and economics, and describe the decreasing fatality rates as an evolutionary risk adaptation by models, borrowed from psychological learning theory. The analysis of the relations between growth and adaptation show that mobility growth and risk adaptation are inherent to the evolutionary system of traffic. The generalized and new developed theory of adaptive evolution for self-organizing systems, such as technological and other energy dissipation systems, is presented in a forthcoming book (Koornstra, forthcoming). The mathematical description of the adaptive evolution theory for traffic and safety is also presented in Oppe & Koornstra (1990), while a conceptual presentation is also given by Koornstra (1991).

1.2. Exposure, risk and adaptation

In the above figure we used:

FATALITIES = FATALITY RATE X VEHICLE KILOMETERS

This is tautological in nature, but following Hauer (1982) we rather define
SAFETY = RISK X EXPOSURE

in such a way that the reasoning is not totally circular. In our analysis we use this type of risk definition, which is nothing else as a probability measure. Given the occurrence of relevant events in a particular traffic condition, there will be a probability for a particular class of adverse outcomes. Several severity classes of adverse outcomes for events can be distinguished, each with its adverse outcome probability. We define safety as the product of exposure to events and the multivariate probabilities for several categories of adverse outcomes. Following these lines of reasoning, we define collective risk as safety per unit of exposure for all road-users in the time period and area under observation. The amount of relevant events as a measure of exposure is still not precisely defined, but it is supposed to be an identical measure for all categories of adverse outcomes. The estimate of the number of possible encounters in traffic will depend on the amount of kilometers in traffic. However, it is also clear that the estimate of the number of possible encounters as exposure is also partly dependent on the physical facilities of the transportation system. Changes in the infrastructure may change the exposure as well as the risk, and sometimes in opposite ways. Great care must be taken to measure both indices of risk and exposure in order to evaluate safety measures.

Collective risk as a probability measure is also the collective result of individual risks. We have conceptualized individual risk behaviour as a dynamic adaptive subsystem within the traffic system by our risk-adaptation theory (Koornstra, 1990). This risk-adaptation theory is based on a cybernetic integration and dynamic formulation of psychological choice and risk theories in ambivalent conditions. It constitutes a theory for individual risk in traffic which contains the major existing theories of traffic risks as special cases. The general theory and the derived mathematical theory of ambivalent behaviour in cognitive conflicting situations, of which risk behaviour in traffic is an example, will be outlined in Koornstra (1992). On the one hand we distinguish structural adaptation as the changing physical and rule-based traffic system that makes the system safer and on the other hand individual adaptation as changing risk acceptance and risk behaviour of road users. In the nowadays popular risk-homeostasis theory (Wilde, 1982) it is argued that, unless changes in risk acceptance are obtained through motivational measures, safety measures are compensated by other riskier behaviour of road users. However, risk-adaptation theory, as a more general theory which incorporates the risk-homeostasis theory as special limit case, states that individuals implicitly evaluate risk on a subjective risk scale with respect to a consciously unknown point of reference which is the mean level of risk experienced in daily traffic. Structural safety changes in the traffic system decreases that reference point on the subjective risk scale for individual risk judgement, without explicit knowledge of the individual road user. By this unnoticed lowering of the reference point the risk experience of road users increases and they, so one could say, unconsciously compensate by objective safer behaviour. An individual who have judged a particular behaviour in a situation as an acceptable risk in the past, may judge that same situational behaviour as rather too risky now. On the other hand, risk-adaptation theory predicts that a sudden change to markedly safer environments in reference to the existing mean risk level will be experienced as unduly safe for some period. During such periods compensatory behaviour with partial increased risk will occur. This subjective adaptation to the objective mean risk explains why aggregated objective risk only show a gradual decrease and why individuals only partially compensate for infrastructurally increased safety.

2. GROWTH AND COLLECTIVE RISK ADAPTATION

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 extensively motorized countries a decreasing growth seems apparent in the more recent periods. The theoretical notion of some 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 the growth models to models which are described by sigmoid curves. We concentrate on three types of sigmoid curves with time as the independent variable often used in econometrics and biometrics. In the literature (Mertens, 1973; Johnston, 1963; Day, 1966; May & Oster, 1976), these three sigmoid growth curves are well documented. These growth curves are known as the logistic curve, the Gompertz curve and the log-reciprocal curve. The mathematics of these curves in the context of traffic are extensively handled by Koornstra (1988) and by Oppe & Koornstra (1990).
In Figure 3 we give an impression of the shape of these curves. Generalization of growth functions for flexibility of their applicability is

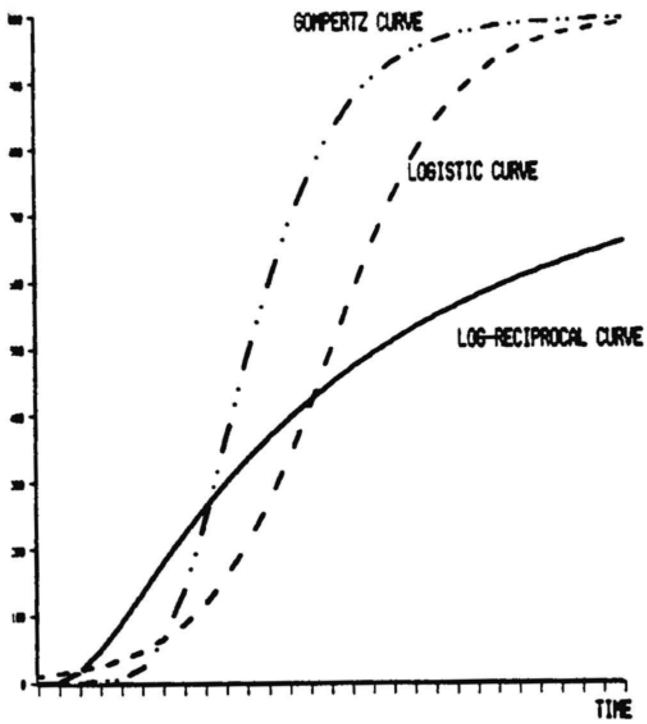

Figure 3. Some curves of monotonic growth with saturation.

achieved by (stretching or shrinking) power transformations of the axes. Since scale and origin of time are undetermined such a transformation is applied to a linear transformation of the time axis. Koornstra (forthcoming) shows that such generalized asymmetric logistic curves span the space of possible sigmoid curves fairly well.

The increase of growth for these curves can be described mathematically as the product of growth achieved and (some function of) growth still possible. This leads to an interesting aspect related to the mathematical description of risk adaptation. It enables one to write the rate of increase (comparable to percentage of growth) by monotonic decreasing functions of time. In Figure 4 we show the corresponding curves for the rate of growth increase for the three standard curves, named acceleration curves.

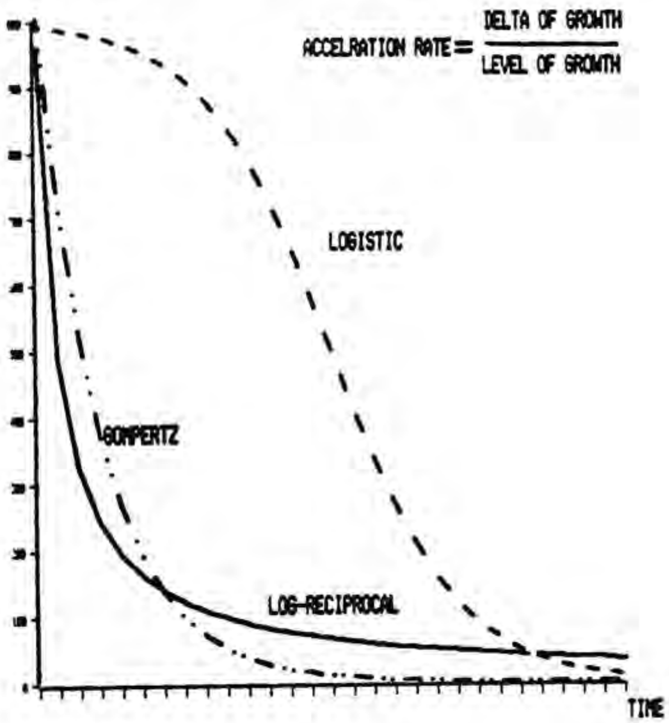

Figure 4. Curves for the acceleration of saturating growth.

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

2.2. Description of collective risk 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, which could be better described as "adaptation", since generally adaptation is a function of time.

Koornstra (Oppe et al., 1988) rejects Minter's interpretation on two grounds. In the first place the fatality rate decreases more than the injury rate. In Minter's interpretation, it means that individuals learn to avoid fatal-accident situations better than less severe accident situations. This hardly can be explained by individual cumulative experience with such situations. Secondly the mathematical learning curve functions as a function of time do fit the data better then or as well 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 the evolutionary interpretation of traffic growth and adaptation presented in the sequel as well as in the incorporation of adaptation-level theory of Helson (1964) in our risk-adaptation theory (Koornstra, 1990, 1992).

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. Although traffic growth as such leads to more accidents, growth of the traffic system also leads to the gradually safer traffic conditions. Growth of traffic implies by the renewal and enlargement of the road network an enhanced safety of the road network, but also replacements by more and safer vehicles and the implementation of better and coordinated rules. Generally these safety effects are not immediate but delayed. New laws, like belt laws, lead to belt-wearing percentages gradually growing in time. Reconstructions of hazardous routes and black-spots are reactions of communities on a growing number of accidents leading to a reduction of accidents later. Traffic growth leads to the enlargement of motor freeways which after long periods of planning and building-time attract traffic to these much safer roads. Some counter-effects may also occur, such as present in gradually rising speeds of road traffic. Rising speeds, however, are made possible by better roads and cars, which are also inherently safer by improved constructions. As Helson's adaptation-level theory (Helson, 1964) states, adaptation is the pooled effect of different classes of influences. Taking into account that adaptation level is a pooling of different classes of gradual changes in traffic environment, while safety effects are lagged and over many years accumulated results, we conjecture that adaptation to safer traffic can be well described by a function of time.

Referring to the incorporation of Helson's adaptation-level theory in social system theory (Hanken, 1981) and our risk-adaptation theory (Koornstra, 1990; 1992), one possibility is to assume that the adaptation process reduces the probability of a fatal accident per unit of exposure by a constant factor per time interval. Comparing this assumption with mathematical learning theory (Sternberg, 1963), one assumes a model similar to Bush & Mosteller (1955) in their linear-operator learning theory or to aggregated stimulus-sampling learning theory of Atkinson & Estes (1963). The difference is that now time is the function variable, instead of the number of relevant events, since in the Bush & Mosteller or linear-operator learning model the probability of error is reduced by a constant factor at any event. Two other mathematical learning models have been developed, the so-called beta-model from Luce (1959) and the so-called urn-model from Audley & Jonckheere (1956). The urn-model has its roots in the earliest mathematical learning theories (Thurstone, 1930; 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. As for the linear-operator model a similar aggregation, now not over sampled stimuli but over response classes and individuals, allows us to assume an aggregate safety scale on which the community changes by a constant factor with time. This leads to a time-related formulation of a beta-model for adaptation. One of the many possible time-related reformulations of the urn-model for our evolutionary replacement process in the traffic system, can be based on the assumption that the evolution of the traffic system increases the number of safe traffic situations constantly in time. An urn-model then originates from the correspondence between encounters in safe and hazardous traffic situations and drawing balls from an urn; e.g. safe situations as white balls in the urn and situations liable to accidents as red balls in the urn which last ones are reduced constantly in time.

