The direct endangering of the living space: a proposed set of quantitative concepts

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THE DIRECT ENDANGERING OF THE LIVING SPACE (A PROPOSED SET OF QUANTITATIVE CONCEPTS)

BY

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PREFACE

A feature of modern society is that much of our environment is created by ourselves and, therefore, we are responsible for its possible effects, e.g., pollution, death or injury, or economic loss. Safety regulations and laws needed to control these dangers must be based on the risks we are willing to accept since absolute safety from these dangers cannot be attained. This paper makes a study of the types of risk and defines those which should be considered in safety regulations as basic risks. An analytical procedure to determine basic risks is proposed which takes into account social, moral and economic requirements. This paper provides a useful insight into the question "How safe is safe enough?" which arises, for example, in setting building code rules to protect the public against such catastrophes as fire or collapse.

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[Die unmittelbare Gefährdung unseres Lebensraumes (Versuch eines quantitativen Begriffssystems)]

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THE DIRECT ENDANGERING OF THE LIVING SPACE

(A PROPOSED SET OF QUANTITATIVE CONCEPTS)

> "We are living in a period of transition from a time when technology was supposed to protect man from nature to a time when it must now protect nature (including humanity) from man."
>
> Edward Wenk

1. Introduction

1.1 Motivation

One of the salient characteristics of the middle third of the present century, at least in the industrialized countries, has been a preoccupation with such words as "growth", "progress", "gross national product", etc. However, the rapidly increasing consumption of a definitely limited space by the activities of a continuously growing and more and more demanding population has become the root cause of various actual and potential conflicts. The activities that man has introduced in the search for a better life are, it is true, producing the desired economic, technical and social gains, but at the same time, in a very real sense, they also constitute factors that endanger his living space. Within this restricted space these conflicts have now reached a stage at which more and more groups of citizens are becoming conscious of the problem. We have experienced an initial phase of awareness over the last 20 years in relation to water pollution, and for some time now this awareness has been expanding to take in such matters as air pollution, noise pollution and the various environmental threats posed by road traffic, air traffic, gas, electricity, etc. However, the groundwork needed for an objective appraisal of the problem as a whole remains largely undone. Questions arise concerning the overall level of these threats, their principal components and the time taken for the danger to develop, as well as matters of natural or acceptable limits, and so on.

The present paper deals with the typology of the environmental crisis as well as a terminology and methodology, with a view to a rational response to the dangers, i.e., a response that is consciously consistent with a well defined system of values.

This set of problems is interesting from the planning and political standpoint, because so many of the most important human activities involve municipal, regional and generally, even national and international communities. Thus it is often representative organizations, such as government agencies, which elaborate and frequently put into practice regulations, laws and guidelines designed to limit the various threats to the living space.

For two reasons, therefore, it is necessary to undertake a systematic and, as far as possible quantitative study of the problem: first, in order to get a better overall view of the increasing number of environmental hazards being introduced, and second, in order to be able to mobilize the available means for combatting these hazards in the best possible way.

1.2 Direct and indirect hazards

Threats to the living space due to human activities can be divided into two main groups (Figure 1):

Indirect, and hence long-term hazards due to noise, air and water pollution, "thermal pollution", etc. This group is characterized by a considerable time lag between the cause and the appearance of the effects. This seems to be basically why, in general the community only becomes aware of the casual connection when it is already "too late", i.e., when the effects are already painfully evident. We have not been able to escape these consequences, not yet at least, in relation to either water, air or noise pollution. It is to be hoped that a better understanding of the relationships, better forecasting methods and a deeper insight will enable us to avoid such experiences in other areas. Special efforts to gain such new insights are being made today, especially in the United States, the very country that has led the way and gone farthest in the direction of insouciant growth[1,2]. Aurelio Pecci's article "The predicament of mankind", which appeared in Successo, shows however, that the appeals have found a response at the international level.

Direct or short-term hazards due to aeroplane crashes, explosions, the collapse of structures, nuclear power plant accidents, traffic accidents, the transporting of dangerous materials, earthquakes, etc. constitute a second group of environmental dangers. Although here cause and effect are closer together, there is a latent helplessness in our efforts to assess danger or to determine the importance of such events. Disasters of this sort do indeed attract immediate massive attention at the time and place of their occurrence, and the direct, subjective impression often results in rather unrealistic demands for the elimination of the hazard. Characteristically, however, the emphatic character of such reactions decreases sharply with time and distance. A hundred casualties in New Caledonia have about the same effect on us as an explosion disaster that occurred 20 years ago.

1.3 The problem

The problem of the endangering of the living space can be expressed generally in the following terms:

The activities of our society aim primarily at a technical-economic optimum. If we regard the various aspects of the endangering of the living space as an additional moral-psychological component of this purpose function, we can then attack the problem in two stages:

1. What moral-psychological constraints should be imposed on various activities when the endangering of the environment is taken into account?
2. How are these moral-psychological constraints to be distributed among the different activities so that, given certain socio-economic and socio-moral values, the system as a whole can be considered balanced?

This formulation is applicable both to direct and indirect hazards. It is represented schematically in Figure 2. For direct hazards, with which we are hereinafter concerned, it can be further broken down as follows:

1. In general, what constraints should be imposed for reasons of safety (against direct hazards) on various socially desirable activities such as the generation and distribution of electricity or gas, transportation systems etc.?

2. How are the technical-economic expenditures (and restrictions on personal freedom) for safety measures to be distributed among the different activities, and what measures should be taken on the one hand to produce a balanced system and on the other to achieve an overall optimum for the safety of all activities at a given total expenditure?

The arguments that follow should not be regarded as prescriptions for solving these problems, but rather as suggestions for getting a better perspective on problems concerning the (direct) endangering or safety of the environment, along with a more objective awareness of these problems.

2. Nomenclature

There is still a considerable hiatus in the safety field, inasmuch as there is still no precise, unequivocal, generally accepted terminology. Many concepts, e.g., safety, risk, damage, frequency, probability, etc., are used too imprecisely or ambiguously. The gap is now gradually being closed by science, especially in the English language, but in our daily decision-making it still looms large. If the problem is to be amendable to exact logical analysis it is essential to have an unequivocal (credible) definition of a conceptual framework with as quantifiable a content as possible.

