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RISK IN TECHNOLOGY AND TRANSPORT - MODELS AND INDICATORS

The risk associated with any form of human activity has become currently one of the most important research categories. There is no explicit mapping studies of risk to a particular field of knowledge. Kind of risk is defined by associating with the kind of consequences (loss). In the study of risk appear methodological discrepancies already from the very beginning, i.e. at the level of interpretation, models and indicators. Need a reminder of this topic was the first motivation to write this paper.

RYZYKO W TECHNICE I TRANSPORCIE - MODELE I WSKAŹNIKI

Ryzyko związane z każdą formą aktywności człowieka - stało się aktualnie jedną z najważniejszych kategorii badawczych. Nie ma jednoznacznego przyporządkowania badań ryzyka do określonej dziedziny wiedzy. Rodzaj ryzyka jest definiowany poprzez skojarzenie z rodzajem konsekwencji (strat). W badaniach ryzyka pojawiały się rozbieżności metodologiczne już od samego początku, czyli na poziomie interpretacji, modeli i wskaźników. Potrzeba przypomnienia tego ważnego tematu była głównym powodem do napisania referatu.

1. INTRODUCTION

As noted long ago: "*human danger, by a technical activities (...) the easiest way you can capture in a reasonably way as stochastic values product: the probability of the occurrence of dangerous phenomena and the size of the harmful effects. So defined value can be regarded as an objective risk by technical activity* ", [1]. This simple but profound observation, which has initiated development of risk analysis methods.

Nothing happens without risk; agreeing to any risk, you should put an important and somewhat perverse formulated question: how safe is safe enough? [2]. This question concerns the principles for evaluation of risk and is an important "dilemma breakdown " ("sharing dilemma"), [3]. In this sense, it is also one of the main problems of risk management.

The proper functioning of transport systems depends to a large degree on efficient management. It should cause the transport was highly functional, pro-ecologic, economically optimal and, above all, safe. Effective management of safety is management by objectives, i.e. the kind of management system, which basic principle is: "we manage

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safety" by "risk management". Need a reminder of this topic was the first motivation to write this paper.

2. RISK IN THE METHODOLOGY OF SCIENCE

The risk associated with any form of human activity has become currently one of the most important research categories. There is no explicit mapping studies of risk to a particular field of knowledge. Kind of risk is defined by associating with the kind of consequences (loss). If you want to compare the risk in carrying out similar tasks the point of reference are the advantages/benefits interpreted as one of the measures of risk exposure. For example, in the transport of such benefits measure is the product of: "the size of the cargo x distance". The risk may be related also to other measures of exposure: the time which elapses, the distance traveled, etc. Discussion of risks always refers to the man. This approach extends the framework of research on the risk - takes account of the psychological, sociological, economic, legal and administrative aspects and political risks of the activity of human activity. With risk is related the problem of its value. The risk is the effect of changing technology, social development, social and legal norms. Therefore, there is no commonly acceptable level of risk, however there are different acceptable limits that depend on the possibility of financing risk reduction, sometimes (unfortunately) a political calculation and administrative restrictions. In the study of risk appear methodological discrepancies already from the very beginning, i.e. at the level of interpretation. Another question, is the lack of consistency in the methodology of risk assessment; a lot of risk indicators is defined without a deeper theoretical justifications. Today there are many contentious areas for research on risk; you need to include, inter alia: 1. relation to new technologies and new threats. 2. the global nature of the changes in the world. 3. responsibility for decisions to bear the risks and policy risks.

There are four basic sources of errors in risk assessment: 1. error relating to the interpretation and risk models; 2. empirical data error (statistical); 3.estimation of losses error; 4. the error of measurement of risk assessment. Essential characteristics of the risks are [4]: 1. source and purpose of risk; 2. possible implications of the risk; 3. take risks; 4. Risk realization; 5. possibility of tampering risk.

Clarifying the question of danger man, by the technique Thomas A. Jaeger returns (as one of the first) he operative definition of "technical risk”. He finds that considering the hidden risk in the potential threat by engineering systems, requires the introduction, the concept of technical risk, which can be grasped in a reasonably way as a product of stochastic rate: “the probability of the occurrence of dangerous events” and "the size of the harmful effects" [1]. It appears that the fact of presentation of risk affect on its perception by society, which uses in various promotional activities of safety. The risk is that concept, which is easy to manipulate. In the literature on the subject exists the concept of "magic circle of risk protection", [5]. It equates to string of the following implications: (1) uncertain data in risk assessment procedures; (2) inaccurate estimate of the risk; (3) fear of experts before risk underestimation; (4) experts overestimate the risk; (5) social reaction against excessive risk; (6) decision makers require stringent standards and regulations for controlling risk; (7) uncertain data in risk assessment procedures etc.