In Figure 5 (taken from Sternberg, 1963, p.51), the curves for different behaviours of these adaptation models are sketched. Here the model parameters of the time axis (time has no origin nor a fixed unit of scale), are such that 0.25 and 0.75 probability of failure coincide for the three models.

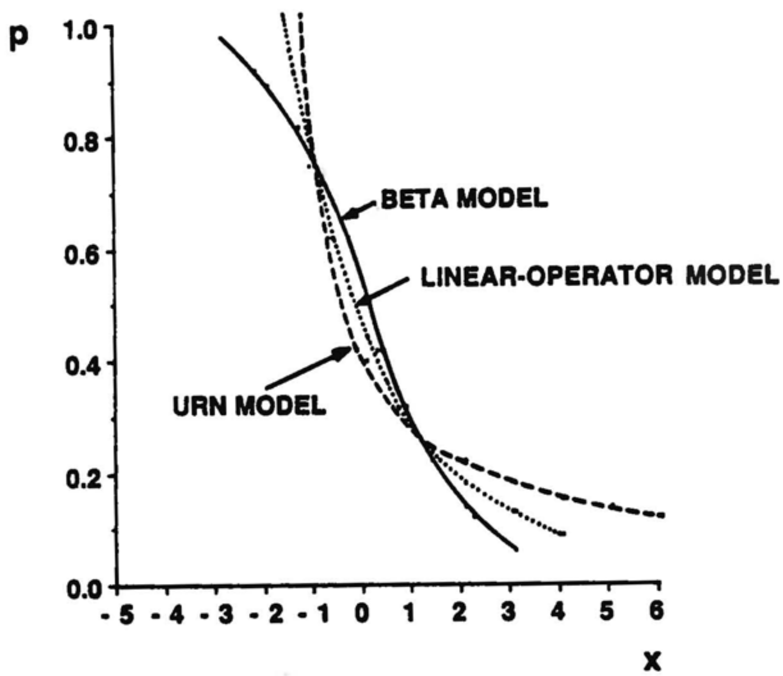

Figure 5. Nomogram for models of adaptation.

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 the learning theory of Bush and Mosteller (1955), risk adaptation to a non-zero probability level can be assumed as a generalization (Oppe & Koornstra, 1990) which may be needed for the application to risk adaptation in traffic, especially for risk adaptation to less severe accidents.

Chatfield (1987), Koornstra (1987), Broughton (1988), Haight (1988) and Oppe (1989, 1991a), used the linear-operator model for the fit of the fatality rate, implicitly assuming that fatality rate is a probability measure which reduces to zero in the end. They found remarkable good fit for time-series of the USA, Japan, FRG, The Netherlands, France and Great Britain over periods ranging from 26 (France) to 60 (USA) 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 cumulation of vehicle kilometers as an index for the collective number of past learning events.

2.3. Relations between growth and risk adaptation

Oppe and Koornstra (Oppe, 1989; Oppe & Koornstra, 1990) fitted logistic curves to traffic growth data and the linear-operator model to fatality rate data. Oppe (1989) found that the independently fitted parameters for slopes of growth and risk adaptation are related, while Koornstra (in Oppe et al, 1988) showed that such a particular relation implies that the number of fatalities can be expressed by a power function of the increase of traffic growth. This inspired the search for intrinsic relations between growth and risk adaptation, instead of analyzing and fitting curves to observed data for the different models of growth and of risk adaptation separately. In the spirit of this approach we have directly expressed mathematical relations between acceleration of growth and risk adaptation (Koornstra, 1988; Oppe et al., 1988; Oppe & Koornstra, 1990).

In the description of growth curves we stated that the expressions for growth acceleration are monotonic decreasing curves and as such are candidates for description of risk adaptation. Indeed, if we compare Figure 4 with graphs of the three models of growth and Figure 5 with the three adaptation curves we can identify, apart from differences in location and scale of time, identical shapes of curves for

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

Mathematically the expressions for acceleration and the expressions for adaptation show a one to one correspondence between the above-mentioned pairs of curve expressions. This correspondence enables one to express adaptation as mathematical function of the rate of growth. 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 parameters for difference in the location of time and for the ratio of units on the time-scale. The differrence of location forms a time-lag between the growth and the adaptation processes (Oppe & Koornstra, 1990). If growth precedes adaptation, there is a time-lag for the time-scale of adaptation with respect to growth. The ratio of units of time-scales will be unity if the growth and adaptation processes develop with the same speed. This is not a necessary assumption; if the ratio is not equal to unity either growth or adaptation is a faster process. From preliminary results of data inspections (Koornstra, 1988), we are inclined to think of adaptation as a lagged process at an equal or slower speed compared with the speed of the growth process. In this way the expressions for growth rates and the expressions of risk adaptation models are related in a meaningful way by a linear transformation of the time-scale in the exponential expressions for these corresponding curves. In terms of the direct relation between growth rate and risk curves the multiplicative factor in the exponent forms a power function for the possible difference in slope of the curves and the additive factor in the exponent yields a time-lag for the difference in location on the time-axis of these curves.

According to the mathematical derivations of Koornstra (1988) one can formulate a general relation between growth and adaptation more or less independent from which particular model for growth or adaptation is assumed.

The basic assumption is:
<u>Transformed growth and fatality rates are proportional if the transformations consists of power-functions for vehicle kilometers and rates, while the fatality rate is lagged in time.</u>

A simplification arises if one assumes that exposure to fatalities is well expressed by untransformed vehicle kilometers.
This leads to the so-called <u>specific assumption</u> as:
<u>The lagged fatality rate is proportional to the power-transformed growth rate of vehicle kilometers.</u>

An even stronger simplification arises if ratios of vehicle kilometers with a fixed time delay are assumed to be approximately constant (an assumption which only can be exact for exponential growth, but may hold approximately for short delays).
This approximation assumption can be formulated as:
The lagged fatalities are approximately proportional to the powertransformed increase in vehicle kilometers

This last simplification would imply that the number of fatalities is not dependent on the absolute level of vehicle kilometers, but only on the increments of vehicle kilometers.

Let index t denotes years, F_t the number of fatalities and V_t the motorized vehicle kilometers both in year t, V_{max} the saturating level of V_t and τ a time lag, then a direct relation between the development of fatalities and vehicle kilometers can be expressed with parameters V_{max}, w, x, y, z and c as

$$F_t = z \cdot V_t^x \cdot V_{t-\tau}^w \cdot [(V_{max}/ V_{t-\tau})^c - 1]^y$$

The generality of this relation is our basic theoretical result.
For asymmetric logistic growth combined with beta-model adaptation w=cy, while combined with linear-operator adaptation w=0. For Gompertz growth and linear-operator adaptation as well as for log-reciprocal growth and urn-model adaptation w=0 and lim c -> 0 such that the term in brackets reduces to $\ln(V_{max})-\ln(V_{t-\tau})$. For the specific assumption x=1 and for the approximation assumption V_t is approximated by a factor of $V_{t-\tau}$ while x+w-cy=y, which in case c=1 and w=0 means x=2y and thus, if x=1 too, y=0.5.
Oppe (1989, 1991a) analyzed the growth of vehicle kilometers by symmetric logistic functions and the fatality rate by exponential decreasing adaptation (liner-operator model). For this combination of growth and adaptation models (where in the formula c=x=1 and w=0), Koornstra (in Oppe et al., 1988) proved that the approximation assumption can only apply if y=0.5. Indeed Oppe's empirical results (for c=x=1) have shown that y=0.5 for the six countries in his analysis (Oppe, 1989, Oppe, 1991a), while there were also strong indications for a time-lag of about ten years (e.g. τ=10). Further data analysis of time-series of fatalities and vehicle

kilometers for several countries has supported that at least the specific assumption can be appropriate (Oppe & Koornstra, 1990).

Although all this may seem to imply rather strong assumptions and complex mathematical data analysis, the face-validity of the above assumptions can be investigated by a simple inspection of observed time-series for fatalities and fatality rates compared with time-series for the increase of vehicle kilometers and growth acceleration which last two can be calculated without any assumed growth model from so called smoothed central differences of observed values, as presented by Koornstra (1988). In order to illustrate the face validity here, some of such graphs (e.g. (West) Germany and the USA) are presented too. In Figure 6 we plot the developments of fatalities and smoothed increments of vehicle kilometers for the post war period in (West) Germany. The figure reveals a remarkable overall time-shifted resemblance in development. As predicted from the theoretical relations between growth and adaptation, the shift for fatalities with respect to increments indicatesa time-lag for the relation between both curves. The time-lag for fatalities with respect to the increase of the traffic volume is about 9 or 10 years. The coinciding lagged development of fatalities and growth increments seems to sustain the approximation assumption with a time-lag.

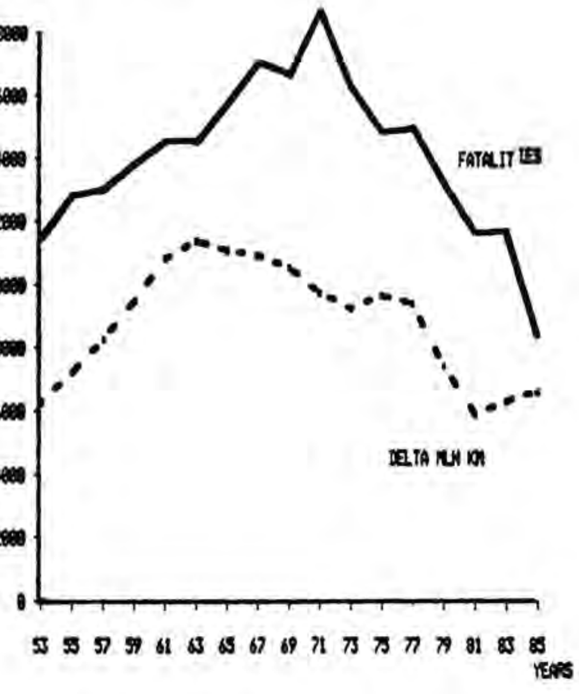

Figure 6. Traffic increase and fatalities in Germany (West).

Figure 7 illustrates the formulated correspondence by time-series of the growth rate (acceleration) and fatality rate in (West) Germany. The correspondence between acceleration of growth and fatality rate is nearly perfect if we shift the acceleration curve by 10 years forward, as was indicated by the time-lag of Figure 6. This correspondence in curves is even more remarkable, since theoretically derived power transformations on these curves are not applied for optimization of its correspondence.

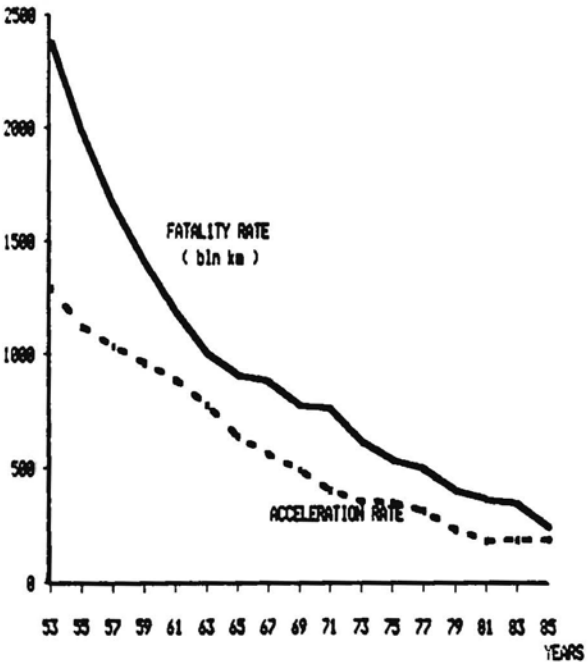

Figure 7. Growth acceleration and fatality rate in (West) Germany.