2.1 Situation

In any autonomous human community (e.g., a country) many different activities* (activity systems, cf. also Figure 2) are carried on. It is taken for granted by the community as a whole (or by the determining or governing part of the community) that these activities

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* Activities are any operations such as construction, the running of a transportation system, the setting up or operation of a manufacturing process, a sport, a supply industry, etc.

are fundamentally desirable. The activity is carried out by an operator [an individual or organization, on his or their own initiative or as agents of the community (public sector)]. Some (or all) members of the community receive the results of this activity as *clients*; those members not receiving it are termed *non-participants*.

A danger exists wherever there is any possibility of events occurring as a result of the activity which would produce damage, injury or loss of human life. The danger may differ, of course, for the operator (and his members), the clients and the non-participants.

On behalf of the community a neutral *safety agency* representing the community (e.g., a government agency, department etc.) must provide for the safety measures which will correspond to the above-mentioned, economic-moral optimum.

2.2 Risk

The endangering of the environment by an activity is expressed in a risk R which is determined by the extent A of the possible effects and the frequency of possible dangerous events, i.e., their probability w.

$$R = f\ (A,\ w) \tag{1}$$

As a rule A and w, and hence also R, are stochastic quantities. The simplest logical relationship of R, A and w is the product:

$$\begin{aligned} R &= A \cdot w \\ \text{Risk} &= \text{Effect} \cdot \text{probability} \end{aligned} \tag{2}$$

A risk so defined implies a certain span of time. Thus the risk becomes an expectancy of damage per unit time. It increases proportionally to the expected probability of an event w and the extent A of the effects

A logical expansion is obtained for the case of several activities i as follows:

$$R = \sum_{i=1}^{n} R_i = \sum_{i=1}^{n} A_i \cdot w_i,$$

i.e., a total risk can be determined as the sum of its partial risks.

The term safety is generally employed as the antithesis of risk. This term can be defined mathematically in various ways.

Safety is often taken as a pure probability and varied between zero and one. This is compatible with the above concept of risk where safety is investigated with respect to certain distinct events, especially events that have a definite effect.

But it is also possible to expand the concept of safety so that it also constitutes a quantity depending on the effect and probability of an event. For example, it can be defined as the reciprocal of risk.

The problems raised hereinafter are always considered from the standpoint of risk.

2.3 Objective and perceived risks: classes of events

The form of risk defined in equation (2) is rational and objective. An activity that produces 20 events in a decade with an effect of one fatality per event is assigned the same risk value as a single serious event during a decade with 20 fatalities. This value is therefore termed an *objective risk* R_o. However, the subjective appraisal of activities as a rule tends towards an aversion to serious events. In other words, events having serious effects are felt to contain a risk that is more than proportional to the effect A.

Hence, the risk R as a function $f(A, w)$ of the probability w and the effect A can no longer be expressed in the simple, purely linear form of equation (2).

We can now define a subjectively *perceived risk* R_e by introducing a subjective aversion function $\rho(A)$ depending on the effect A which will appear as an additional factor in the product. The perceived risk can then be written as follows:

$$R_e = A \cdot \varrho(A) \cdot w = R_o \cdot \varrho(A) \qquad (3)$$

or

$$R_e = A_e \cdot w \quad (4)$$

where A_e could be termed the perceived effect in the event.

If the aversion relates not merely to the seriousness of the effect of a single event but, in general, to the expected effect over a given period of time - regardless of the number of events involved - the aversion function then becomes dependent on the product $A \cdot w$:

$$R_e = R_o \cdot \varphi'(A \cdot w) = A \cdot w \cdot \varphi'(A \cdot w) \quad (5)$$

The aversion function - whether in the form of equation (3) or (5) - cannot be derived scientifically. It is the quantitative expression of a subjunctive moral-psychological value system which can be different even from one person to another. It indicates that a catastrophic event with dozens of fatalities is felt to be more than proportionally more serious than an event with a few fatalities, if the number of fatalities is introduced as a measure for the characterization of an event. In other words, it expresses in a general way a non-linearity in the relationship between a perceived risk and an effect [equation (3)] or an effect times a probability [equation (5)].

The aversion function takes this fact into account by a virtual increase of the effects, e.g., of the number of fatalities. Actually of course, the effect changes qualitatively, because such aspects as increasing perception of the risk to oneself, jeopardizing of the activity as a whole (e.g., in the military) etc., are connected with the perceived effects.

In relation to the technical-economic analysis, the introduction of the aversion function means that people are prepared to accept substantially higher costs (e.g., a thousand times more) for safety measures to prevent a catastrophe with e.g., 50 fatalities than to prevent one with only two or three fatalities. Figure 3 presents an example of such an aversion function.

In practice, an aversion function divided into steps according to classes of events can be grasped more readily than a continuous one. Each class of event is defined with a fixed aversion value.

Again we must bear in mind that the numerical value of the aversion "band width" of the class of event on the *A* axis have only a subjective, not a scientific basis. Table I gives the classes of event by way of example as plotted with the broken lines in Figure 3.

The quantitative terminology set forth here for risk and aversion is very useful for the rational derivation of safety concepts for potentially dangerous activity systems like the storage, consumption or transport of gas, oil, gasoline, munitions, electricity, radioactive materials, etc. It enables us to construct a logically verifiable chain of ideas between certain subjective (socio-moral) values and the actions that conform most closely to them. The concept has already been applied to the treatment of practical safety problems (munitions storage, pipeline installations).

2.4 Classes of risks

We now come to the question of the criteria that are to be adopted in order to determine the socially optimum safety level. Since these criteria imply moral-ethical values, it is clear that the limits of tolerance will be subjectively determined. However, by putting these conditions into a logical model we can at least make a relative appraisal of the risks involved in various activities in a way that will be compatible with a consciously adopted scheme of preferences, and the measures to be taken can then be derived in the most rational way possible.

