Article

The importance of the human factor in the safety at the transport of dangerous goods

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Abstract: The article discusses the issues related to the safety of transport of dangerous goods by road. Research on accidents in transport unambiguously points to the human factor, which is most responsible for causing the accident. Determining the causes of driver unreliability in the human-vehicle-environment system requires thorough research. Unfortunately, in this case, experimental research with human involvement is limited in scope. This leaves modeling and simulation of the behavior of the human factor, i.e., the driver transporting dangerous goods. The human being, due to its complexity, is a challenging element to parameterize. The literature presents various attempts to model human actions. In their work, the authors used heuristic methods, specifically fuzzy set techniques, to build a human factor model. In these models, human actions were specified using a verbal or linguistic description. The specificity of fuzzy sets allows to "naturally" limit the "precision" in describing human behavior. The model was built based on the author's questionnaire and expert research, based on which individual features were selected. Then, the traits were assigned appropriate states. The output parameter of the model is λ_L - the intensity of human error. The obtained values of the intensity of the accident caused by the driver's error were implemented into the author's method of risk assessment. They constituted one of the factors determining the probability of an accident in the transport of dangerous goods, which allowed to determine the optimal route of transport of these goods characterized by the lowest risk of an undesirable event on the route. The article presents the model's assumptions, structure, and features included in the model, which have the most significant influence on shaping the intensity of human error. The results of the simulation studies showed a diversified effect of the analyzed characteristics on the driver's efficiency.

Keywords: Human factor, hazardous materials, transport, safety

1. Introduction

The rapid development of transport has, on the one hand, increased the mobility of people and the transportation of goods, but, on the other hand, it has become one of the greatest threats of the 21st century [1-3]. That is why, in recent years, priority has been given to measures aimed at ensuring safety in both passenger and freight transport, and, in the latter case, in particular, the transport of dangerous goods. The package of measures includes: implementing relevant normative documents, obtaining certificates according to ISO standards, setting up non-governmental institutions to ensure safety and control in transporting dangerous goods.

The Strategic Road Safety Action Plan of the European Commission for 2021-2030 is aiming to achieve zero road accident victims by 2050 ("Vision Zero") [4]. There are many examples from all over the world of accidents or disasters involving dangerous goods in literature [5-10]. In Poland, an average of 100 road accidents per year occurs in the transport of this type of goods, with more than 1,000 accidents in 2010-2019. Accidents involving tankers represent, on average, about 75% of all accidents per year. This trend remains stable and may even increase, as forecasts for the coming years show that truck traffic will increase [11]. Accident records kept by various state institutions, such as Transportation Technical Supervision, Fire Brigade, or Police, indicate human factor as the main cause of errors leading to an accidents, in addition to other reasons: technical condition, infrastructure, or weather conditions. Apart from accidents or environmental disasters, there is often an uncontrolled release or unsealing of tanks, which in extreme cases may lead to a state of emergency or crisis in the area where it occurs. Statistics show that in Poland, 88-90% of dangerous goods are transported by road and only 10-12% by rail. Whereas in the EU, the transport of hazardous goods is as follows: inland transport (ADN) - 6.8%, by rail (RID) - 27.4%, by road (ADR) - 65.8% [11-12]. On the map of Poland, there are places characterized by high intensity of accidents and incidents in road transport, including those involving goods with, particularly hazardous properties. Particularly problematic places occur in four provinces: Małopolskie, Śląskie, Podlaskie and Lubuskie. This is due to the location of chemical plants and the consequent increase in road traffic with dangerous goods. Dangerous goods in the 21st century can also be a weapon in the hands of terrorists. In July 2016, a terrorist of Tunisian origin drove a tanker truck into a group of people on a promenade in Nice, taking the lives of 87 people. Other such incidents or possible threat scenarios have been written about, including [13-14].

From an analysis of the available literature and press reports, it appears that the carriage of these goods poses a significant hazard on the roads [15-18]. While the number of accidents is low compared to accidents involving passenger vehicles, the losses and danger are incomparably higher. Therefore, it is extremely important to have a comprehensive approach to analyzing the causes of dangerous events, taking into account the main elements of the transport process: man - driver, technology - vehicle, and environment. Since man is the weakest link in the system and at the same time the most important one, he is the one who should be given the most attention, followed by the other elements, assuming that each of them is more or less likely to cause accidents resulting in human losses.

The concept of human factors, and their importance to the safe performance of tasks, was recognized during World War II when it was recognized in the British Air Force that losses incurred in combat with the enemy were comparable to losses that resulted from a variety of human errors [19]. Chapanis first wrote that 'pilot error' was the result of several components and could arise from poor control panel design. This was a challenge to contemporary thinking and highlighted the importance of design in reducing human error [20].Three approaches currently dominate the human error literature. These are Norman's (1981) error categorization, Reason's (1990) classification of errors and violations, and Rasmussen's (1986) classification of skill, rule, and knowledge errors. In road transport, Rasmussen's theory is the closest, stating that the whole system and not just the operator performing the activity must be taken into account when analyzing an error that has occurred [21-27]. The systems approach maintains that most errors made in complex systems are caused by hidden or error-producing conditions (e.g., inadequate equipment and training, poor design, maintenance errors, ill-defined procedures, etc.). This approach is particularly important in road transport.