In Figure 8 we inspect the fatality rate and the growth rate of vehicle kilometers for the USA in period after World War II. As can be seen the acceleration curve as well as the fatality rate curve is not monotonic decreasing. Although there is a decrease on the long run, as also Chatfield (1987) showed for data from 1925 to 1985, such a monotonic decrease seems to be disturbed by cyclical deviations. The remarkable thing, however, is the evidence for a coinciding correspondence in the departures from a monotonic decrease for the two curves.

The apparent cyclic disturbance of a gradual decrease in acceleration seems to have a coinciding effect on the fatality rate. This may be a quite appropriate assumption if it is true that fatalities are foremost dependent on the increase in vehicle kilometers. If so, influences from

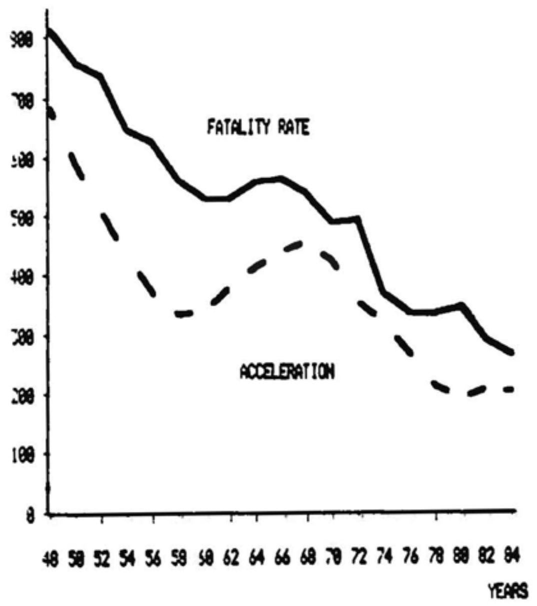

Figure 8. Growth acceleration and fatality rate in USA.

deviations of the monotonic growth, such as cycles of relatively large decreases and small decreases or even increases for growth acceleration must be reflected in risk adaptation. In fact Oppe (1991b) showed that deviations from smoothed developments of the change rate of vehicle kilometers and fatalities tend to be cyclic and that these cycles for growth and fatalities are related. Economic recessions and upsurges may deter or accelerate traffic growth, but it seems as if the momentary system safety is not well adjusted to such temporary extra increases of growth. For accurate predictions the data of the USA show that one has to model not only monotonic trends but also related cyclic deviations around monotonic curves of growth and risk adaptation.

In fact such preliminary inspection and comparison of such graphs of time-series for several countries (without fitting of curves, since these variables are time-series of observed data or simple ratio's of smoothed differences of observed data) has guided the mathematical formulation of our theory of the relation between growth and risk adaptation. Successively correlated deviations from monotonic growth and adaptation can be analyzed as an autoregressive processes, either by autoregressive Markov functions or by single or multiple phased or harmonic cycles or by both. The latter can be described by the so-called Fourier functions and the former by the so-called analysis of the autocovariance structure. We refer to literature on time-series analysis (Anderson, 1971) without further specifying the analysis here. Our original description of deviations from sigmoid growth

(Oppe & Koornstra, 1990) resembled the successive analysis of multiplicative factors in econometric time-series analysis (Durbin, 1963) by which the underlying saturation level in the model varies cyclical. Further data analysis, however, fitted better a model for factors which accelerate or deter the slope parameter of the sigmoid growth process itself by long term cycles and short term autoregressive irregularities. It will be noted that if long term cycles, as Kondratiev cycles, are operative, great precaution must be taken to distinguish cyclic influences and sigmoid trend. A long phased cycle around that sigmoid curve only will become separable if the sigmoid curve has passed its inflexion point and if the cyclic deviation has passed more than one complete cycle. We observed coinciding cycles for growth acceleration and fatality rate. If generally so the derivative of cyclic deviation in growth coincides with cyclic influences on the fatality rate. It will be noted that this would mean that the cyclic influences on growth itself are shifted backward by a quarter of the cycle period with respect to these cycles around the fatality rate.

3. DATA ANALYSIS AND PREDICTION RESULTS

Former data analysis (Oppe, 1989, 1991a,) confirmed that growth of vehicle kilometers and fatality rates can be modelled by an S-shaped growth function and exponential decay functions in a macroscopic sense, but that correlated cyclical deviations also are present (Oppe & Koornstra, 1990; Oppe, 1991b). These cyclic deviations can be modelled fairly accurate by cyclic deterring or accelerating the time-speed parameter of the growth and adaptation functions, as is shown by the figures of the illustrative results obtained by an analysis of the data for Japan, Germany (former west part only), Great Britain and the USA.

3.1. Japan

In Figure 9 below we show the observed motorized kilometers (given as dots in the figure) from 1951 to 1990 in Japan and the predictions by simultaneous fit of sigmoid trend and cyclic deviations (given as a solid line). In order to show the influence of the cyclic deviations the underlying sigmoid curve is also presented (intermitted line).

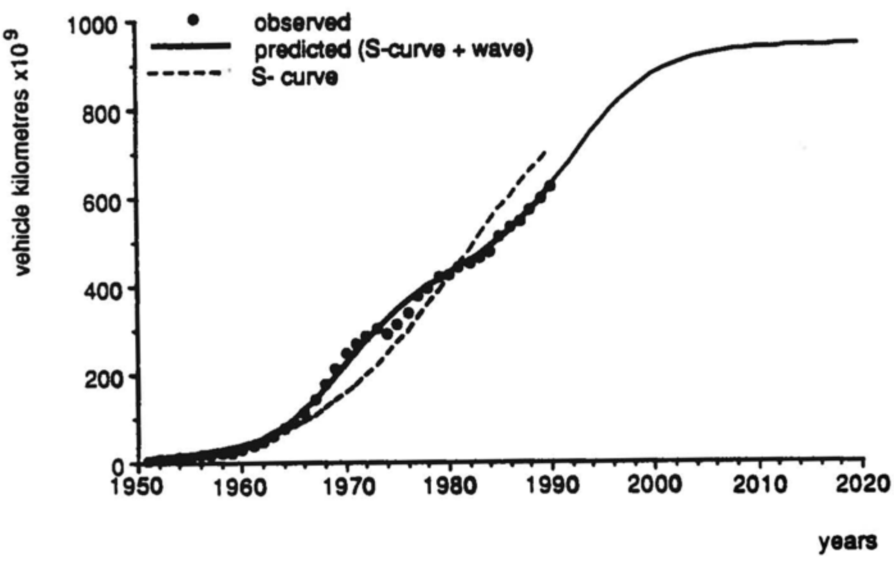

Figure 9. Prediction of vehicle kilometers in Japan.

The optimal cycle has a period of 36 year and the saturating growth level reaches about 950×10^9 kilometers which implies a growth of about 50% from

1990 onward. Without the simultaneous fit of the cycle the sigmoid curve is closer to the observed data and its saturation level becomes much lower, allowing only a growth of about 15% after 1990. Not only has such a small amount of further growth less face validity in view of the recent growth, the additional cycle improved the fit significantly (F-test on residual variance yields $p < 0.01$). As can be seen from this figure the model with a cycle around sigmoid growth fits remarkable well, apart from a deviation shortly after 1973 which are the years of the intervention from the oil crises of 1974. It will be noted that for Japan the steepest increase of the sigmoid curve nearly coincide with the steepest decrease of the cyclic deviations around the sigmoid curve at the end of the seventies. The actual increment of the joint predicted growth curve is the highest around 1970 and 1990. Here we note already that if fatalities are foremost a function of these increments, as it is conjectured by our strongly simplified assumption, one would expect the highest numbers of fatalities around these years and relative lower numbers before, between and after these periods. Although the predicted curve is only a function of time it will be noted that the data from 1951 to 1990 are fitted well.

Figure 10 gives the analysis for the fatality rate in Japan over the same observation period. Again the observed rates are given (dots) along with the fitted prediction curve (solid line) and the underlying exponential

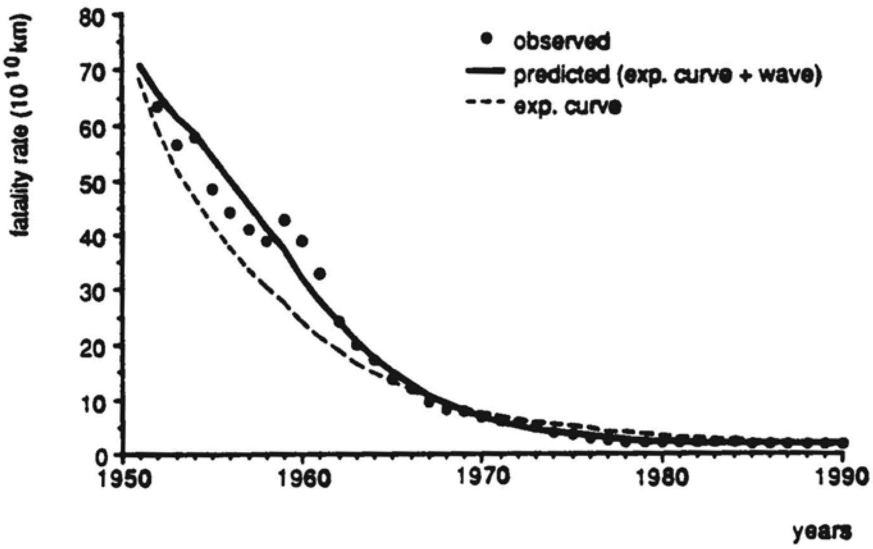

Figure 10. Analysis of the fatality rate in Japan.

decreasing curve (intermitted line) which is modified by a cyclic influence on the exponential curve. It must be noted that this cyclic deviations is proportional and, therefore, small cyclic deviations at low values compare to large cyclic deviations at high values. Again this cyclic modification improves the fit significantly with respect to a simple exponential curve (if fitted without cycle it lies closer to the observed values than the simultaneous fitted exponential curve). The fitted cycle for deviations around the exponential curve is exact proportional to the derivative of the cyclic curve around the sigmoid growth curve and is, therefore, shifted by a quarter of the period. This means that relative cyclic increases or decreases of the fatality rate follow the cycle of the vehicle kilometers with a 9 year time-lag. Therefore, a partial delayed overlap of relative increments or decrements in growth of vehicle kilometers and in fatality rate is present. This can have disastrous effects on the number of fatalities in predicted periods of partial overlapping relative higher vehicle kilometers and relative higher fatality rates.