2.41 Concept of the basic risk R_g

The principal aim of these considerations is to single out from the total risk a *basic* one R_g which will represent the "inescapable" risks, again in the sense of the moral-economic optimum. These are the minimum risks that each individual has to accept by reason merely of the fact that he is a member of the society, although he himself is not conscious of being personally involved in activities which by legal criteria are the causes of an event.

The definition of such a basic risk yields the criteria by which the socially accepted minimum risk level is established, and by which the safety measures must be erected for activities to which the individual is exposed through the implied consensus of the society.

The public must be assured that no activity exceeds this basic risk, and every responsible person is obligated to maintain this condition (obligation to be careful).

We can now define this basic risk more percisely:

The basic risk *Rg* encompasses that part of the total risk which lies outside the personal sphere of influence of the individual affected, and for which no blame (negligence or culpable behaviour) attaches to the responsible people.

The most important concepts of this definition and the classification criteria used can be explained as follows:

Parties involved: The following parties are legally involved in events that produce damage:

Responsible party: The person or institution having an obligation to exercise care in the execution of an activity (in the sense of the moral-economic optimum of the de facto law).

Injured party: Persons or institutions who suffer a material or non-material injury.

Third parties: Persons or institutions not included in either of the above groups, but having some connection with the event.

Act of God: Occurrences or forces not accessible to human influence.

- *Classification criteria*

The basic risk defined above has been differentiated from the the total risk on the basis of the following criteria:

1. Was the event within or beyond the sphere of influence of the injured party? In the former case, was the injured party aware of the normal risks arising out of the activity because

of his special connection with it (e.g., automobile driving, flying as a pilot or passenger, etc. Not included, for example is danger to a person on the ground from the crashing of an aircraft).

2. Does any blame attach to the responsible party, i.e., has he or has he not exercised the care required of him, or has he even acted culpably?

2.42 Personal and liability risks

The total risk is broken down graphically into these parameters in Figures 4 and 5. As Figure 4 shows, only non-contractual events are considered[(4)]. Besides the basic risk R_g which, although quantitatively the smallest, is conceptually the most important in this connection, we identify two additional classes. The logical relation between these is brought out most clearly in Figure 5.

The personal risk R_p encompasses all risks to the activities of which the injured party has a personal relationship and is essentially aware of the risk to himself arising out of the activity. This awareness distinguishes him from others who may be confronted, perhaps accidentally, with the activity. Examples of this class are risks (with or without own fault) associated with sport, industrial accidents, etc.

The liability risk R_h relates to cases in which some blame is attributed to the responsible party. The responsible party has an obligation to exercise care. Damage incurred by an injured party because the person responsible for the activity failed to meet this obligation belongs in the category of liability risks. Most road traffic accidents (except "own fault" accidents) are of this kind. So is a train derailment where the cause is, for example, poor track maintenance (as the fault of the responsible company). However, should it be the fault of the train driver or a barrier guard, and the responsible party has fulfilled his obligation, the event belongs in the basic risk category.

2.43 Intermediate situations

The above classification is rigidly structured and well suited to quantification. It should be kept in mind, however, that in any given case there may be intermediate stages that fall between the different categories of risk, because often different parties may be partially to blame rather than either totally at fault or totally innocent. The components of the various risk categories must then be divided accordingly, depending on the degree of fault. For example, if the collapse of a building claims 12 human lives and the court assigns one third of the blame to the responsible party, the basic risk component in a statistical analysis would then be $R_g = 8$, leaving $R_h = 4$ fatalities for the liability risk component. (The obvious assumption here is that the event lies entirely outside the sphere of influence of the injured parties).

There are also intermediate stages in the degree to which an activity lies inside or outside the personal sphere of influence, i.e., the extent to which the injured party may be aware of the risk. In this sense the risk categories defined above are limiting cases, in reference to any given event.

2.44 Illustrative examples

We can illustrate the application of the above concepts by reference to a few practical examples. The orders of magnitude of the basic risk and the total risk were determined by a very rough analysis of Swiss accident statistics. This basic risk is a useful value for purposes of comparison, indicating the level of risk (i.e., the number of fatalities in one year in a country) that is considered morally and economically acceptable.

A very rough estimate for Switzerland for 1967 showed that the basic risk R_g comes to about ten fatalities per year, whereas the total risk is of the order of 3500 fatalities (numbers suffering injury and extent of material damage not investigated). Thus, the total accidental death rate in Switzerland is about $0.6 \cdot 10^{-3}$, of which the basic risk component is about 1% or $0.6 \cdot 10^{-5}$ per year.

In order to determine whether a given event lies wholly or partially in the basic risk category it is necessary to settle the responsibility and liability question, see Figure 4. Three examples of such decisions may be cited by way of illustration:

Example 1: A man riding a motor scooter is struck by lightning. *Verdict*: Act of God, hence basic risk.

Example 2: A motor vehicle collides with a deer; three people killed. *Verdict:* If the owner of the road has fulfilled his obligations with the proper care (game fence and posting of warnings) and provided (driver's) own fault can be excluded, there is no "qualifiable responsibility", hence basic risk. In case of (driver's) own fault the correct category would be personal risk, and in case of failure on the part of the responsible party to exercise due care it would be liability risk. For statistical purposes a division among different categories is possible.

Example 3: Snow slides from a roof, killing two pedestrians. *Verdict*: If the snow fell from a private house the owner of the house, as the responsible party, has the obligation of removing the snow. In this case the responsible party would be at fault, hence liability risk. If the snow were to fall from a building (e.g., public building) from which someone legally instructed by the responsible party (e.g., an employee) had failed to perform his snow clearance duties, and provided he was reasonably well supervised by the responsible party, the fault is that of a third party, hence it belongs in the basic risk category.

A rough statistical evaluation of accidents in Switzerland in 1967 shows the following distribution:

1.	Total risk		3500 fatalities
2.	Basic risk		
	- Third party fault	20 fatalities	
	- Acts of God	10 fatalities	
	- No qualifiable fault	10 fatalities	40 fatalities

It is clear that a currently acceptable or tolerated basic risk could be derived empirically from a systematic study of accidents and their legal verdicts.