Similarly, Wierwille et al., addressed the nature of error making systemically. He identified four basic groups of accident causation factors: human conditions and states (physical/physiological, mental/emotional, experience/exposure), direct human causes (recognition errors, decision errors, execution errors), environmental factors (highway-related, ambient conditions) and vehicle-related factors [28]. The driver-operator being part of the system may make errors: strategic errors - resulting mainly from a wrong decision made by the driver (e.g., concerning driving in difficult weather conditions, inoperative vehicle or driving in an inappropriate physiological or mental state), tactical errors - resulting from inappropriate vehicle maneuvers while driving, and operational errors - resulting from lack of appropriate driving skills.

One of the theories for understanding human-driver behavior on the road in such a system is Ajzen's theory of planned behavior (TPB) [29]. It explains driver decision-making as a result of intention and motivation. Therefore some behaviors are unplanned and sometimes irrational and result in accidents and related losses.

The driver in the system has a range of tasks to perform and is additionally loaded with a lot of information. A huge number of different stimuli reach the driver while driving. It is estimated that on a low-traffic urban road, it can be 5 stimuli per minute, while in dense urban traffic, even 120 stimuli in 1 minute [30].

In relation to the problem, the authors defined the system as a set of three elements: the driver transporting dangerous goods, the vehicle - a tanker for transporting dangerous goods, and the environment, i.e., the material working environment (D-V-E). The D-V-E system has specific tasks that are performed in the process of transporting dangerous goods. Due to the wide range of duties and the high level of responsibility for the transport of dangerous goods, the driver is required to have a good knowledge of the regulations in the area of the goods transported and to be conscientious and accurate in carrying out his/her work. However, despite mandatory training, the driver, as the weakest link in the system, makes mistakes due to: the adaptation to work, the equipment of the workplace, and the state of the environment near and far.

Human error is therefore one of the main factors adversely affecting the road traffic safety. As statistical data show, the defects of means of transport constitute a second most important group of issues influencing the abovementioned problem. The most popular vehicle used for transportation of hazardous materials is a tank truck. Its common use results from the development of motorization and growing demand for such fuels as gasoline, diesel or natural gas. Tank trucks receive road corridor permits from the Transport Technical Supervision. It should be emphasized that creation of a faultless DVE system is practically impossible, despite the supervision of technical devices and numerous compulsory trainings for drivers. Tank truck transportation of hazardous goods poses certain risk for a man and it is impossible to rule out the probability of an accident. Thus, the interactions within the DVE system should be analyzed and, based on the results, preventive measures should be adopted in order to reduce the risk within the transportation chain of hazardous materials.

The above mentioned arguments have become an inspiration for elaboration of a new risk assessment method that takes the human factor into consideration and is intended for analysis of transportation of hazardous goods. Consideration of the human factor as a key cause for an accident overcomes a shortcoming of the method, since, as we may read in the literature [31- 43], no complex risk assessment method including human factor has been elaborated so far. In this article the main concept of the method described in the next paragraph was presented, with the focus on human factor modelling and its role in transportation of hazardous materials. Heuristic techniques – particularly, fuzzy set methods – were used in the assessment of human-driver.

2. Materials and Methods

In Poland there is no such a thing as a recommended risk assessment method that would take into consideration the specific nature of this kind of transportation. Statistical data that have been gathered for many years show that the majority of accidents taking place in Poland are caused by driver’s mistake. This tendency is also present in other types of transport. The above described situation became an impulse for carrying out a research on a new approach to the analysed issues, taking into account numerous factors determining the level of risk in the process of transportation of hazardous materials. These factors include: human factor (the most important one), technical factor (vehicle), environmental factor (workplace material environment), road factor, as well as a factor related to traffic intensity around fuel storage centres and refineries. Additionally, the method emphasizes the problem of human-driver fatigue, which limits his efficiency and, consequently, decreases the level of road safety [44].

In the method it has been assumed that fatigue increases with time. The above premises were, therefore, the basis for undertaking research concerning a new approach to the problem in question, taking into account the many important factors influencing the level of risk in the process of transporting dangerous goods. Among them, one can distinguish: the most important one - the human factor, as well as the technical factor, i.e., the vehicle and the ambient factor, i.e., the material environment at the workplace, moreover, the road factor and the factor related to the intensity of vehicle traffic at fuel depots or refineries. In the proposed method, particular attention was also paid to the problem of human-driver fatigue, which affects the reduction of efficiency and, consequently, road safety [44]. An obvious assumption was made that fatigue increases with time. Actions aimed at minimizing the risk consisted in selecting the optimal route for the transport of dangerous goods, burdened with the least risk and thus the least losses. Due to the characteristics of the goods transported, losses may be of various types: human, ecological, and, as a result, financial.