Figure 11 shows the results for the fitted and predicted fatalities in Japan. This prediction is based on the product of the predicted curve of Figure 10 and observed (and after 1990 predicted) values of Figure 9. Due to cyclic deviations in both underlying curves (Figures 9 and 10) and their locations in time with respect to the steepest increase of the sig-

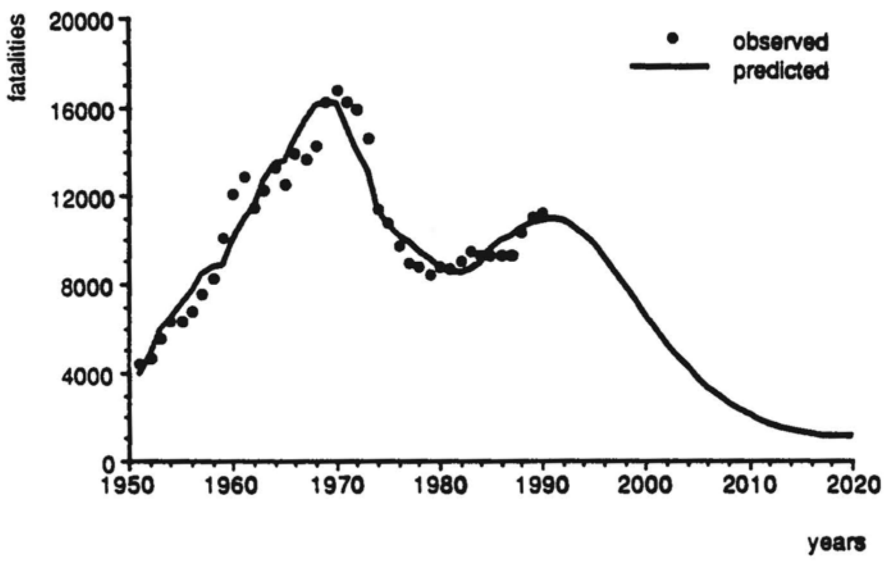

Figure 11. Fatalities in Japan.

moid curve, the Japanese results show two peaks in the number of fatalities. Again the predictions from 1951 to 1990 fits remarkable good. Due to the saturating growth in vehicle kilometers and due to prediction of the fatality rate which virtually reduces to zero if time proceeds infinitely, the long term prediction of fatalities is very optimistic.

3.2. (West) Germany

Figures 12 and 13 give the results for motorized kilometers and fatalities in former western Germany as mean two-years values from 1953/54 on ward to 1989/90 retrospectively predicted and prospectively predicted to 2019/20, obtained by the same model analysis as for Japan.

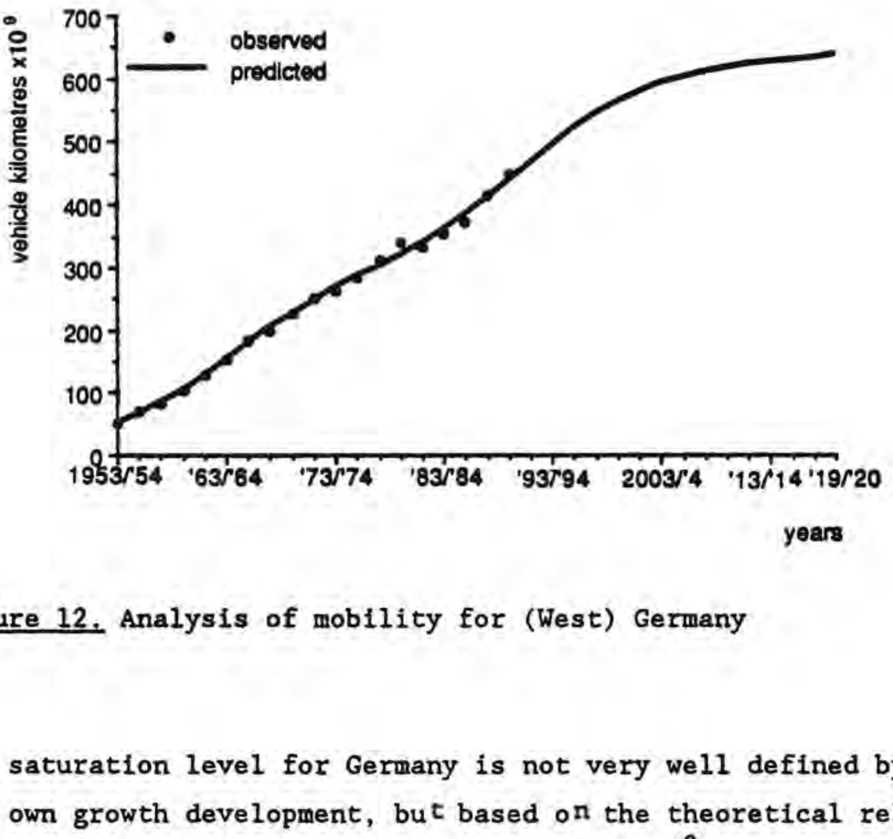

Figure 12. Analysis of mobility for (West) Germany

The saturation level for Germany is not very well defined by the fit of its own growth development, but based on the theoretical relation with fatalities, it can be taken to be about $675x10^9$ km. Higher estimates, however, are not significant worse. There is a significant cyclical deviation from the sigmoid growth trend with a period of 38 years. The oil crisis of 1974 follows shortly after a positive cycle deviation and just precedes the steepest increase of the sigmoid trend, which seems to be a common aspect for the results of most other motorized countries. The oil crises of 1974 seems, therefore, more an induced reaction to demand for oil than an unexpected disturbing factor. In contrast to Japan, however, the maximum increment of the underlying sigmoid growth does not coincides with a maximum decrease of the cyclic influence. Therefore and because of smaller cyclic influences than in Japan, the actual development of fatalities hardly can show a second peak in (West) Germany.

The retrospective and prospective prediction of fatalities (the solid lines of Figure 13) are again obtained from the observed and predicted vehicle kilometers and the fitted risk adaptation curve. The reduced cycle around the exponential risk curve fits the predicted time lag of a quarter of the cycle period compared to cycle around the sigmoid growth curve. The cycle around the exponential fatality rate contribute significantly to the fit of the estimated risk curve. The fit is only so optimal if the predicted fatality rate reduces infinitely to a virtual zero level. Hence fatalities will also reduce to virtually zero in the end.

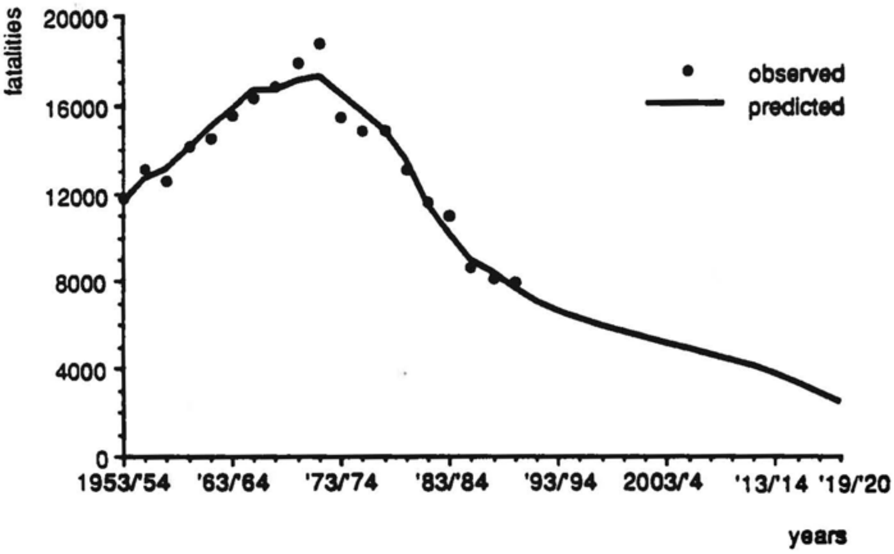

Figure 13. Analysis of fatalities in (West) Germany

Figure 14 pictures the development of road casualties registered in (West) Germany as it is observed as well as retrospectively and prospectively predicted from an analysis with a casualty rate which decays less than the fatality rate and therefore does not reduce to zero if time proceeds to infinity.

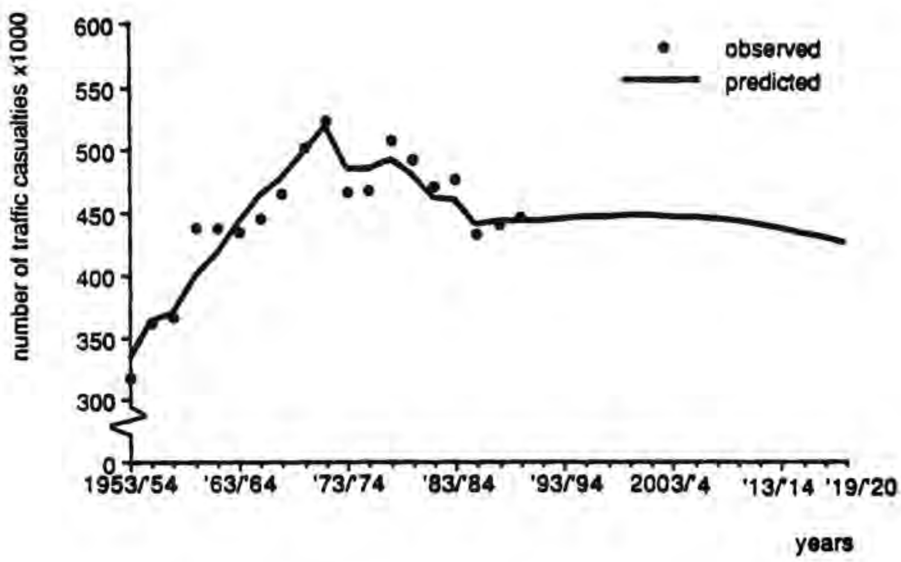

Figure 14. Analysis for casualties in (West) Germany.

As for other countries an exponentially decay curve for the casualty rate only fit rather well if it does not reduces to zero rate, but to a positive rate value. A proportional reduction of the fatality rate plus such a positive rate value generally fits the observed casualty rate also. This means that the prediction of casualties can as well be based on a weighted sum of fatalities and (power-transformed) vehicle kilometers. Figure 13, therefore, is also a weighted sum of (rescaled) Figure 11 and Figure 12. Due to the nature of a weighted sum, in which the stabilizing level of vehicle kilometers is part, it follows that the number of casualties will not reduce to a zero level. In fact for (West) Germany the number of casualties is predicted to stabilize on a level around 400.000.

3.3. Great Britain

In the same way as for (West) Germany Figures 15 and 16 display the results of the analyses of mobility growth and the development of fatalities from 1951 to 1990 for Great Britain as well as the their predictions up to the year 2020.