2.5 Value categories

In every instance of damage some values are destroyed. In analyzing the problem with a view to alternative verdicts it is important to bear in mind that different kinds of values may be involved, and that these different categories are dealt with in fundamentally different ways with respect both to the methods and the units of measurement employed when determing the risks.

- *Economic (material) values*

  This category applies to goods or services whose values can be expressed in monetary units, i.e., they have a market value and are usually replaceable. Two examples would be the cost of reconstructing a collapsed building (including interest losses) and the replacement value of an automobile. Risk aspects relative to material values can be covered in the technical-economic model in the form of expectancy values. In other words, the trade-off between safety (risk) and economy can be arrived at by direct optimization in monetary units. Whether a temporary suspension bridge should be dimensioned for a wind speed of 100, 130 or 150 km/h can be decided (assuming no traffic over the bridge in high wind conditions) by weighing the saving in costs certainly achieved by choosing the smaller parameter against the higher damage expectancy due to the greater probability of collapse.

- *Human life*

  At the other end of the value spectrum we have human life. Values of this type can be termed moral-ethical values. Although it is possible to assign a monetary value to a human life from a purely commercial standpoint (e.g., the value of the life insurance or the value of the labour output in a lifetime), the true scale of these values lies outside the ecomomy. Nevertheless, whenever it is necessary to determine a safety measure for an activity (e.g., the safety factor of a building or a bridge, the safety characteristics for the transporting of dangerous materials, etc.) a decision has to be taken on how much money is to be spent for reducing the risk of loss (or injury to) human lives. Herein lies the question of the moral-economic optimum. The decision must always be a subjective one, since it is comparable to the familiar addition of apples and oranges, i.e., two fundamentally different units and scales of values are involved.

- *Cultural-ideal values*

  This third category of values occupies the ground between the two above. It can apply to either material or non-material commodities, the real value of which cannot be expressed in market terms (monetary units). The protection of landscapes and waterways, apart from activities that endanger life, is associated with values of this kind. Damage of this type can be compared with material values only on a subjective basis.

2.6 Admissible basic risk component of an activity

In this section we shall explore the question of the criteria by which an optimum distribution can be found in the socio-economic sense over the various activities for a given morally and economically accepted risk.

Here we become aware of the fundamentally dual character of the problem. The determination of the generally tolerated risk (e.g., per individual or for a country) is a compromise between moral and economic decisions, whereas the question raised in this section, of optimizing the distribution among different activities is concerned basically with socio-economic and technical, but not moral aspects. A distribution undertaken according to the criteria sought should on the one hand lead to a system of activities that is balanced from the point of view of risks, but on the other hand should conform to the accepted total risk at minimum expense.

From the planning standpoint this question can be explored only in relation to the basic risk, because laws, enactments and safety regulations directly govern only the general scope of the basic risk and its distribution among the activities. The general scope and distribution of the other two categories, liability risk and personal risk (cf. Figure 4), are determined primarily by the personal behaviour of each individual in the society and his personal attitude towards the safety code postulated by the society collectively. The structure of the system of behaviour in relation to the three categories of risk that have been identified is represented schematically in Figure 6 (cf. also Figure 4). The total risk R_{tot} and the personal risk R_p are governed directly by the behaviour of the individual. The basic risk R_g is governed directly by the safety code (laws, regulations). In addition, however, there are the important feedbacks that are indicated, besides the existing relationships between R_{tot}, R_g, R_p, R_h.

In what follows we present a simple theoretical optimization model which takes the following very important distribution aspects into account:

WB_i	= economic importance of the activity i (e.g., "production value" of the activity, cf. also Reference 5)
A_i	= financial expenditure on safety measures in the activity i (e.g., fr./yr)
ϕ_i	= degree of socio-economic priority attributed by society to the activity i (non-dimensional; ϕ large for an important activity)
Ψ_i	= psychologically determined degree of care expected of the responsible parties by society
R_{gi}	= basic risk component of the activity i (expected value of number of fatalities or injuries per year)
$R_{g_{tot}}$	= total basic risk of all activities

A few clarifications and expansions of these terms should be introduced at this point:

- The product of the economic importance WB_i and the degree of socio-economic priority ϕ_i gives a socio-economic importance (weighted economic importance):

$$SOB_i = WB_i \cdot \phi_i \tag{8}$$

- The product of expenditures on safety A_i and the degree of socio-economic priority ϕ_i gives the socio-economic safety expenditures (weighted expenditures on safety):

$$SOA_i = A_i \cdot \phi_i \tag{9}$$

- The degree of care Ψ_i enables us to take into account the psychologically different scales of expectancy that society appears to apply to different responsible parties. A clearly graduated scale can be discerned for example in the degree of care we expect to be exercised in the activities of individuals, large private companies, the public authorities and e.g., the military. Thus, people expect the owner of an explosives factory to exercise a great deal more care than they are presently ready to demand or see enforced on a motorist (e.g., in the choice of a maximum speed), even though the risk involved in road traffic is hundreds of times greater than the risk incurred in the manufacture of explosives. This tendency could be taken into account, for example, by applying the following factors Ψ_i:

Individuals	Ψ_i	=	1
Large firms or public authorities	Ψ_i	=	10
Military	Ψ_i	=	100

(These factors are referred to risk not to costs.)

- The product of the basic risk component R_{gi} and the expected degree of care Ψ_i gives the socio-psychological basic risk component R'_{gi}

$$R'_{gi} = \Psi_i \cdot R_{gi} \tag{10}$$

Endless scientific and emotional discussions have already taken place on the utility or otherwise of the quantification of such objective value concepts as ϕ and Ψ and of the quantitative models employing them (cf. References 9 and 10). In every case the answer depends on what we expect of the model and on how naively and dogmatically we use such uncertain quantities as a basis for reaching decisions. In this connection J. Forrester's argument[11] is incisive: the value of such models has to be measured not against an absolute scale of accuracy, but against the alternative of not formulating the model at all.

The most important basic information required for a quantitative solution of the problem is the specific safety cost function $k_i(R_{gi})$ for each activity i. This shows the relation between the costs of safety measures and the risk component (cf. Figure 7).