3. THE BASIC MODEL OF THE RISK

Probabilistic risk analysis based on the model, in which the risk R is interpreted as an ordered triple of parameters:

$$R = (S, P, C) \tag{1}$$

where:
S - scenario of accident ; P –probability of scenario realization S; – consequences (losses) of accident.

Quantification of risks is most often given multiply form of dependency P and C:

$$R = P \cdot C \tag{2}$$

This risk model can be used in different ways, depending on the interpretation of the size C and P.

Risk indicators belong to quantitatively and qualitative induction methods of risk assessment. The likelihood of adverse effects of the events is written as a function of parameters of relevance in assessing risk. In the indicator methods assessing at least three parameters of risk; most often these are: E - risk exposure; P - probability of adverse events; G – elimination factor or reduction of risk; I - is the number of exposed persons. Parameter values are expressed by using different scales of quality. Risk level (category) is due to count the product of the risk parameter values. The general risk measure used in indicatory risk analysis methods is described [6]:

$$R = \text{function}(S, E, P, G, I) \tag{3}$$

Here are three sample risk indexing methods.

Risk Score method, [7]: risk ratio R = S x E x P, where: S - potential effects (loss) of the event (6-stages scale); E - exposure to danger (6-stages scale); P - probability of adverse event (7-stages scale). The method gives two different 5-stages scales of risk evaluation, and five activities of risk reduction.

Five steps to risk assessment method: risk ratio R = P × F × S × I, where: P - probability of adverse events (8-stages scale); F - frequency of exposure (6-stages scale); S – effects (consequences) of adverse events (7-stages scale); I - the number of exposed persons (4-stages scale). The risk is assessed 4-stages scale.

The risk indicator WPR: risk indicator *R = A x B x C x D*, where the risk parameters are: A - probability of adverse events; B - frequency of the exposure; C - type of injury; D- range of damages. The first three parameters are estimated in 7-stages scales, and the last in 5-stages scale. The risk is assessed in 8-stages scale.

The level of risk is a function of increasing exposure of danger and the intensity of danger carrier. Danger exposure is the issuance (of the object) on destructive activity of coercive agents – i.e. exposing. A natural measure of the risk consequences is time: for example, in road traffic individual risk of accident rises with an increase of travel time and the increase of traffic. Often as a period of exposure is assumed 1 year of the H-T-E system functioning. In aviation is used a reference to 100 thousands hours of flights. Occupational risk refers to 100 million hours of operation [8].

One of the important issues in the construction of risk models is modeling the relationship between: (1) risk exposure E; (2): accident risk A/E; (3) injury risk I/E. And here is a simple model illustrating the issue:

$$\text{Vol (I/A)} = \text{E} \cdot \text{(A/E)} \cdot \text{(I/E)} \tag{4}$$

Here Vol (I/A) is a measure of consequences (loss) of the accident. Notice that in above model A/E factor corresponds to the concept of active safety and the I/E factor of passive safety. It is essential to define the measurement of threat exposure E.

4. RISKS AND ITS MEASURES AND INDICATORS

Mostly risks are classified according to the criterion of the consequences as are the effect of adverse events in considered system technique: thus, you can talk about the following types of risk:
1. individual risk (IR) and societal risk (SR) - risks of fatalities; 2. economic risk; 3. environmental risk; 4. integrated risk (total risk); 5. the potential consequences of a hazardous activity, [9].

4.1. Individual risk

Formula (2), is an example of individual risk measure. It refers to a case where pm unit of time undergoes only one adverse event (leading to a loss) and this event relates to one person, or if the frequency of such events is low enough that the simultaneous occurrence of several such events may be suppressed. The average risk value relative to the group of N people, expressed in units of loss (e.g. monetary) per unit of time - describes the level of expected risk for a group of *N* people in a unit time. If on area a group of *N* people is threatened, then you can talk about societal risk. Then the expected value of the potential loss *C*, during the interval *Δt* can be calculated with the formula [10]:

$$\text{E(C)} = \int_{t}^{t+\Delta t} C dF(C) \tag{5}$$

where *F(C)* is a distribution of probability variable random of *C*. Then the general formula of individual risk IR calculation is as follows:

$$\text{IR} = E(C)/N \cdot \Delta t \tag{6}$$

From the above formula it is clear that the individual risk is defined as the expected loss *E(C)* (expressed as the number *N* of fatalities, injuries, monetary value) to be converted into a single person and unit time *Δt*. You can also define individual risk somewhat differently: as average annual probability of the death of a man who found itself in a point of danger which comes from industrial installations. Usually the value of IR = 10^{-6}/year is accepted. When you put on a map of the area around the industrial installation value of individual risks – then we get a geographic distribution of risk around this setup. The lines connecting the points (around installation) with assigned the same value of the individual risk are called isolines (contour lines) . Danish definition of IR used in area planning is as follows:

IR is defined as “the probability that an average unprotected person, permanently present at a certain location, is killed due to an accident resulting from a hazardous activity”, [9]. Different measures of individual risk are described in the work (Bedford & Cooke, 2001).