As for (West) Germany in Great Britain the maximal cycle growth is followed by the oil crises of 1974 and also the maximal increase of the un-

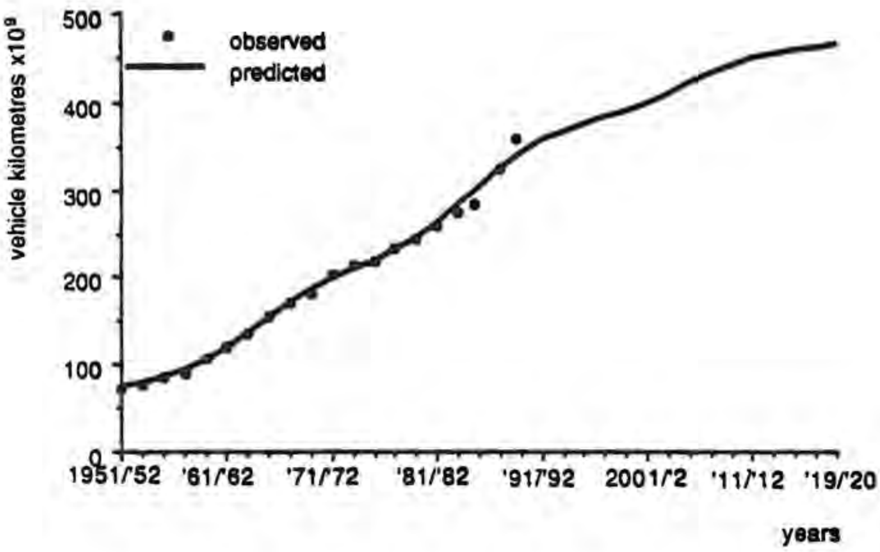

Figure 15. Mobility analysis for Great Britain

derlying sigmoid growth is located shortly thereafter. In the nineties the cycle causes again a comparable increase in motorized mobility which begin to level off against the year 2000 or some what later if the not well determined saturation level of vehicle kilometers is taken to be higher than the fitted value of 500x109 km. In contrast to Germany and Japan the cycle

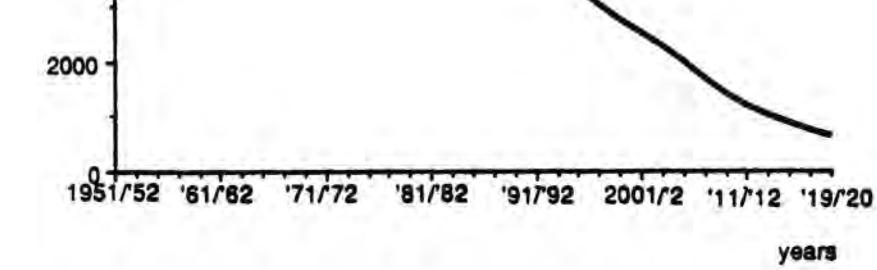

Figure 16. Fatalities analysis for Great Britain

around the sigmoid growth curve is estimated to have a period of only 22 years. If, however, a higher saturation level is estimated the length of the cycle period increases.The cycle is also present in the risk-adaptation curve, but its contribution is less than for the above countries. According to a fit of fatalities by the direct formula the time lag between mobility growth and risk adaptation is, as for most countries, about 9 years. This is in contradiction with the theoretical expected quarter of the period of the cycle and, indeed, the shift of the cycle around the exponential risk curve compared to cycle around the sigmoid growth curve is also not a quarter of the period. The prediction of the further development of the number of fatalities by the product of the fitted curves for fatality rate and vehicle kilometers results in a steady decrease of fatalities in the future Figure 15 shows that less than 1000 fatalities in 2020 can be expected; however, if the saturating level of vehicle kilometers is underestimated this may be too optimistic.

3.4. United States of America

Figure 17 and 18 we picture the analysis for millage and fatalities in the USA from 1923 onwards by an analysis without a cycle around the sigmoid growth curve and the exponentially decreasing fatality rate.

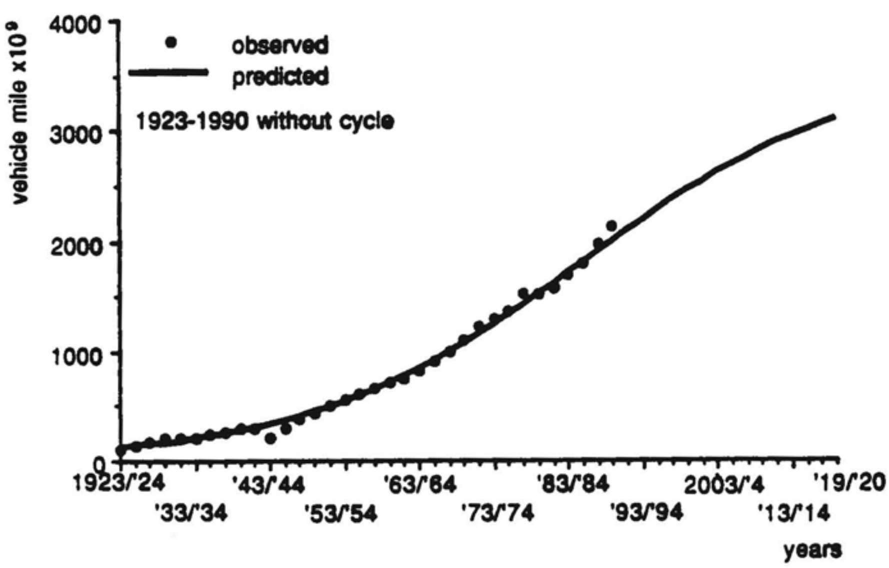

Figure 17. Mobility analysis in the USA from 1923 to 1990.

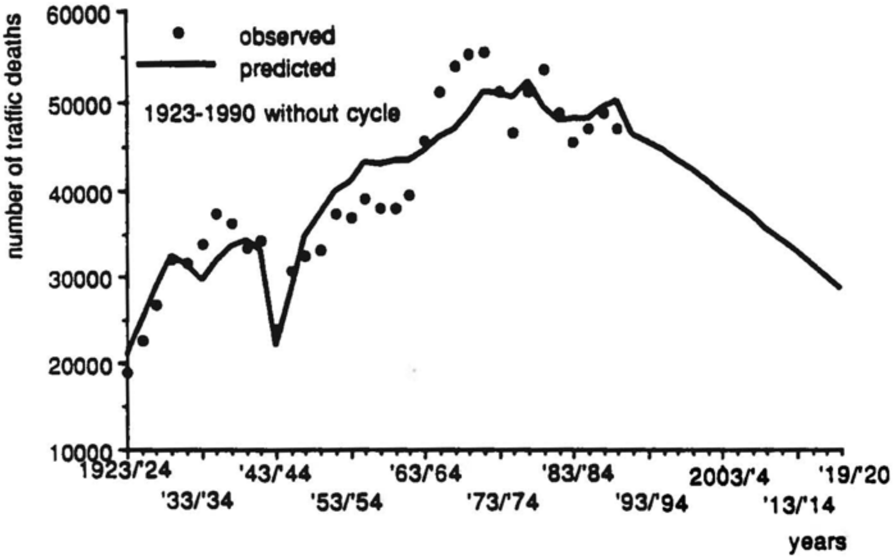

Figure 18. Analysis of fatalities in the USA from 1923 to 1990.

The reason for omittance of a cycle is that the apparent post war cycle is disrupted by World War II and does not have the same location (and perhaps phase) before that war. Nonetheless, as Figure 17 shows, the overall trend in vehicle mileage is well represented in a macroscopic sense. This also holds for the macro-development in the number of fatalities, but the deviations of the actual values are very large. Although the downward trend in the prediction of figure 18 may be correct, its actual prospective prediction value is doubtful in view of the deviations observed for the past prediction period (despite the good prediction of the low number of fatalities in the war). If we analyze the post war period, where a regular cycle around the sigmoid growth curve and the exponential curve for the fatality rate can be observed, by the former described methods of monotonic curves and cyclic deviations around these monotonic curves the precision of the retrospective predicted values of mileage and fatalities enhances markedly. This is shown in the Figures 19 and 20 for the two-year mean values of mileage and fatalities from 1949 onward. The retrospective prediction error for yearly mileage remains within the 5% range and for fatalities per year within the range of 8%. The effects of the cycles are also very well visible in the prospective prediction up to the year 2020.

The presented analyses for the four countries illustrate that mobility growth and traffic risk adaptation and the resulting fatalities can be

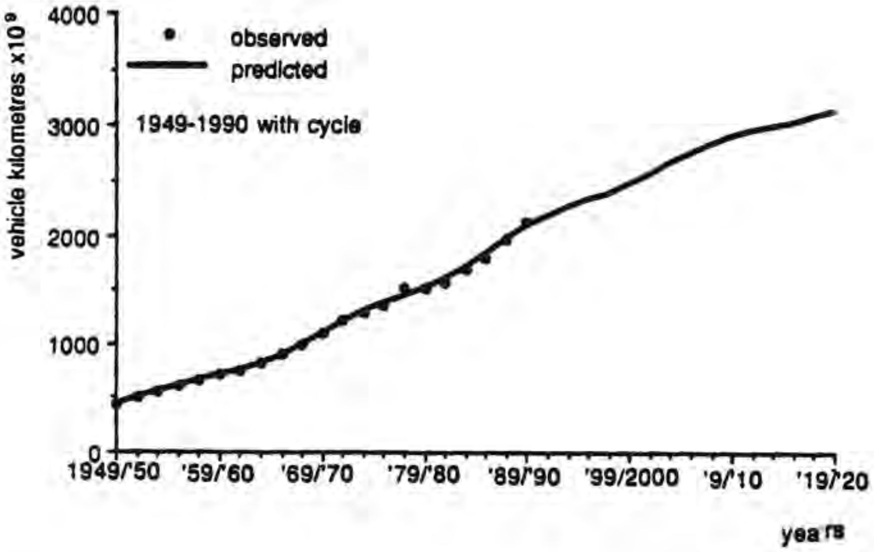

Figure 19. Mobility analysis in the USA from 1949 to 1990.

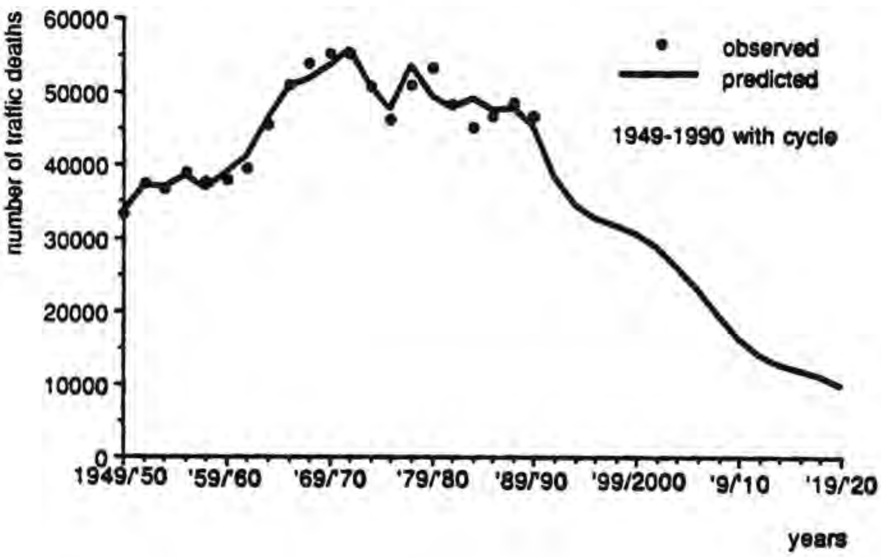

Figure 20. Analysis of fatalities in the USA from 1949 to 1990.

modeled by processes which only depend on time, while the effects of relatively increased and unadapted growth can be disastrous for the development of the fatalities. So it has been in all the industrialized countries with a peak in road fatalities in the beginning of the seventies and it also will be so for Japan (and Israel see Koornstra, (1991)) in the nineties. The non-decreasing (or even increasing) number fatalities in the period before or around 1990 in the presented countries is, according to our analysis, the result of the relative increased growth of mobility in the recent past which also causes, according to our analysis, a temporary and delayed reduction of the decay in the fatality rate. As shown in the prospective predictions, this is not a sign of permanent worsening of the safety in the road traffic of the future. On the contrary, our long term predictions are optimistic due to the best fitting limit value of zero for the fatality rate with time proceeding to infinity. Since the independent variable is time which is a perfectly predictable variable and because the past period of 40 years or more in many countries is fairly accurately predicted by our time-based models which, as we present in the sequel, are rooted on a general theory of technological evolutions, these models also provide a scientificly quite acceptable and probably reliable prediction method for the future development of mobility and road safety in the next decade. This is more than any other model based on ad hoc independent variables which themselves must be predicted for the future, such as socio-economic indicators (Partyka, 1991), can claim.