In the analysis the risk was calculated as a product of the probability of an accident and the value of losses. An accident may lead to different scenarios of its consequences and in the analysis they were interpreted as follows: an overturn of the vehicle with no additional consequences, an overturn of the vehicle with a leak, an overturn of the vehicle with a leak and a fire, an overturn of the vehicle with a leak and an explosion. The risk assessment model required the following assumptions:

1. to select factors of different nature (human, technical, environmental) affecting the probability of accident occurrence,

2. to take into account the influence of driver error on the probability of accident occurrence by means of a human factors model based on fuzzy set techniques,

3. build a heuristic model to determine the severity of the accident due to human error. The model was developed based on factors considered "relevant" - generated from the analysis of the specificity of the system operation, procedural requirements of the type of transport in question, analysis of accident causes and original surveys of drivers,

4. division of the transport route into sections of different length (rectilinear or curvilinear),

5. to develop for each road section, defined according to the permissible speed limit, a road route environment

6. definition of parameters of the intensity of accidents caused by the technical condition of vehicles, other road users, driver fatigue, traffic density,

7. the value of intensity parameters λ were assigned to consecutive sections of a specified length, and the probability of occurrence of accidents caused by the above parameters was determined

8. definition of criteria enabling the categorization of human, ecological and as well as financial losses,

9. assigned to each event scenario the level of human, ecological and financial losses,

10. determination for each categorized section of the sub-risk and the corresponding measure of loss value,

11. construction of a simulation model enabling the selection of the route for the transport of dangerous goods from the start point to the endpoint in terms of minimization of human, environmental well as financial losses, whereby the route consists of different sections defined in points 5 and 6.

12. simulation studies

13. verification of the model on selected actual transport routes of dangerous goods

A simulator, based on the Breath First Search algorithm, was developed for the model, and a number of simulation experiments were carried out to select the optimal route depending on the objective function set, which is to minimize human, environmental or financial take-offs.

The proposed method is a new approach in the field of risk assessment in the transport of dangerous goods. It allows not only to generate the optimal route for the transport of dangerous goods, taking into account the influence of individual factors on the probability of an accident, i.e., the human factor, driver fatigue - which changes with time, technical factor /vehicle/, road factor, but it also estimates the risk and is strictly parameterized, which in turn allows it to be used for the transport of all classes of dangerous goods.

2.1 Human factor in the transport

The profession of a driver-operator falls into the category of difficult and dangerous ones (ADR 2019-2021) [45]. In the road transport system human factor plays decisive role and has two functions: performs as a co-author of road traffic and as a road user. The driver carrying hazardous materials is exposed to numerous factors, which deteriorate his ability of job performance and even lead to deterioration of his health. Driver's safe functioning within road traffic systems much depends on his psychophysical characteristics, social adaptability, driving etiquette and his ability to deal with complex situation, such as driving a vehicle. Carrying out test verifying drivers' vocational usability (the so called "professional selection") is a duty of specialized services [46-47]. Methods of such a selection are thoroughly developed. The final decision to offer a job is made based on required documents and appropriate professional courses certificates, medical examinations and observation during trial period. According to the literature, selecting only those drivers with certain predispositions is a highly effective method of reducing the risk of accidents in the transport of hazardous materials.

Professional profile of the driver carrying hazardous goods includes the following [46-47]:

1) Sensorimotor efficiency:
a) Critical features: visual acuity, colour sensitivity, stereoscopic vision, night vision, sense of smell, visual-motor coordination, quick reflexes, perceptiveness, dexterity;
b) Useful features: good hearing, sense of balance, sense of touch.
2) Abilities:
a) Critical features: powers of concentration, ability to multitask, imagination and creative thinking, technical skills;
b) Useful features: good memory, logical reasoning.
3) Personality
a) Critical features: long-term endurance, self-control, ability to work in isolation, ability to work under monotonous conditions, courage, precision;
b) Useful features: emotional endurance, ability to follow instructions, readiness to work under difficult environmental conditions, perseverance, patience.

The analysis of transport systems shows that technical machine operator makes mistakes, despite his abilities that meet his professional profile. Those mistakes are due to not only his individual features, but also to workplace conditions, such as existing vibrations, noise, microclimate, etc. Monotony constitutes a significant element of truck driver's work process. The higher is the level of monotony, the lower is the driver's alertness, which may pose a risk to life and safety of the driver and other road users [48]. Driving at night, which entails straining driver's eyes, decreases his vigilance. The modern constructions of driver's cab improve operator's work conditions: his comfort at work increases and physical effort related to driving is reduced. However, these improvements do not manage to isolate truck driver completely from vibrations and noise created by vehicle's movement. The impact of the factors mentioned grows with the increase of speed and the number of road users. As a consequence, driver's fatigue rises quickly. Weariness leads to the decrease of physical efficiency, leg-hand coordination disorder and limitation of visual field. As an effect, sleepiness and apathy increase. Driver's fatigue has also an influence on: reaction stability, speed and scope of perception, attention and reaction time. Taking into consideration a complexity of the situation, in which driver carrying hazardous materials operates, we can distinguish various types of fatigue, for example: muscle fatigue (related to driving posture and holding steering wheel), sensory fatigue (reduced capacity to answer to stimulation) and mental fatigue (decrease of cognitive performance caused by constant focus on a task and monotony of driving conditions). The consequences of driving despite appearing fatigue may be dangerous not only for drivers themselves, but also for other road users. The highest share of accidents caused by drivers' fatigue has been recorded on highways A2, A1 and A4, as well as on national roads n°2, 3, 17, 18 and 22. Conclusion from above mentioned arguments support a thesis that it is practically impossible to protect drivers carrying hazardous materials from temporal information overload, emotional tension or real and unexpected situations. It should be noted that a man to a great extent is responsible for safety of the DVE system, although he is just a component of the greater whole. Therefore, a penetrating analysis of this component and actions aimed at strengthening it will reinforce the whole system.