The specific safety cost functions k_i of Figure 7 can be converted to socio-economic safety expenditure functions SOA_i as the product of the specific safety costs k_i and the socio-economic importance SOB_i of an activity i, i.e.,

$$SOA_i = k_i \cdot SOB_i = k_i \cdot WB_i \cdot \varphi_i \qquad (11)$$

We can now represent the optimization problem formally as follows:

The total socio-economic or weighted safety expenditures must be a minimum,

$$\sum_{i=1}^{n} SOA_i \; (R'_{gi}) = \min \; ; \text{where } R_{gi}{}' = \Psi_i \cdot R_{gi} \qquad (12)$$

It is a necessary condition here that the sum of all effective basic risk components shall be less than the socio-morally accepted total basic risk $R_{g_{tot}}$, i.e.

$$\sum_{i=1}^{n} R_{gi} = R_{g_{tot}}{}' \; * \qquad (13)$$

The solutions of equations (12) and (13) gives the socio-economic

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* It can be shown that all functions k_i are monotone and the optimum is then reached for $\Sigma R_{gi} = R_{g_{tot}}$. Otherwise we would have to put $\Sigma R_{gi} \leqq R_{g_{tot}}$.

optimum distribution of the basic risk among the n activities. This means that it is the most economical distribution, taking into account the subjective weighting factors ϕ_i and Ψ_i. A purely economic optimum (i.e. the cheapest possible) would be obtained by putting all ϕ_i and Ψ_i values equal to unity. The socio-economic optimum results in a more expensive (but socio-economically more acceptable) solution. In all cases, however, it is assumed that only technically and economically optimum solutions are considered; this means that all the solutions implied in Figure 7 represent minimum costs for each risk level.

In the above deliberations we have deliberately avoided any detailed discussion of how (by whom) the correct social values ϕ_i and Ψ_i are determined. (In this connection see, e.g., References 6 and 7.) In passing however, the following should be stated. The frequently encountered belief that such social utility functions are undeterminable (as may be true under certain circumstances, cf. Reference 6) and are therefore of no use, is like taking refuge from the rain under a downspout. We do in fact get closer to a desired solution when even the subjective value concepts are formulated explicitly (as trends) instead of leaving them barely recognized in the subconscious (cf. also Reference 8, page 10).

It will now be shown that the solution to the above optimization problem is obtained when the weighted marginal expenditures $\overline{SOA}_i \cdot \Psi_i$ are equal for all activities and the true basic risks do not exceed the given total $R_{g_{tot}}$; i.e.,

$$\overline{SOA}_i \cdot \Psi_i = \frac{d\ SOA_i(R'_{gi})}{d\ R'_{gi}} \cdot \Psi_i = \alpha = \text{const};$$

$$i = 1 \ldots n \tag{14}$$

and

$$\sum_{i=1}^{n} R_{gi} = \sum_{i=1}^{n} R'_{gi}/\Psi_i = R_{g_{tot}} \tag{15}$$

If we know the functions SOA_i, we can find the solution to equations (14) and (15) by successive approximation.

Condition (14) therefore represents the optimal solution, because in this case no juggling of risks and expenditures between different activities can bring a reduction in total expenditure without increasing the total risk. In otherwords, all activities must make the same weighted effort towards a reduction of risks.

It is true that we still lack, for the most part, the exact information on the specific cost-risk functions that would be needed in order to arrive at a demonstrably optimum risk distribution, i.e., according to the model of equations (12) and (13), (14) and (15). Nevertheless, considerable improvements over the (presumed) status quo could even now be achieved by approximate, partially subjective estimates of the functions k_i. Moreover, important generally applicable assertions can already be derived from the general characteristics of all k_i curves (Figure 8) and the influence parameters ϕ_i and Ψ_i.

In an activity system that is optimally balanced from the socio-economic standpoint with respect to risk, the admissible basic risk component R_{gi} of an activity i:

- Increases when the national economic importance of the activity WB_i *increases;*
- Increases when the socio-economic degree of priority ϕ_i increases;
- Decreases when the degree of care expected of the responsible party Ψ_i increases;
- Increases when the specific safety costs k_i increase.

3. <u>Summary and Conclusions</u>

The increasing prevalence of potentially dangerous activities in our society has two distinct consequences: a growing multiplicity and complexity of the various sources of risk, and a rising level of total risk. Therefore it is becoming ever more necessary to have analytical instruments at our disposal which could:-

1. Enable us to determine how the total risk level and its main components change with time, and
2. Provide a logical and rational representation of the relations between social-moral concepts of risk values and the decisions

that are made in the area of safety (or limitation of risks) which will correspond most closely to these value concepts, i.e., they must permit a rational monitoring of risks.

The analytical methods presented here are offered as a contribution in this direction.

Classifications of all kinds of dangers and the risks in the human environment associated with them according to various criteria are introduced. First we consider the overall framework shared between indirect hazards, such as water and air pollution, which have delayed effects, and direct effects such as traffic, etc.

Thereafter we confine our attention to the direct hazard category. For a quantitative scale of hazard we define the objective risk as the product of the probability and the effect of an event. The subjective experienced risk is the objective risk weighted with a subjective aversion function. References to risk determination in many activities are given. Using the aversion function, four different groups of events, namely accidents, misfortunes, catastrophes and disasters are introduced as concepts to each of which we assign different values of the aversion function.

The breakdown of the total risk spectrum into risk categories according to legal criteria plays an important part. For a comparison value the basic risk is identified as the most important category. It constitutes the component of the total risk that is morally and economically tolerated by society. Along with the basic risk we identify two other categories, namely, liability risk and personal risk. It is found that these concepts, especially the basic risk, are very useful for arriving at decisions in the planning stage.

By identifying three different kinds of values - economic-material, human life and cultural-ideal - it becomes possible to deal with each of these separately and logically in our analysis so as to assess the risks. This classification is necessary in order to maintain the homogeneity of the units; thus, the moral and economic values of a human life have to be dealt with separately.