4. GENERAL SYSTEMS APPROACH

The intimate relation between mobility growth and risk adaptation is theoretically intriguing and asks for an acceptable understanding. How can it be that the development of road fatalities is solely dependent on the trends and cycles of growth in motorized mobility? Must we believe that the achieved road safety constitutes only a lawful and autonomous result of the developments of the growth of motorized mobility?

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 throughput. 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 traffic norms in industrial societies are phenomena which are largely driven by growth of motorization and mobility. In a general systems approach these phenomena can be conceptualized as replacements of subsystems by sequences better adapted subsystems within a total traffic system. The steadily decreasing fatality rate can be viewed as adaptation of the system as a whole.

4.1. Evolutionary semi-closed systems

The above-mentioned characterization of the traffic system can be conceived as an evolutionary system, known as self-organizing systems (Jantsch, 1980) in the framework of general systems theory. There are striking parallels between the growth of traffic and the growth of a population of a new species. The dynamics and structure of such evolutionary systems are investigated in ecology and population biology, but nowadays the self-organizing principles of evolutionary systems have got far reaching applications in many sciences (Eigen & Winkler, 1975; Jantsch, 1980a; Prigogine & Stengers, 1984). In biological systems 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 variability in reproduction and the process of selection guarantees that only those members who survive the premature period, will produce new offspring. This process of selection leads not only to an increasing population, but also to a reduction of probability of non-survival before the mature reproductive life period. Our main interest in this process is the rise and fall of the number of premature non-survivors, comparable to the development of traffic fatalities. The growth of the population follows a sigmoid curve, just as the growth of vehicle kilometers. 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. In the same way the decreasing fatality rate in combination with growth of vehicle kilometers produces a bell shaped curve for traffic fatalities.

The differences between open controlled systems and closed self-organizing 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 open systems feedback goes from output to input through a comparator based on deviations from objectives. Unlike biological systems, here the process is not governed by an autonomous mechanism, such as mutation and selection, but by actions of decision-making bodies or purposeful designed apparatus. The control in open systems is directed to manipulation of the input, while the inner operational production subsystem itself remains unchanged. Although the system is characterized by a closed loop, the system is called an open system because it relates input and output from and to the environment. In contrast to open control systems there are so called 'closed' systems, where the recursive loop in the system is not based on control of the input. The feedback action in 'closed' systems changes the structure of the operational production process itself in order to bring the output in accordance with the objectives, but leaves the input unchanged as a given set of resources or as self-produced input. The system is called 'closed', since it operates within the system by changes in the substructure of the production system. It takes the outside world from which the input comes as given and output is viewed as throughput with effects on the inner parts of the system. The resemblance of closed systems and biological evolution systems is apparent. Now, instead of mutations and a selection process, we have actions from a decision-making body which changes the production process, but the system structure is more or less identical with respect to its closing. This closing is the strongest in closed self-organizing reproductive systems, where the intermediate throughput, is a replacement of subsystems in the system by sequences of new subsystems. Resources for these dissipative systems are taken for granted or as self-produced within the system, although the supply of resources from outside is a crucial condition for their existence.

In classical open control systems the aim of closed loops is maintenance of stability at a equilibrium level of output through manipulation of input. In closed systems the input is not manipulated, but the operational structure itself changes. Strictly closed systems are self-referencing systems where 'output' becomes delayed 'input' as system throughput; they are also called autopoietic systems (Varela, 1979; Zeleny, 1980). Given surrounding boundary conditions, its functioning can be analyzed as internal throughput production. The growth of throughput is foremost described by non-linear equations, such as throughput equations in electrical circuits or in autocatalytic reaction cycles (Nicolis & Prigogine, 1977). Apart from 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 (Jantsch, 1980b). For human production systems the relevance of such semi-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

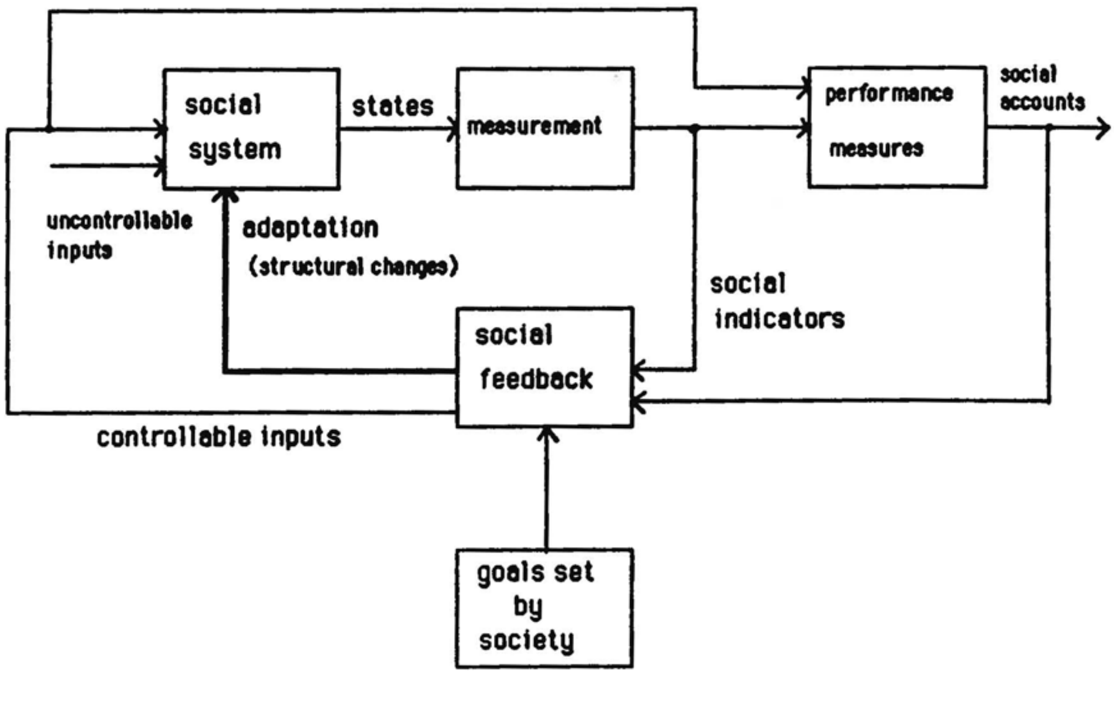

Figure 21. A mixed open and closed social system.

in the operational structure in order to enhance the quality and quantity of the performance, but cannot be analyzed solely as classical open control systems. Although mixed systems are mathematically difficult, on a conceptual level they can easily be described simultaneously and as such are pictured by Figure 21 (taken from Laszlo et al., 1974).
This mixed system description can be applied to the emergence of motorized traffic and road accidents. We concentrate on the inner closed feedback loop from measurement (of intermediate throughput) through the feedback compartment to structural changes in the social (production) system as an adaptation process on a conceptual level.

4.2. The semi-closed traffic system

The emergence of traffic and traffic accidents can be described as a semi-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 of the road network and the increasing use of motorized cars in modern industrial society. This is done by:
- building roads, enlarging and improving the road network,
- manufacturing more motorized vehicles, while improving their quality old ones are replaced and the market for vehicles is enlarged,
- teaching a growing driver population to drive motorized vehicles in a more controlled way, while laws and enforcement and education practices are improved.

This growth by multiple substitutions and renewal is a technological evolution in which adaptation is inherent to growth. The growth can be quantified by numbers of cars or license holders, by length of roads of different types and as a gross-result by the fast growing number of motorized vehicle kilometers. We take motorized vehicle kilometers as the main indicator of this growing motorization process of industrial society. For traffic safety we concentrate on the number of fatalities as the most relevant safety indicator. The adaptation process with regard to this negative aspects 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 become better drivers than the 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 this replacement process, characterized by growth and renewal, there is hardly any enhancement of safety conceivable.

In Figure 22 we display the structure of this semi-closed traffic system.

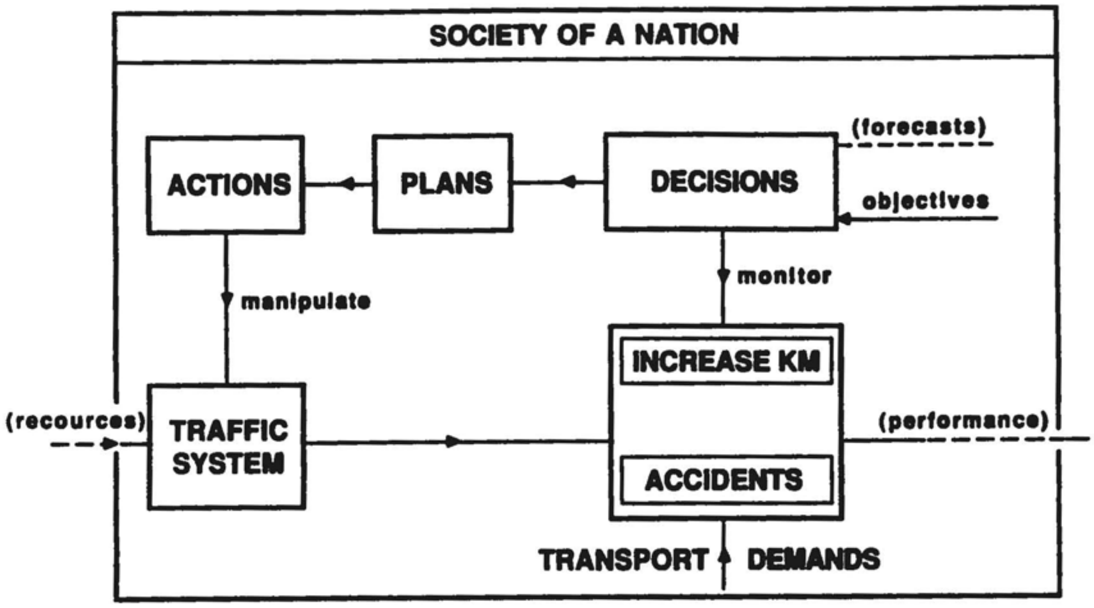

Figure 22. The semi-closed traffic system.

Growth of vehicle kilometers is not unlimited, because the system is not strictly closed and also dependent on inputs which are not infinite. The number of actual drivers is restricted by the population number and by time available for travelling. The main actual limitations are available time (e.g. travel time), space (e.g. length of road-lanes) and energy (e.g. the scarcity of resources). In the long run are dominating restrictions imposed by environmental consequences and other adverse consequences for the quality of life, especially in densely populated areas. We conjecture therefore a still unknown saturation level for the number of motorized vehicle kilometers, viz. a limit for growth of traffic. An interesting question we have tried to answer is, to which extent such a limit of growth also imposes, by its postulated inherence for risk adaptation, a limit to the attainable level of safety.

4.3. General principles of adaptive evolution

Not only the data for traffic growth in several countries show that its evolution is rather well described by logistic curves. Many economic and technical growing substitution processes have been shown to fit this logistic curve very well (Fisher & Pry, 1971; Herman & Montroll, 1972; Montroll, 1978). This led to our general theory for evolutionary growth and adaptation. The mathematical foundations of this general theory of adaptive evolution will be presented in Koornstra (forthcoming) and for traffic the main mathematical principles are also presented in Oppe and Koornstra (1990), while the general principles for evolution and adaptation are summarized conceptually below and in Koornstra (1991).

The first evolution principle states that in the absence of any limiting or temporary disturbing factors, evolution constitutes a Malthusian exponential uninhibited growth process characterized by a constant growth rate.