The analysis of driver's performance has allowed to determine the structure of factors having potential influence on the probability of an accident. This structure is presented in the Figure 1. In the years 2012-2018 the factors mentioned were evaluated through a survey by drivers carrying hazardous materials. The evaluation was carried out among 250 drivers in various age groups, with different work experience and who drove different types of vehicles used for transport of hazardous goods. The respondents between 36-49 years old constituted the most numerous age group. As an average, those drivers were making between 10000-12000 km per month. Their vehicles were relatively new – they were produced in the years 2009-2017. The anonymity of the survey gave the respondents the opportunity to discuss openly existing difficulties and risk related to their workplace. The data gathered through evaluation was statistically analysed with the use of R Development Core Team Software R 3.6.3 (Holding the Windsock. The results show that factors considered by drivers as arduous include the following ones: vibrations (95%) and noise (73%), that is, vibroacoustic environment conditions; night shifts (52%), time pressure (59%), monotony (50%) and stress (56%). Based on the research results and specialist literature, the most significant factors from the point of view of ergonomics and safety in the transport of hazardous materials were selected. Subsequently, a fuzzy model was created, which allows to generate the intensity of accidents caused by driver's mistake (λ_L), described in detail in the following paragraph.

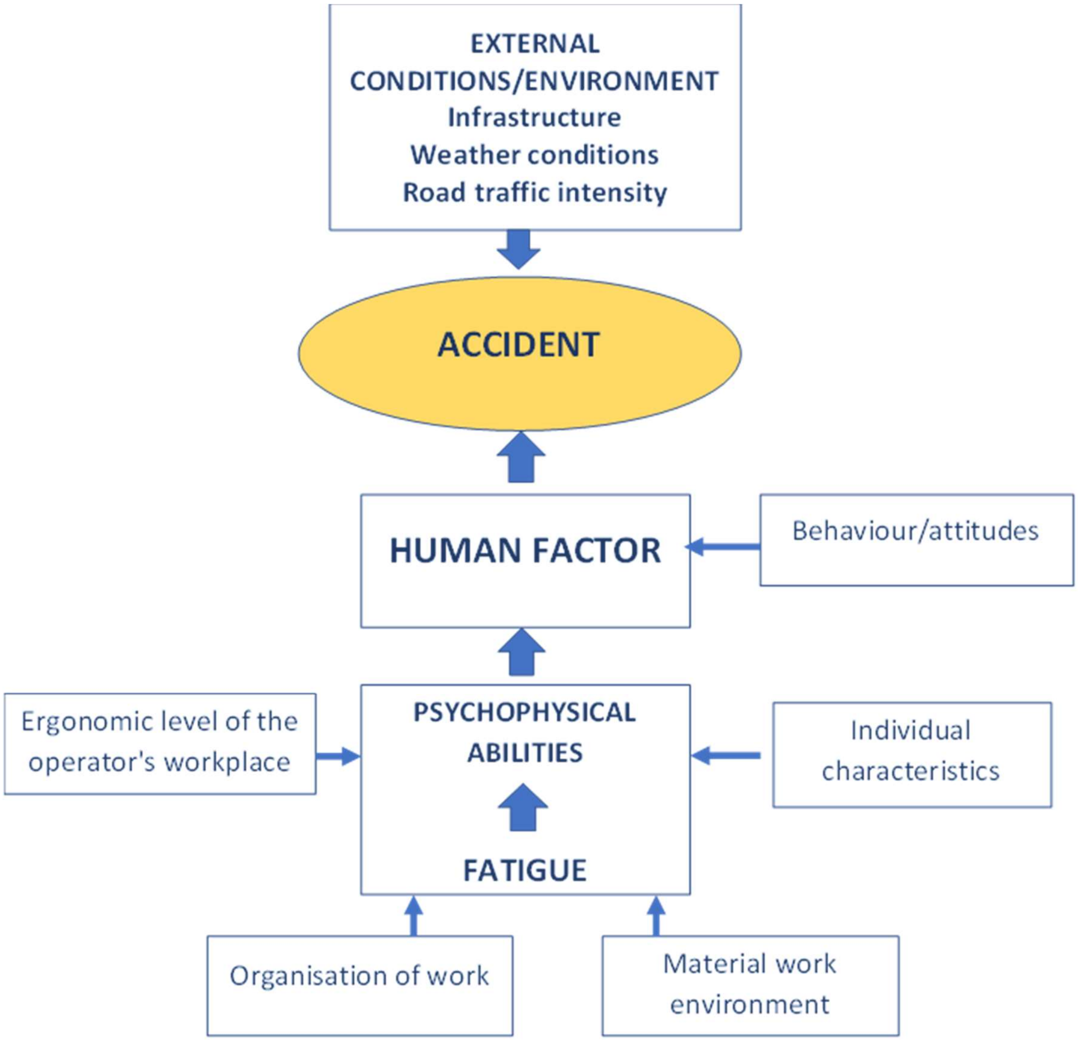

Figure 1. Factors potentially influencing probability of an accident

2.2. Assumptions of heuristic model