In transport risk management, you can use some of the known characteristics and individual risk measures, such as: 1. the loss of life expectancy; 2. the delta yearly probability of death; 3. the fatal accident failure rate (FAFR), of which the variant is the death of per unit activity. These characteristics quantify the risk of car trips, train, aircraft, calculated per kilometre of journey. A long list of measures of various kinds of risk are provided in the work [9]; the bibliography focus.

If you want to show the level of individual risk in the area around hazardous installations, for example, transport routes, showing a map of this area with the selected so-called risk contours (sense of isolines). Such maps are used for spatial planning.

In the Netherlands, shall be adopted in spatial planning and environment protection, the following standard for populated areas [11]: IR < 10-6 (per year). The risk of higher order should be reduced by one of the known criteria such as ALARA (as reasonably achievable). In turn, in the method of TAW is proposed a wider range than voluntary after involuntary risk. There is proposed the following standard [9]: $IR < \beta \cdot 10^{-4}$ (per year); Here, β is the value of the policy factor, depending on the degree of voluntary activity and the expected benefits.

4.2. Societal risk

Societal risk shall be calculated as the average of group of *N* concerned people. By analysis about an individual risk, you must always specify which group of people is this average. Individual risk does not give information about the possible number of casualties among *N* people in the analyzed vulnerable zone. This is why it is necessary to assess SR. For a group of *N* people, it shall be calculated by the formula:

$$\mathrm{SR} = E(C)/\Delta t \tag{7}$$

Societal risk is expressed in units of C consequences (e.g. monetary units) per unit time Δt. This describes the level of expected risk for a group of N people in a unit time Δt. There is here an obvious relationship between IR and SR:

$$\mathrm{SR} = N \cdot \mathrm{IR} \tag{8}$$

4.3. Risk fields

In wider preventive safety technology are implemented strategies for people risk-oriented who residing in the vicinity of the technology installation. Then is considering the "risk fields" appearing around such installations. Then is useful the concept of "impressed" risk field" *R(r)*, which should be everywhere less than fixed maximum admissible R_{adm}:

$$R(r) \le R_{adm} \tag{9}$$

for all the positions (of coordinates) r

The formal record of the strategy for limiting societal risk SR of people residing in the vicinity of technological installations must be topped up the second condition [10]:

$$\text{SR} = \int R(r) \cdot B(r)df \leq R_{adm} \cdot 100\, persons \qquad (10)$$

With this formula shows that the expected value R(r) must be not greater than 100 times the value of the acceptable risk R_{adm} within a radius r from technical installations; density of population B (r) denotes the function of density distribution of the random variable B (population) in the area around the installation. Admissible base risk R_{adm} coming from a single technical installation may not be, however, absolute base risk. It must be assumed that in many cases the man threatens several technical installations simultaneously. Therefore, the risk R_{adm} accepted in a case of a single technical installation will have to be lower. Admissible base risk is also assigned to important areas of life such as work, road traffic, household and leisure time. There is introduced the concept of relative risk here RR, which is defined as the quotient of the real risk (designated from the statistics of accidents) and the acceptable base risk for a given area of human activity. Here are some of the estimated value of risk R_R: work (1.4), household (1.7), transport (2.4).

Next measure SRI is scaled risk integral (SRI), [9]:

$$\text{SRI} = P \cdot IR_{HSE} \cdot T/A, \text{ where } P = (n+n^2)/2 \qquad (11)$$

where IR_{HSE} is the individual risk per million year (cpm), as defined by The British Health and Safety Executive (HSE); *T* the share of time the area is occupied by *n* persons; *A* the surface of the area in hectares; *P* the population factor and *n* is the number of persons in the area.

4.4. Risk integral (RI)

Among few popular proposals of risk measure risks it is worth noting introduced by HSE a weighted risk integral parameter called the risk integral (COMAH) (RI_{COMAH}), [9]:

$$\text{RI}_{\text{COMAH}} = \int_0^\infty x^\alpha \cdot f_N(x)dx \qquad (12)$$

The coefficient $\alpha \geq 1$ is a measure of social perception of risk aversion in respect of accidents with a large number of fatalities.

4.5. Perceived collective risk (Rp)

This measure is described using the following formula, [11]:

$$\text{R}_\text{p} = \int_0^\infty x \cdot \varphi(x) \cdot f_N(x)dx \qquad (13)$$

where φ(x) is the risk aversion, a function of the number of fatalities *x*. Measure R_p is used to count the expected value of the number of fatalities E(N) as weighted-average; weight is a risk aversion function φ(x).