A starting evolution behaves as if there is unrestrained access to unlimited resources for growth and its growth rate seems constant. However, any evolution increases order in the evolving system at the cost of energy dissipation. According to the first law of thermodynamics total energy is constant and, therefore, growth can never be unrestrained. A sigmoid shaped growth to a stable maximum level, can be described by a covert exponential growth which is inhibited by a function of that covert explosive growth itself. Saturating growth can be conceived as the result of a growth force for covert uninhibited exponential growth and a delayed anti-growth force which increases monotinic with underlying exponential growth. Such a gradual monotonic increasing anti-force for socio-economic systems can be seen is the delayed increasing disutility of growth which reduces the utility of further growth.

The second evolution principle, therefore, states that evolutionary growth force is a constant reduced by an anti-growth force which, in the absence of temporary disturbing factors, is a monotonic increasing function of underlying exponentional growth force itself.

If these two principles of evolution are valid, evolution only leads to a system with a stable volume if underlying growth and anti-growth become in balance as time progresses, as also the world dynamics models of Forrester (1971) and Meadows (1972) shows. Koornstra (forthcoming) shows that this holds if the underlying exponential growth is multiplicatively reduced by the reciprocal of a specific power transformed linear function of that underlying exponential growth itself. The intrinsic decrease of further growth as postulated will not be the only factor which influences underlying exponential growth. External factors may be of influence too. Economic recessions and upsurges will deter or accelerate growth in technological systems as much as cycles in temparature and food supply have influenced the biological evolution of species.

We formulate this notion more precise as a third principle for the actual growth of a semi-closed system: actual growth of an evolutionary system is characterized by a growth rate which is deterred or accelerated by temporary factors additionally operating on the underlying growth and anti-growth forces.

These first and second principles of evolution are first principles of an axiomatic nature, the third principle is a derived one. It describes the actual growth as some empirical deviation from axiomatic underlying growth, just in the same way as resistence is a derived principle from the principle of constant acceleration for free fall in Newtonian physics. Simultaneously these principles can offer a parsimonious theory of evolution which can be validated by empirical growth data.
The basic assumption on the relation between growth acceleration and adaptation in traffic fits very well the just described principles. The basic assumption for adaptation is that the rate of change in negative outcomes can be seen to be a simple function of the anti-growth force, because negative outcomes of the growth process are part of the anti-factor. Negative outcomes in this evolutionary context can not be defined arbitrarily. Negative outcomes must be self-destructive outcomes of growth events or at least be related to such self-destructive outcomes. In biology this may be

outcomes which defeat the growth of a population (premature non-survival). In the traffic system it may be outcomes of events which wash out mobility (fatal accidents).

We now formulate an evolutionary adaptation principle for a self-organizing systems which are characterized by a stabilizing growth as the fourth principle: the change rate in the probability of self-destructive outcomes of growth events is inversely proportional to the underlying anti-growth rate in an evolutionary system with a stable saturating level.

This means that risk adaptation is a power function of the derivative of the anti-growth function, which by the first three principles is a temporary externally deterred or accelerated negative exponential function of time which has zero value for infinity of time. This adaptation principle in evolutionary systems resembles what Teilhard de Chardin has already formulated. He wrote: - "Where we, however, have to remark that the <evolution> process for very large aggregations - as is the case for the human mass - has the tendency to "evolve errorless", because on the one hand of chance the probabilities of success increase, and on the other hand of freedom the probabilities of refusal and failure decrease, proportional to the multiplicity of the related units" (Teilhard de Chardin, 1948, Postscript Section 3).

Defining negative outcomes as only partially self-destructive outcomes which may not adapt to a zero probability level in the end, we can formulate an even more general hypothesis for evolutionary adaptation in the theory of adaptive evolution.

This fifth principle reads: the probability of a partial self-destructive outcomes is a linear function with positive valued parameters of the probability of self-destructive outcomes of growth events.

One can formulate a corollary deduced from the last two specified principles as the evolutionary adaptation corollary: the number of partial self-destructive events is a weighted sum of the number of self-destructive events and the (power transformed) volume of achieved growth in an evolutionary system.

The application of the fifth principle to traffic means that the probability of injuries will not reduce to a zero level in the end and in case of saturating growth the number of injuries has to stabilize on a positive level. Moreover, principles four and five imply that the external influences which deter or accelerate growth are inversely and delayed reflected as their derivative in the deterred or accelerated risk adaptation. This phenomenon is observed in the apparent and simultaneous correspondence of non-regular decrease and increase in curves for acceleration of growth and fatality-rate for some countries, as was phenomenally shown for the USA and analytically in the analysis of several countries. In view of our semi-closed and self-organizing system interpretation of traffic such disturbed evolutionary growth, brings the relative adaptation of the system to a level of adaptation that corresponds to an evolutionary rate of increase which corresponds with the growth level of underlying evolutionary growth. The level of risk adaptation is, so to speak, respectively pushed forward or retarded by external accelerating or deterring forces. Since this effect is assumed to be dependent on the derivative of the cyclic effect on growth, the cycle effect on risk adaptation is delayed with respect to the cycle effect on growth by a quarter of the cycle period. This seems to cause that the actual time lag in the assumptions in para. 2.3 is indeed a quarter of the fitted cycle period.

5. SOCIETY AND TECHNOLOGICAL EVOLUTION

5.1. Socio-economic self-organization of the traffic system

The traffic system contains the individual road user as an elementary subsystem. Although road-users do interact on the road, they interact in a physical way and only mutual perception and prediction of the behaviour of road users determines the interaction. There is no explicit communication for a rational process of conflict settlement. Therefore, we can describe collective risk as the sum of individual risks and the collective system of road users as a plain aggregation of subsystems of road users. They may, by learned reciprocal influences of individual behaviours, build a kind of unwritten social traffic code. It, however, only exists for so far as individuals learn to take expectations of the behaviour of other road users into account. On the other hand we have the man-made physical and law based traffic system in which the collectivity of road-user subsystems is embedded. In the evolutionary system approach we describe how this man made physical and law based traffic system changes by system growth and renewal of subsystems. This growth and renewal is pushed by growth of traffic and lack of safety and ask for investments and plans of societal decision making bodies. The implementation of societal decisions with respect to the man-made physical traffic system in turn depends on the economy and resources in that society of a nation, state, region or town. How on a macroscopic level growth of the traffic system of a nation is restrained and can be influenced by economic developments, is described by the cyclic deviations and the saturating growth process. The economy and resources of a nation is embedded in the economy and available resources of the world. Non self-supporting nations depend on export and import with other nations and transport of energy from other countries. Such an hierarchical embedding of subsystems as is described here, however, does not describe the crucial circular relations in the self-organizing traffic system, such as the relation between the societal decision system and individual road users.

Individual road users in the democratic societies of industrialized countries are not only subsystems in the traffic system of a nation. In a democratic society decisions are based on the influences of their members by votes, by pressures of lobbying parties and by action groups. The road users of the traffic system are also individuals which influence societal decision making. Their influence makes that the decisions of societal decision taking bodies depend on the preferences of individuals and their collective choices. We summarized by reference to our risk-adaptation theory (Koornstra, 1990; 1992) how an increasingly safer infrastructure influences the risk evaluation of road users and how their risk-acceptance shifts on the risk scale to a lower acceptance of risk in traffic during the evolution of the traffic system. Although it sometimes may seem as if the minds of road users are not the minds of members of our responsible society, the validated theory of cognitive dissonance (Festinger, 1957; Wicklund & Brehm, 1976) in cognitive and social psychology justifies the assumption of the ultimate congruence between safety norms of road users in traffic and of individuals in society. As a consequence the safer norms of individuals will also influence the collective choices and the decisions of governing bodies in our democratic and motorized countries. Implementation of decisions for a safer traffic system result in an increasing safer physical and law-based traffic system. This self-reinforcing relation between the traffic system, the individual subsystem and the societal decision system is illustrated by the evolutionary hypercycle of Figure 23.

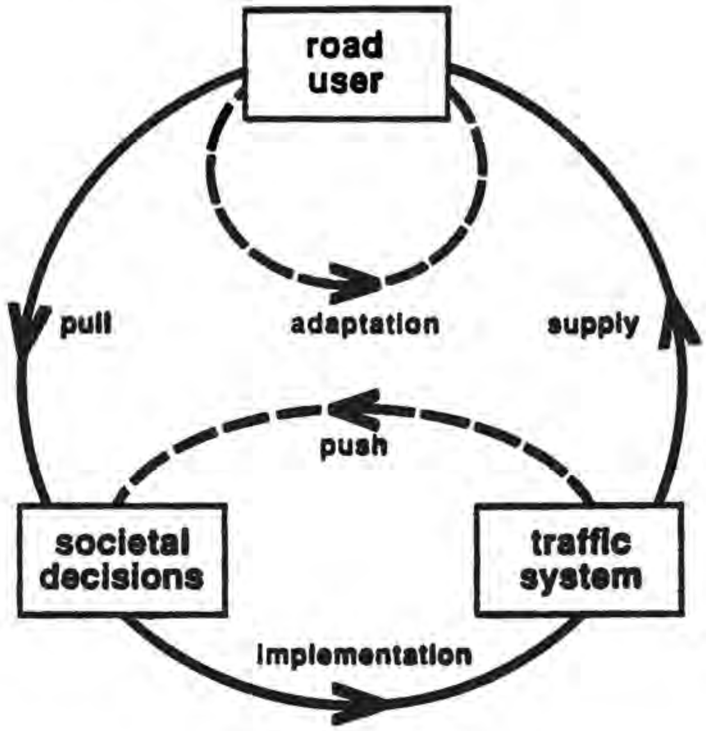

Figure 23. The hypercycle of traffic and safety.

This hypercycle is not only driven by the safety pull and transport demand of individuals based on their risk adaptation and positive utility for enhanced transport, but also by the societal control based on statistical accounts of growth and safety. The latter forms a pushing factor by itself. The increased safety of the system, however, is mainly accomplished by the recursive influence of safer transport facilities on the risk acceptance of individuals and their recursive influence on societal decisions for safer transport facilities.

The structure of self-organizing systems and the theory of adaptive evolution is of a general nature. Its notions are applied to biochemical evolution (Eigen & Schuster, 1979) and evolution biology of single species (Williamson, 1972; Hassel et al. 1976). As shown this self-organizing system description and the theory of adaptive evolution is also applicable to traffic as a social economic or technological evolution. We conjecture that its structure and dynamics are applicable to other socio-economic and technological evolutions in our modern democratic and industrialized countries. Herman and Montroll (1972) have characterized the increasing nonagricultural development by an evolutionary growth based on a logistic function for the ratio of nonagricultural labor force and total labor force. Fisher and Pry (1971) applied this logistic evolutionary model to increased use of many technological products versus comparable natural products in several countries. Montroll (1978) analyzed such logistic evolution for intercity air-travel versus rail travel in the USA and for the history of steamboats versus sailboats in the U.S. merchant fleet. He also refers to the educational evolution in the USA as a logistic pattern for the fraction of persons receiving university degrees since 1900. Such a logistic replacement processes arises if growth itself is of an asymmetric logistic nature (Koornstra, forthcoming). So our hypothesis that the theory of adaptive evolution is not only applicable to traffic and some biological processes, but to socio-economic and technological evolution as well, seems sustained. The relation between growth and adaptation in our general theory, however, still needs further evidence from other growth processes. If it holds for other growth processes as well, than the analyses by the world model of Meadows et al. (1991) for the environmental consequences from the growth of energy consuming industry are partially incorrect, since in their world models the rate of negative outcomes is not reduced as some function of growth itself. But it seems quite reasonable to assume that the rate of environmental load per unit of production is decreased, while the rate of production growth is decreasing. Such a development would fit our general adaptive evolution theory, but need not to result in the disasters described in "The limits of growth" and "Beyond the limits".