The aim of the modelling was to determine the influence of selected factors, referred to as features in this model, on the intensity of accidents caused by driver's mistake. The features had been selected based on expert-based surveys and literature. The Mamdani model was used for model creation [49].
The procedure of creating the model included:

1. Selection of features, that is, external characteristics formed by organizational and technical conditions, such as: working time, skills, vibrations, noise, knowledge of procedures; and internal psychological and physiological characteristics, such as: stress, age, time of day, monotony.
2. Assigning certain levels of selected features with their corresponding fuzzy sets, that is: monotony (low, mid, high), knowledge of procedures (good, poor), skills (good, bad), working time (standard, overtime), vibroacoustic conditions (bothersome, non-bothersome), stress (low, mid, high); treated as a "submodel" of internal characteristics), age (young, middle, mature), time of day (day, night).
3. Assigning trends in the formation of λ_L (the intensity of accident occurrence due to

human error) in the form of ideograms as keywords:
Very small ↓↓
Small ↓
Medium ------
Large ↑↑
Very large ↑↑
The analyzed structure has been presented in the Figure 2.

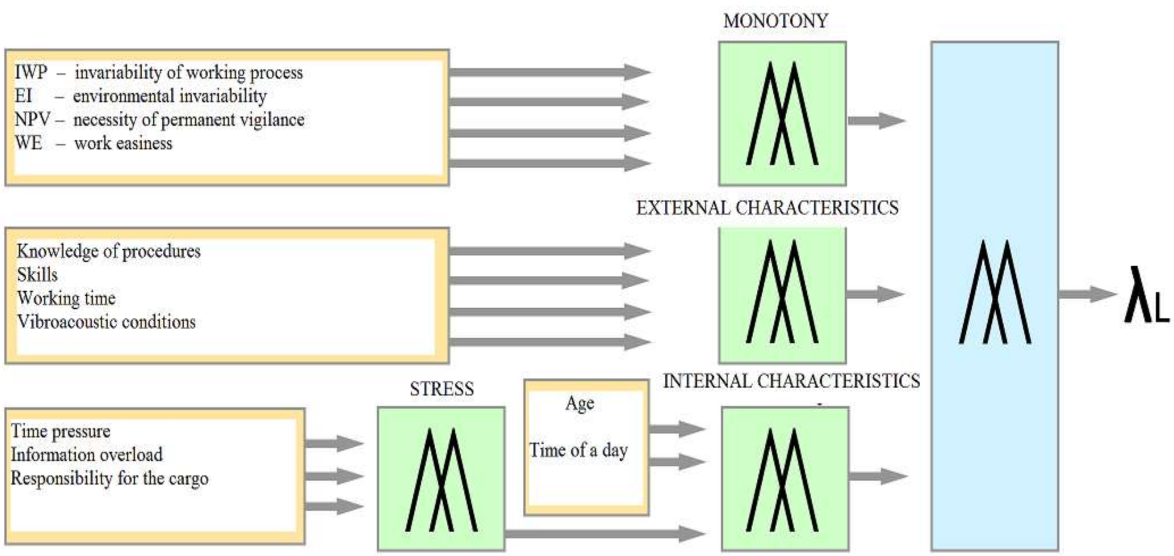

Figure 2. Heuristic model of intensity of accidents caused by driver's mistakes

In heuristic modeling, numerical values that are "measures" of a given feature should be assigned to particular components. Due to the numerical effectiveness of the algorithms described in the following section, the value of the quantity λ_L occurring in the model, i.e., the intensity of accident occurred as a result of human error, was normalized according to the formula:

$$\lambda_L = \frac{x - x_{\min}}{x_{\max} - x_{\min}} \qquad (1)$$

where:
λ_L – intensity of accidents caused by driver's mistake,
x – current value of a real variable,
x_{min} – minimum value of a real variable,
x_{max} – maximum value of a real variable.