Finally in Section 2.6 we take up the question of how to determine the safety requirements of various activities from the planning point of view so as to arrive at the most economical solution for a given total risk (human life). Subjective value concepts regarding the relative socio-economic desirability of activities and the liability expectancies of different institutions are simulated by specifically identifiable quantitative terms. This results in a clear general model of the relationships. The approximate distribution of the economic means available for risk reduction can be determined more or less rationally in accordance with the desired socio-economic value concepts. The utility of this model lies not in any automatic applicability, but in affording a better understanding of the existing conditions. The model could be used to uncover and correct possibly existing gross imbalances in our safety system.

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Table I

Representation of aversion in the form of classes of event

Class of event	Range of effects (Fatalities)	Aversion value (Examples)
1 Accident	1 - 2	1
2 Misfortune	3 - about 8 - 10	10
3 Catastrophe	About 8 - 10 to "a few dozen"	100
4 Disaster	More than "a few dozen"	1000

Total biophysical endangering of the human living space

Direct or short-term hazards

- Traffic (road, air, etc.)
- (Earthquakes and other natural events)
- Collapse of structures
- Explosions
- Nuclear power plants
- Sport
- (War)
- etc.

Indirect or long-term hazards

- Population explosion
- Air and water pollution
- Depletion of raw materials
- (War)
- etc.

Fig. 1

Classification of hazards as direct and indirect

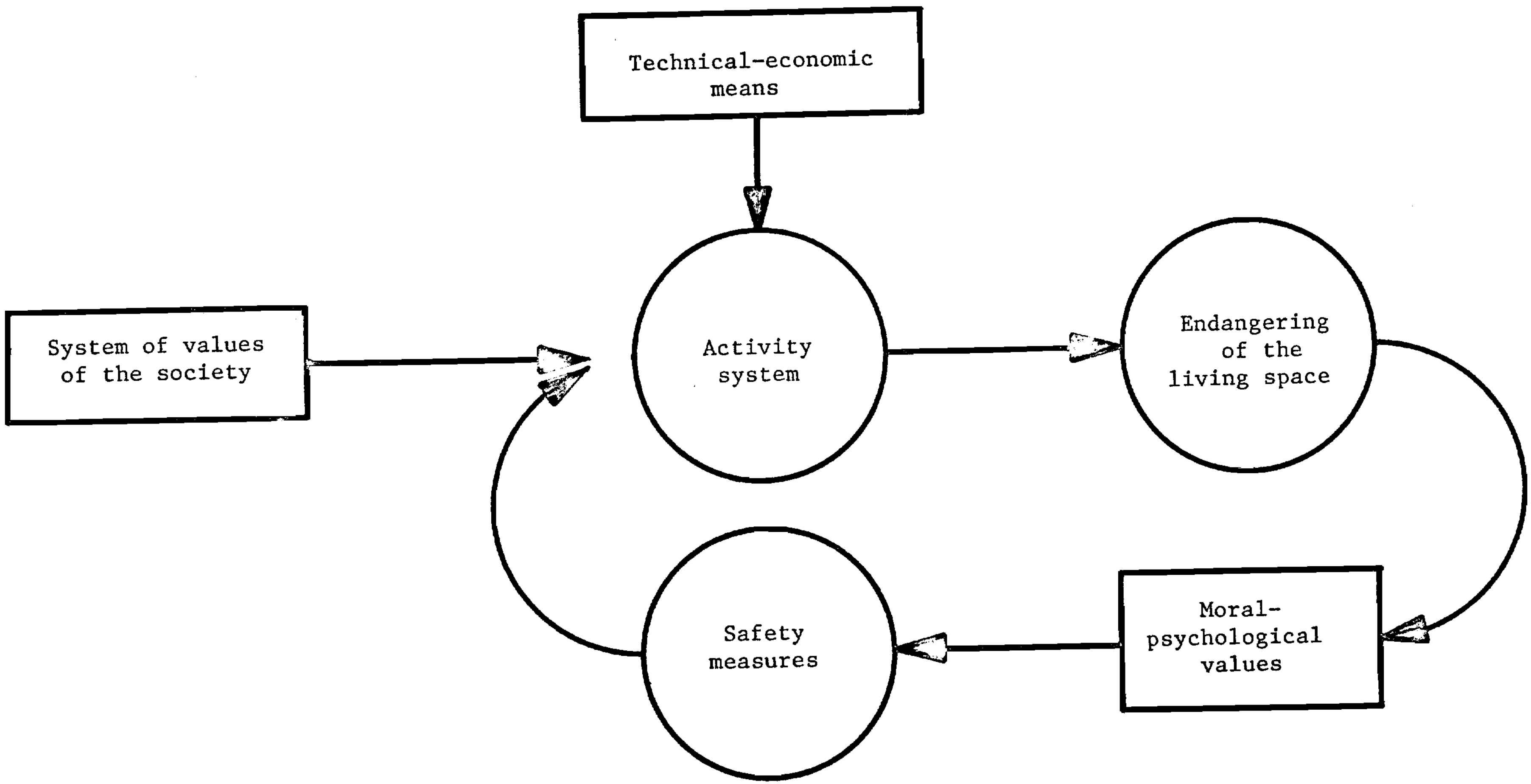


Fig. 2

Influencing the activity system
by moral-psychological values
results in a social optimum