5.2. Selection and technological evolution

Evolution is always based on dissipation of energy for a self-organizing process of replacement of subsystems by sequences of identical or modified subsystems. The possible modifications are based on selection of varieties in subsystems. As Eigen (Eigen & Winkler, 1974; Eigen & Schuster, 1979) has shown for non man-made evolutions, selection is a property of evolutionary processes that is not guided by teleological principals, but based on the cumulation of reproductive variability stored in the subsystems and the survival value of produced reproductive varieties in the changing macro system. Survival value is not an 'a priori' property as such but an 'a posteriori' inferred value deduced from the apparent survival in the changing macro-system. This stored reproductive variability of subsystems hides the fylogenetic history of survival values of reproductive components obtained during the history of the changing macro system. It makes evolution not a wholly blind random process, nor a purposive developing process, but a flexible adaptive process in which variation and selection play their roles.

Man-made technological evolutions, like motorized traffic, are also based on the dissipation of energy for replacement processes and selection of modified subsystems with a higher utility in the self-organized macro system. Man-made evolution may be purposive, but man-made evolutions can not violate the principles of evolution. Purposive human acts and societal actions, however, can enhance the desired direction and speed of evolution. By that, man-made evolutions can add to the autonomous cycles of evolution a purposive hypercycle in the self-organizing socio-economic technological evolution. The general principles of adaptive evolution, therefore, can have some policy impacts for traffic and road safety, as an example of a socio-economic technological evolution.
- First, we noted that increased acceleration of growth resulted in an increased fatality rate. The control of growth acceleration in order to

establish a growth with a monotonic decreasing acceleration is of utmost importance for safety. Otherwise the system becomes relatively less adapted and increased lack of safety is the toll which must be paid.

- Second, the principle of variation on which adaptation by selection is based, asks for the enhancement of variation and creativity in safety measures. This is established by decentralization, local and partial experimentation as well as by creative research.
- Third, purposive selection in evolution asks for objective evaluation of safety effects of decentralized trials, planned experimentation and small scale applications of research findings.
- Finally, selective replacement asks for a coordinated replication of effective safety measures in other places and domains and, if no negative interaction under different conditions in other places are obtained, uniform application of effective safety measures on a national and global scale.

5.3. <u>Process autonomy and technological evolution</u>

Adaptation in self-organizing systems is not described in our theory of adaptive evolution as an automatic process, but rather as an autonomous process. If the above policy is applied adaptation becomes a purposive property of technological evolution, although its characterization may remain that of a rather autonomous process. Unlike biological self-organizing systems, adaptation in technological systems is governed by decision making bodies and individuals and their decisions do matter. The characterization of an autonomous process of such technological evolutions in society is the result of democratic control. In our democratic society are individuals free in their decisions, but they are only allowed to take decisions or are only in charge of free decision making for so far as we know that we are not harmed by their decisions. A minister or alderman in charge of safety or health is free not to take the safety or health measures which are known to be effective, but they will not stay very long on their post if they do so. The same will hold for other positions in society and even individuals who behave criminal in traffic are no longer allowed to drive. This is what autonomy of evolutionary systems imply: indeterminateness of activity of subsystems and recursive feedback of output of subsystems as input for other (sub)systems within a self-organizing macro system give rise to aggregated lawful developments of processes. On a physical level we have undeterminate particle movements, but it is the bases for determined laws, such as the stochastic Brownian motion of gas-molecules determining the pressure law of Boyle/Gay-Lussac. On a social level we have the freedom of individual choice, but it is the bases for the lawful course of aggregated socio-economic and technological processes. Indeterminacy or freedom on a micro level is the bases for aggregated lawfulness on a macro level in any semi-closed and self-organizing system. This also holds for indeterminacy or freedom of individual risk in traffic and the lawful developments of road safety in industrialized democratic controlled countries. The given model predictions, therefore, may only hold for democratic countries and only as long as the predictions are not by- passed by a yet unknown evolution of a safer and more efficient system of transport.

LITERATURE

- Anderson, T.W. (1971). The statistical analysis of time series. Wiley, New York.

- Atkinson, R.C. & Estes, W.K. (1963). Stimulus sampling theory. Ch. 10 in: Luce, R.D.; Bush, R.R. & Galanter, E. (Eds.). (1969).

- Audley, R.J. & Jonckheere, A.R. (1956). The statistical analysis of the learning process. Brit. J. Stat. Psychol. 9: 12-20.

- Broughton, J. (1988). Predictive models of road accident fatalities. Traff. Enging. & Control 29: 296-300.

- Bush, R.R. & Mosteller, F. (1955). Stochastic models for learning. Wiley, New York.

- Chatfield, B.V. (1987). System-wide safety improvements: An approach to safety consistency. NCHRP Synthesis 132. Transportation Research Board, Washington, D.C.

- Day, N.E. (1966). Fitting curves to longitudinal data. Biometrics 22: 276-288.

- Durbin, J. (1963). Trend elimination for the purpose of estimating seasonal and periodic components of time series. In: Rosenblatt, M. (Ed.). Proc. Symp. Time series analyses. Wiley, New York, pp. 3-16.

- Eigen, M. & Schuster, P. (1979). The Hypercycle. Springer, Berlin.

- Eigen, M. & Winkler, R. (1975). Das Spiel; Naturgesetze steurn den Zufall. Piper, München.

- Festinger, L. (1957). A theory of cognitive dissonance. Stanford Univ. Press, Stanford.

- Fisher, J.C. & Pry, R.H. (1971). A simple substation model of technological change. Technol. Forecasting and Social Change 3: 75-88.

- Gulliksen, H. (1934). A rational equation of the learning curve based on Thorndike's law of effect. J. Gen. Psychol. 11: 395-434.

- Haight, F.A. (1988). A method for comparing and forecasting annual traffic death totals: The United States and Japan. Proc. Conf. "Road Safety in Europe", Gothenburg. VTI, Linkoping.

- Hanken, A.F.G. (1981). Cybernetics and society. Abacus Press, Tunbridge Wells.

- Hassell, M.P.; Lawton, J.H. & May, R.M. (1976). Patterns of dynamical behavior in single species populations. J. Anim. Ecol. 46.

- Hauer, E. (1982). Traffic conflicts and exposure. Accid. Anal. & Prev. 14: 352-362

- Helson, H. (1964). Adaption-level theory. Harper & Row, New York.
- Herman, R. & Montroll, E.W. (1972). A manner of characterizing the development of countries. Proc. Nat. Acad. Sci. USA 69: 3019-3023
- Hull, C.L. (1943). Principles of behavior. Appleton-Century-Crofts, New York.
- Jantsch, E. (1980a). The self-organizing universe. Pergamon Press, Oxford.
- Jantsch, E. (1980b). Autopoiesis: A central aspect of dissipative self-organization. Ch. 5 in: Zeleny, M. (Ed.) (1980).
- Johnston, J. (1963). Econometric methods. McGraw- Hill, New York.
- Koornstra, M.J. (1987). Ridendo dicere verum. R-87-35. SWOV, Leidschendam.
- Koornstra, M.J. (1988). Development of road safety in some european countries and the USA. R-88-33. SWOV, Leidschendam.
- Koornstra, M.J. (1990). System theory and individual risk. In: Benjamin, T. (Ed.). Driving behaviour in a social context. Proc. Int. Symp. Paris 1989. Paradigme, Caen, pp. 21-45
- Koornstra, M.J. (1991). Evolution of mobility and road safety. In: Hakkert, A.S. & Katz, A. (Eds.). Proc. of 2nd Int. Conf. on New ways for improved road safety and quality of life. Tel-Aviv. 1991. TRI, Haifa.
- Koornstra, M.J. (1992). Change of choice. (To be published)
- Koornstra, M.J. (forthcoming). The evolution of traffic and traffic safety.
- Laszlo, C.A.; Levine, M.D. & Milsum, J.M. (1974). A general systems framework for social systems. Behav. Sc. 19: 79-92
- Luce, D.R. (1959). Individual choice behavior. Wiley, New York.
- Luce, R.D; Bush, R.R. & Galanter, E. (Eds.) (1963). Handbook of mathematical psychology, Vol. II. Wiley, New York.
- May, R.M. & Oster, G. F. (1976). Bifurcations and dynamical complexity in simple ecological models. Amer. Natur. 110: 573-599.
- Meadows, D.L. (1972). The limits of growth. Universe Books, New York.
- Meadows, D.H.; Meadows D.L. & Randers, J. (1991). Beyond the limits. Confronting global collapse; envisioning a sustianable future. Earthscan Publications, London.
- Mertens, P. (1973). Mittel- und langfristige Absatzprognose auf der Basis von Sättigungsmodellen. In: Mertens, P. (Ed.). Prognoserechnung. Physica-Verlag, Würzburg.

- Minter, A.L. (1987). Road casualties. Improvement by learning processes. Traff. Engng. & Control 28: 74-79.

- Montroll, E.W. (1978). Social dynamics and the quantifying of social forces. Proc. Natl. Acad. Sci. USA 75: 4633-4637

- Nicolis, G. & Prigogine, I. (1977). Self- organization in nonequilibrium systems: From dissipative structures to order through fluctuations. Wiley, New York.

- Oppe, S. (1989). Macroscopic models for traffic and traffic safety. Accid. Anal. & Prev. 21: 225-232

- Oppe, S. (1991a). The development of traffic and traffic safety in six developed countries. Accid. Anal. & Prev. 23: 401-412.

- Oppe, S. (1991b). Development of traffic anf traffic safety: Global trends and incidental fluctuations. Accid. Anal. & Prev. 23: 413-422.

- Oppe, S. & Koornstra, M.J. (1990). A mathematical theory for related long term developments of road traffic and safety. In: Koshi, M. (Ed). Transportation and traffic theory. Proc. 11th Int. Symp. Elsevier, New York, pp. 113-132.

- Oppe, S.; Koornstra, M.J. & Roszbach, R. (1988). Macroscopic models for traffic and traffic safety: Three related approaches from SWOV. In: Traffic safety theory & research methods, Session 5: Time dependent models. SWOV, Leidschendam.

- Partyka, S.C.(1991). Simple models of fatality trends revisited seven years later. Acid. Anal. & Prev. 23: 423-430.

- Prigogine, I. & Stengers, I. (1984). Order out of chaos. Heinemann, London.

- Sternberg, S. (1963). Stochastic learning theory. Ch. 9 in: Luce, R.D.; Bush, R.R. & Galanter, E. (Eds.). (1963).

- Teilhard de Chardin, P. (1948). La phénomène humain. Editions du Seuil, Paris.

- Thurstone, L.L. (1930). The learning function. J. Gen. Psychol. 3: 469-491.

- Towill, D.R. (1973). A direct method for the determination of learning curve parameters from historical data. Int. J. Prod. Res. 11: 97-105.

- Varela, F.J. (1979). Principles of biological autonomy. North Holland, New York.

- Wilde, G.J.S. (1982). A theory of risk homeostasis: Implication for safety and health. Risk Analysis 2: 209-225.

- Williamson, M. (1972). The analysis of biological populations. Arnold, London.

- Zeleny, M. (Ed.). (1980). Autopoiesis: A theory of living organization. North Holland, New York.