As it's above mentioned standardization of variables is appropriate from the point of view of numerical calculations (scope of change for each variable is the same and, as a consequence, the problem is numerically very well defined). The equation (1) implies that reverse operation (change from standardized to real variables) is explicitly determined. The minimum and maximum values of a real variable were calculated based on data from the State Fire Service, Central Statistical Office and own research. The analyzed data referred to local chemical and ecological threats involving tank trucks from the last 5 years, the number of tank trucks registered in the same period of time and the average number of annual working hours of tank trucks' drivers. In order to determine λ_{Lmin} and

λ_{Lmax} of the above mentioned period of time, the years with the smallest and the largest numbers of dangerous incidents were chosen and combined with the number of registered tank trucks in a given year. The λ_L parameter takes into account only the incidents related to the probability of an accident caused by driver's mistake. Due to the lack of detailed databases, the analysis were based on the level of men's participation, expressed in %, as a main cause of chemical and ecological accidents according to the National Headquarters of the State Fire Service. Based on the analysis of the available data, the intensity of accidents caused by human mistakes λ_L was determined as the following interval: (0,0000016; 0,0000021). In the case of qualitative variables, this method requires assigning a value that ranges in degree from 0 to 1 to a given feature. This value refers to "expert" evaluation of the feature's intensity. Values assigned to particular features, that is, quantization levels, are presented on the Table 2.

Table 2. Extent of change in the values of the analysed characteristics

Factor /input/	The values of linguistic / fuzzy sets Value in range <0; 1>				
	0	**0,25**	**0,5**	**0,75**	**1**
IWP - invariability of working process EI - environmental invariability NPV - necessity of permanet vigilance WE - work easiness	small				big
Monotony	low		mid		high
Knowleges of procedures	good				poor
Skills	good				bad
Working Time	standard				overtime
Vibroacustic conditions	non bothersome				bothersome
External characteristics	good	more than medium	medium	less than medium	bad
Time pressure	low				high
Information overload	low				high
Responsibility for cargo	small				big
Stress	low		mid		high
Age	young		middle		mature
Time of day	day				night
Internal characteristics	good	more than medium	medium	less than medium	bad

Selected features were assigned by fuzzy sets and their corresponding membership function (MF) [50]. First the monotony model was defined by four factors determining its

level, then the model of external factors and the stress submodel, included in the model of internal factors, were determined. The features, together with their levels, formed grounds for linguistic-based heuristic model, formulated as an implication. A fragment of the rules referred to the stress submodel has been presented below:
"If time pressure is low and the level of information overload is low and responsibility for a cargo is small then the stress level is low.
If time pressure is low and the level of information overload is low and responsibility for a cargo is big then the stress level is low.
If time pressure is low and the level of information overload is high and responsibility for a cargo is small then the stress level is low.
If time pressure is low and the level of information overload is high and responsibility for a cargo is big then the stress level is medium..."

Analogous was creation of remaining models referred to monotony, external and internal characteristics. Their linguistic form was applied to the model of intensity of accidents caused by driver's mistake.

2.3. The structure of fuzzy model and its numerical implementation

Heuristic model, described in the previous paragraph, was numerically implemented in MATLAB/Simulink environment. The model includes three structures, in accordance with the Figure 2. Fuzzification is the main process in fuzzy modelling in which the crisp quantities are converted to fuzzy ones. The conversion into fuzzy values is represented by a membership function. There are various methods of assigning membership values or the membership functions to fuzzy variables. Membership value ranges in degree between 0 and 1, and it represents the degree of membership of each input linguistic variable to a corresponding fuzzy set. In the Mamdani model the Gaussian function was adopted as a membership function [51]. Other available membership functions, that is triangular and trapezoidal, had no significant influence on the results. The Mamdani model for internal characteristics simulation has been shown as an example in the Figure 3.

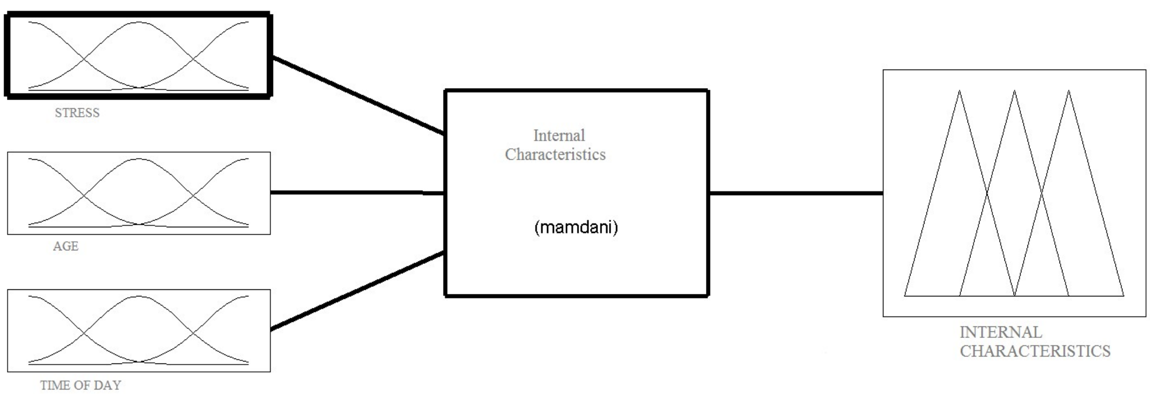

Figure 3. Mamdani model for internal characteristics simulation

The total of membership functions determine the number of quantization levels adopted for the input signal. For each feature the Gaussian membership function has been applied, as it has been shown in the Figure 4.