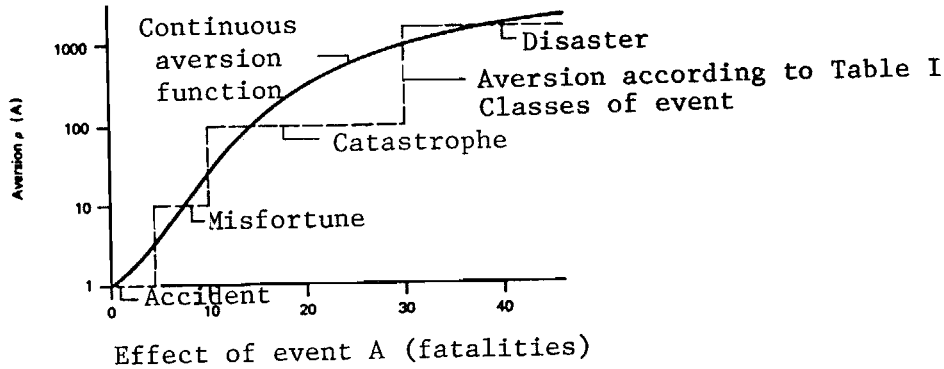


Fig. 3

Example of an aversion function ρ(A) plotted against the effects *A* of an event

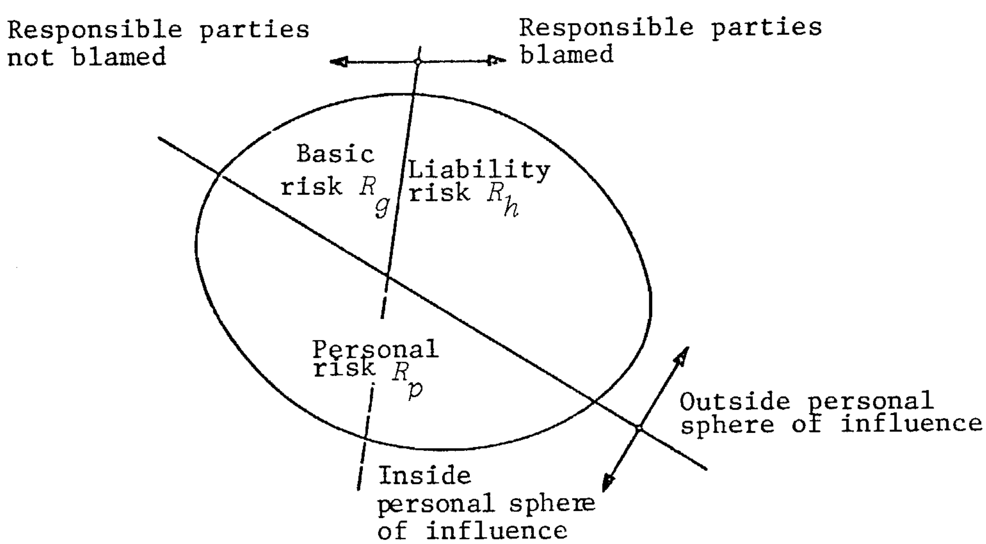
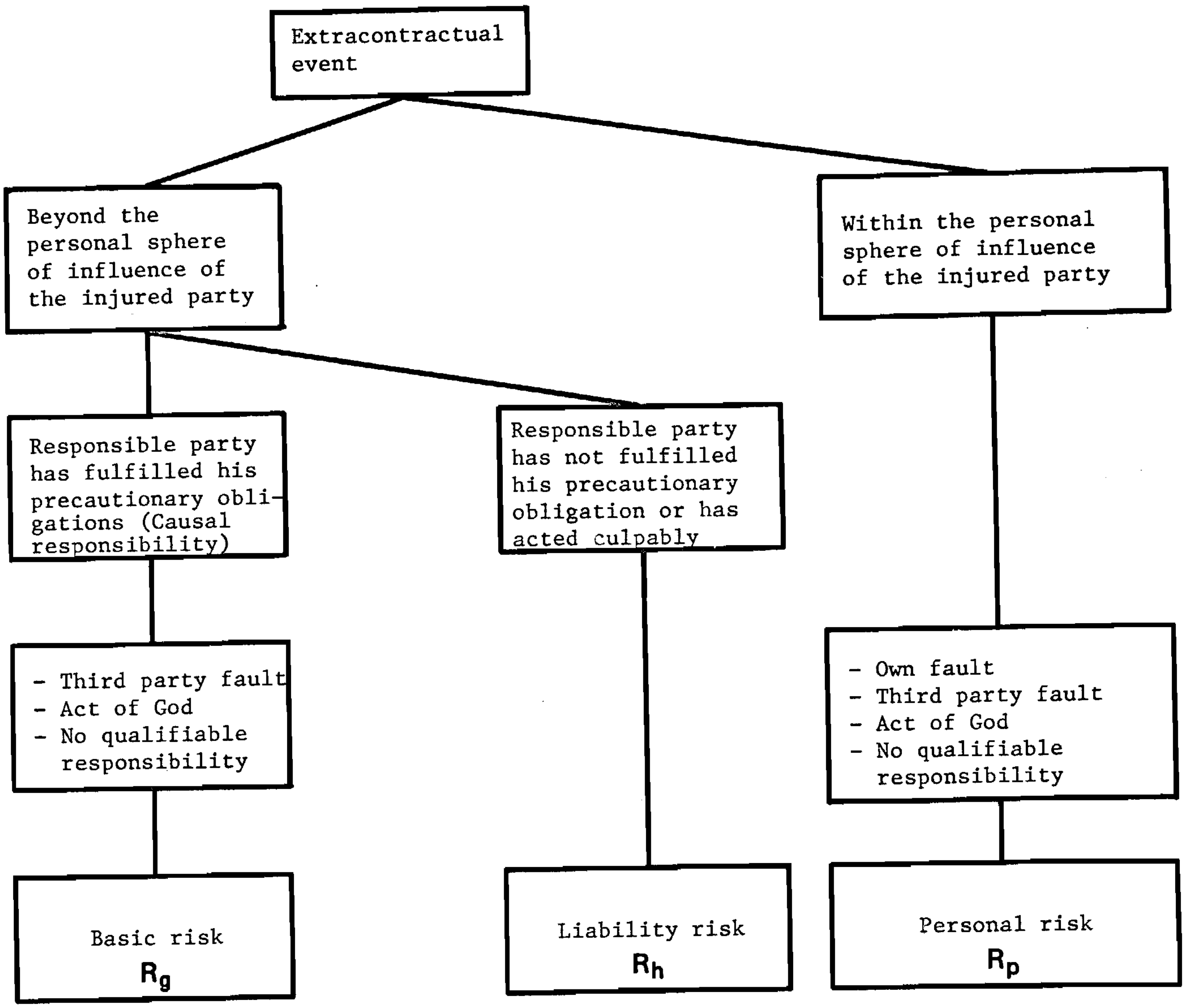