4.6. Environmental risk measures

One of the measure here is the probability of exceedance of the time needed by the ecosystem to recover from the damage, [12]:

$$1 - F_T(x) = P(T > x) = \int_x^{\infty} f_T(x)dx \qquad (14)$$

where $F_T(x)$ is probability distribution function of the recovery time; $f_T(x)$ probability density function of the recovery time of the ecosystem.

4.7. Integrated risk measures

It is about of total quantitative description of the different types of consequences (C). Due to the fact that the consequences C may have a different rank (weight) for the analyzed system is introduced the coefficient K (K ≥ 1) rank of the consequences. If you mark the by Pi, Ci, n - respectively: the probability of an accident and is of i-type and related with it consequence C_i and the number n of all types of accidents that may happen in the analyzed system, then it can be defined the measure of risk - based on "the theory of utility"; this measure is a linear superposition of components of P_i and C_i [13]:

$$R = \sum_{i=1}^{n} P_i \cdot C_i^K \qquad (15)$$

Another proposition presented [11]; it relates the monetary collective risk (*R*m):

$$R_m = \sum_{i-1}^{n} P_i \cdot C_i \cdot \varphi(C_i) \cdot \omega(i) \qquad (16)$$

where P_i - the probability of scenario i; C_i - the consequences of scenario i; $\varphi(C_i)$ - the risk aversion as a function of the consequences C_i ; ω(i) - the willingness to pay for measures to prevent scenario i.

In the above formula are noted: individual risk and societal risk and economic risk. Value R_m can be expressed in monetary terms and interpreted as a willingness to pay for any scenario leading to the consequence $C_{i.}$ This type of measure of the risk was used, inter alia, to analyze the safety of the transportation of dangerous goods.

4.8. Economic valuation of human life

An important issue in the risk management is the monetary valuation of human life. In transport it is connected with the valuation of external costs of transport accidents. In the literature that shows different methods of valuation of life. Frequently are used the following approach: 1. macroeconomic valuation; 2. comparative approach; 3. approach by utility theory; 4. contingent valuation. This last method allows to calculate the value of a statistical life (VoSL) by comparing the willingness to pay (WTP) and the expected number of fatalities *E(N)*:

$$\text{VoSL} = (WTP \cdot population)/E(N) \qquad (17)$$

5. ROAD SAFETY RISK INDICATORS

Measurable effects of risk in road traffic can be a variety of size, and the general definition of road safety risk indicator is as follows:

$$risk = RSO/E \qquad (18)$$

where: RSO - road safety outcome; E - amount of exposure (risk exposure). By such interpretation - risk indicator shows how many adverse events (for example road accidents) fall on unit of exposure (exposing themselves to risks in road traffic). Which means that in the same exposure E, the risk is increasing function of RSO. Which is of course not revealing, but you should understand the regularity.

Because road accidents are "product" (final outcomes) of a road traffic system - therefore RSO is typically the number of accidents or casualties (fatal accidents, accidents with hospitalised or fatally injured victims, fatalities, persons injured). However, interpretations of risks exposure E are based on different sizes; the selection must be dictated by such features as: availability, comparability and usability of risk and exposure data. Due to the fact that to estimation of road risk, you can use different size of RSO and E, the number of road safety risk indicators is big [14], [15]. Let us take, for example, the accident rate: "Accident rate (collision rate) — The number of accidents (collisions) per unit of exposure. For an intersection this is typically the number of accidents divided by the total entering Annual Average Daily Traffic (AADT). For road sections this is typically the number of accidents per million vehicles per kilometers or miles traveled on a section", [16]. Very similarly defines Safety Performance Function (SPF). This function expresses the relationship between the sizes of the AADT and the safety of the road; it is defined as the number of accidents per unit of time and the length of road [17].

Indicators of risk in road traffic can be also found in the group of indicators for sustainable transportation planning. These indicators are its role in creating policies of planning sustainable transport. A lot of information about this type of indicators yields, for example, publications [18].

6. CONCLUSIONS

An important question is the understanding of the relationship between risk and safety. There are definitions of safety, which dispense with the concept of risk, such as the definition of British Standard EN 292. Other definitions of safety use the concept of risk, for example: *safety is the lack of risk or protection against risks* [8], [19]. *Quite often is understood: safety as such a state of system, H-T-E, where the risk is less than some limit risk*. This interpretation leads to the question of the evaluation of risk, i.e. the determination of acceptable risk limit, below which the system is safe. There are many interpretations and definitions of the term "risk", [20]. Here are a few of them:

• risk: the combination of the probability of an event and its consequence. (Risk) Source – item or activity having a potential for a consequence, [21];

• risk: "…the possibility of something happening that impacts on your objectives. It is the chance to either make a gain or a loss. It is measured in terms of likelihood and consequence", [22];

• risk: effect of uncertainty on objectives, [23].

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