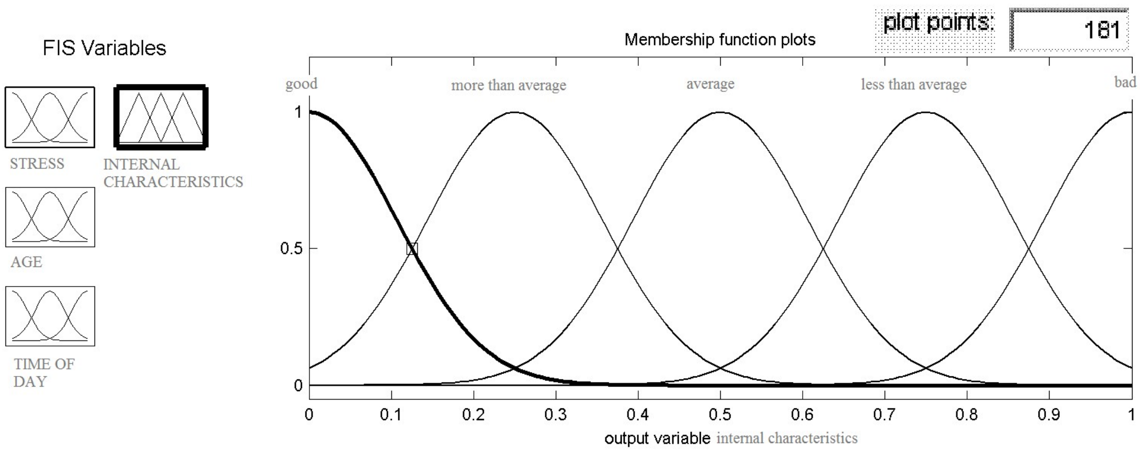

Figure 4. Membership function for internal characteristics

Internal characteristics were developed at five levels, in accordance with the assumptions. Analogous operations were performed for each of model's structure. As we may see, the model has various elements that can be modified and precisely this flexibility allows to reflect the reality. Nevertheless, it entails laborious and expensive experimental researches, as a man himself constitutes their main object.

3. Results

This section gives example results of simulation of the effect of individual characteristics on the intensity of human error accident occurrence using the Mamdani model. Figure 5 shows an example visualization of 29 of the 75 implication rules of the intensity of human error accident occurrence, with assumed settings for monotony, external factors, and internal factors.

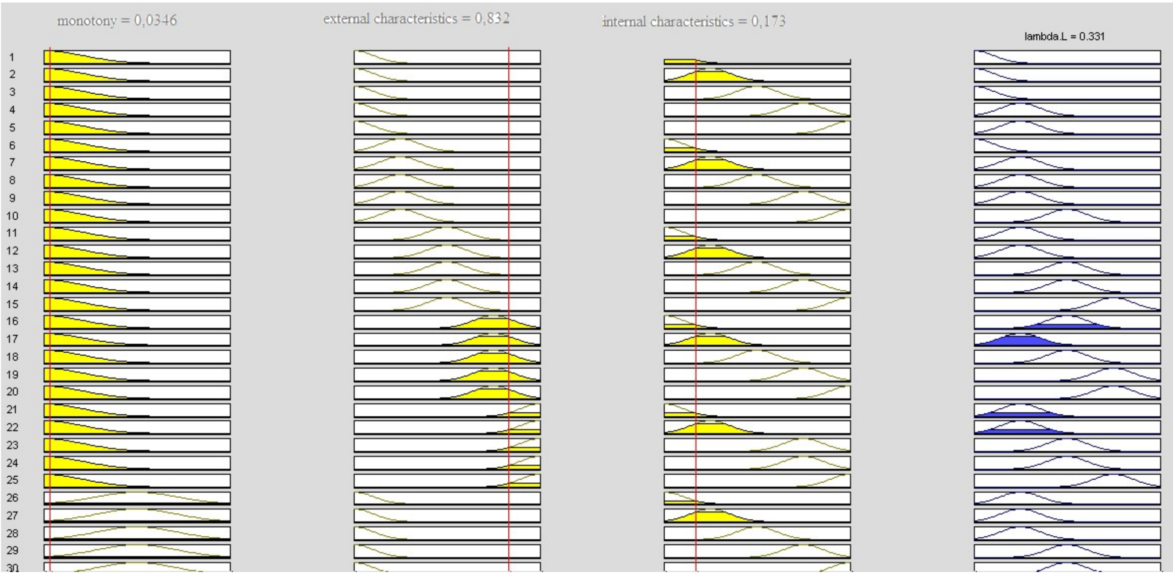

Figure 5. Visualization of implication rules for simulation λ_L

For this simulation, the intensity of the accident due to human error was 0.331 (in standardized variables). Figure 6 shows the intensity of accident occurrence depending on external factors and internal factors. From the shape of the plot, it can be seen that internal factors have a more significant influence on the level of intensity of λ_L than external factors, i.e., the assumption that the level of intensity of λ_L significantly depends on the human factor has been demonstrated.