Fig. 5

Graphical representation of risk categories



Total risk $R_{tot} = R_g + R_h + R_p \qquad (7)$

Fig. 4

Scheme of risk classification

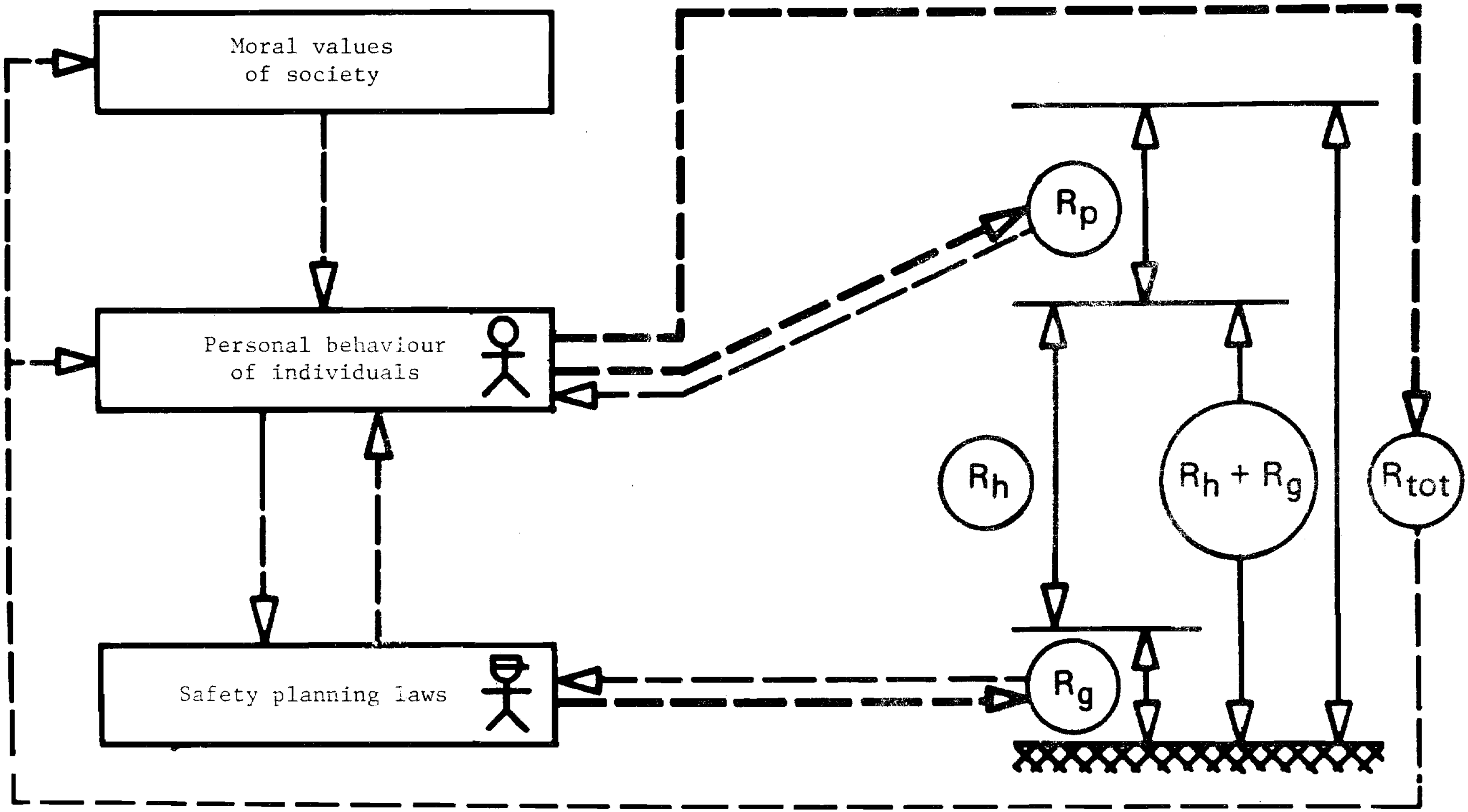


Fig. 6

Reciprocal influencing of laws,
personal behaviour and
risk categories

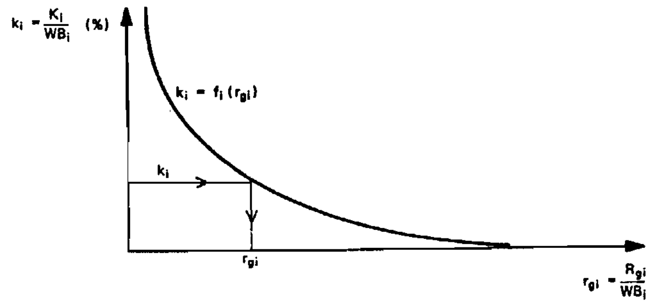


Fig. 7

The specific safety- (or risk-) cost function of an activity, k_i, gives the expenditures for safety that are compatible with the economic importance of an activity as a function of the attained (standard) basic risk of this activity

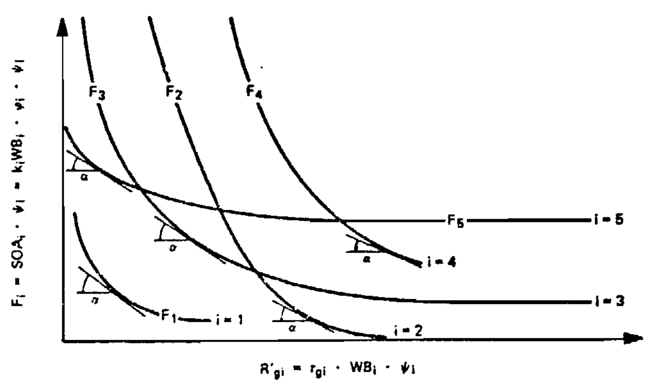


Fig. 8

Weighted socio-economic safety expenditure functions F_i plotted against the weighted basic risk component R'_{gi}. In the optimum solutions the weighted marginal expenditures are equal for all activities (=α)