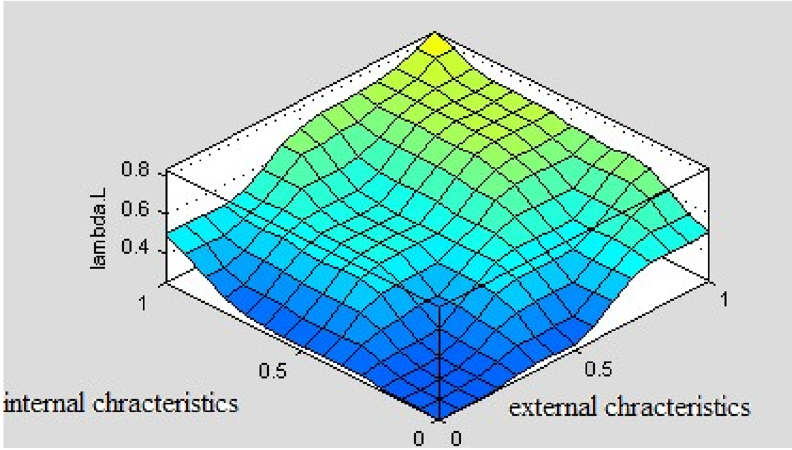

Figure 6. Simulation results for intensity of accidents caused by human mistake depending on external and internal characteristics.

Similar simulations were carried out for the other models. The heuristic model makes it possible to analyze many situations that cannot be studied in reality and assess various human factor characteristics. Computer modeling and simulations are an effective research tool for determining the relationship in the driver-vehicle-environment system. The estimation of the parameter λL is a component of a model called the band model, using which it is possible to generate the probability of an accident occurring in the road transport of dangerous goods and consequently to propose the optimal route for the transportation of hazardous goods with the lowest risk of an adverse event.

4. Discussion

Dangerous goods constitute an essential segment of the transport market and are necessary for the functioning of industry and urban agglomerations. The transport of hazardous goods, regardless of the technical means used, poses a potential safety risk. Measures to reduce this risk are therefore a priority. However, it should be added that even the most stringent requirements can be of little effect without a risk assessment that takes account primarily of the human factor, i.e., the main offender to road accidents. It is impossible to carry out tests under natural conditions, primarily because of their limited scope on the human body. In addition, there are constraints relating to financial and organizational capacity. On the other hand, it is a man who is the most unreliable element in the whole system, and therefore, determining his capabilities and the most favorable working conditions for his efficiency is one of the most important research problems.

A more difficult problem is the quantitative verification of the model. In this case, we can talk about partial verification. The literature contains research results [52- 55] on the causes of accidents, driver performance resulting from a single impact of the factors studied or several simultaneously. There are no studies on driver's efficiency that would consider a set of elements reflecting the nature of a driver transporting dangerous goods to the extent required by the model developed by the authors. No studies clearly define the relationship between the effects of single factors and their collective impact. The authors attempt to model the intensity of an accident caused by driver error and, thus, the selection of the optimal route allows for a more in-depth analysis of the issue and constitutes a step closer to modeling the relations occurring in the whole system.

Full verification of the developed model can be achieved through:

1. an "active" experiment,
2. a "passive" experiment

The "active" experiment requires access to a truck simulator equipped with an appropriate measuring system. It should then be possible to regulate the tested parameters of the human factor, the constructional-technical and material working environment, and count the errors committed. Due to the participation of men in the experiment, working conditions should be shaped with great care. A "passive" experiment is conducted under regular vehicle operating conditions. It requires the vehicle to be equipped with apparatus for monitoring the running process. The monitoring concerns both the factors under investigation and the driver's behavior in selected situations.

Carrying out experimental (complete) verification depends on the financial outlay and organizational capacity of both the university and the transport companies. The results obtained from the simulations make it possible to determine many relationships between individual characteristics.

This type of research and computer experiments gives great cognitive opportunities and can be an effective tool for studying the links in the D-V-E system. The obtained values of the intensity of an accident caused by driver's error were implemented into the developed risk assessment method. They constituted one of the factors determining the probability of an accident in the transport of dangerous goods, which allowed to determine the optimal route of transport of these goods characterized by the lowest risk of an undesirable event on the route.

Author Contributions:

"Conceptualization, S.B. and I.G.; methodology, S.B. and I.G.; software, S.B.; validation, S.B. and I.G. formal analysis, S.B.; investigation, S.B..; resources, S.B. and I.G.; data curation, S.B. and I.G writing—S.B.; writing—review and editing, S.B. and I.G.; visualization, S.B. and I.G. All authors have read and agreed to the published version of the manuscript."

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Conflicts of Interest:

"The authors declare no conflict of interest." "The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results".

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