Research article

Methodology for assessing the risk of incidents during passenger road transportation using the functional resonance analysis method

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HIGHLIGHTS

- Methodology developed for assessing and managing the risks of the process of passenger road transportation.
- An attempt has been made to avoid subjective risk assessment in the implementation of PRT.
- The proposed methodology may be easily adapted to the legislation of any country.
- The relationships between the functions of the PRT and the criteria that affect its safety are identified.

ARTICLE INFO

Keywords:
- Passenger transportation
- Safety
- Reliability
- FRAM
- Risk

ABSTRACT

Safety of passenger road transportation (PRT) is a global problem considered by scientists. The present study is aimed at PRT safety improvement by developing its advanced model with accident risk minimization. Functional Resonance Analysis Method is used to identify factors influencing PRT safety. Accident risk assessment of the combined action of several factors in PRT is based on a phenomenological model. Possible good and bad PRT scenarios were considered differing in the staff professional experience, work shift duration, speed, vehicle service lifetime, and driver's stress load. Method for quantitative assessment of five main functions in PRT with their variability caused by parameters changes was designed. The proposed criteria were used to assess the parameter's deviations from their normative values and determine the major characteristics of each function. The recommendations for monitoring the driver's psychophysiological state at all transportation stages were developed and the relationship of transportation functions characteristics and criteria affecting passenger safety was established. This methodology enables assessing the PRT reliability level at a certain time. The approach allows evaluating the criteria affecting traffic safety, identifying their potential functionally resonant effect for abnormal PRT due to conditional changes; developing mechanisms to reduce accident risks by improving technical and organizational management.

1. Introduction

Passenger road transportation (PRT) satisfies the movement needs of any population. It occupies a large segment in the infrastructure of big cities and plays a significant role in regional and international traffic. The growing demand for PRT increases the risk of road accidents.

Unfortunately, sad statistics data evidence this [1, 2]. Every year, about 20000 passenger buses (PB) are involved in road accidents in the European Union. The consequences of these accidents are 30,000 victims with 150 died [3]. In Ukraine, for the period 2018–2020, 420 accidents occurred with deaths or injuries due to PB drivers (Table 1). In 2021, as things stand on June 30th (compared to the same period in 2020), 56
accidents occurred due to PB drivers (+21.7%) with 6 people died (−50%), 126 injured (+15.6%) [2].

The analysis of statistical data given, for example, in [5, 6, 7] shows that the main causes of RA when performing PRT are driver errors during PB driving, exceeding their own capabilities when making a decision to perform maneuvers, speed selection PB movement, evaluation of actions in conditions of limited time of intensive road traffic. These and other factors leading to an unwanted accident are often due to a change or deterioration in the driver’s physical or psychophysiological state of health. Thus, the almost unchanged working posture while driving the PB with the same type of limb movements, which it affects the PB control bodies over a long period of time, can lead to fatigue, deterioration of psychomotor reactions when driving the PA from the stressful change in traffic intensity. As indicated in [8, 9, 10], monotonous movements and being in a monotonous working position, the presence of an external irritation factor can be the causes of a change in emotional mood, loss of concentration, manifestation of aggression towards passengers or other road users, dissatisfaction with the comfort conditions at workplace, etc.

According to the published information [4, 11, 12], the main reasons for the above accident statistics in the system “driver – passenger bus – road – environment” (DBRE) (Figure 1) include:

- unprofessional selection of drivers;
- difficult working conditions during passenger transportation;
- inadequate psychophysiological and health status of drivers;
- unsatisfactory road infrastructure;
- lack of proper maintenance and repair system, etc.

The listed inconsistencies constitute the basis for improving PRT. In particular, standardization of the requirements for road transportation reliability enables achieving a high level of safety in some EU countries. They introduce various traffic safety management systems for the standard requirements [13], strengthen state road transport regulations, trace road infrastructure and vehicles, systematically train drivers, etc. The European directives on labour protection and traffic rules protect transport workers. Thus, the Directive [14] establishes the basic principles for preventing transportation risks, and the Regulation [15] provides requirements for the time of movement, breaks, and rest for drivers. At the same time, the complete elimination of these risk factors does not guarantee a significant improvement in safety [16, 17, 18, 19]. Therefore, the search for innovative solutions and new technologies is necessary.

Much attention is paid to traffic safety [20]. A significant number of publications have been devoted to it, from a comprehensive study of harmful factors influencing the driver [21] to a detailed specific negative factor impacting transportation efficiency [22]. However, the proposed methods do not consider the safety of PRT. There is a need to search for an approach to solve multiple traffic issues and provide a high-quality and safe transportation service. In [23], the authors consider the road passenger transportation system functioning through aspects of meeting both customers’ and carriers’ needs. It enables to suggest transportation safety measures for the carrier’s policies and requirements. However, the effectiveness of the measures for changeable transportation conditions is questionable.

Experts from the University of Minnesota studied aspects of the PRT system performance, referring to how efficiently and reliably carriers can travel to destinations on the transportation network [24]. However, this
research ignores an aggregate action of different indicators, which can cause an accident.

Specialists from the Iranian University of Science and Technology compared various safety indicators and set the correlation between the efficiency and safety of the PRT system [25]. They found that not every effective system is safe.

To describe the transportation problems, many researchers apply the Functional Resonance Analysis Method (FRAM), which simulates complex systems in terms of the variability of various factors that can cause an accident [26]. But the authors used FRAM to analyse only transport accidents, not fully revealing the method’s relevance in terms of detecting all traffic hazards, which can pose a threat when combined. The judgment assessment based on event modelling is a desirable component of transportation risk management [27, 28, 29].

Thus, the existing studies of the road accident’s risk management do not consider the relationship between all potential hazards. The development of scientifically sound methods for modelling, assessing and managing risks in PRT is a relevant area of research.

Figure 3. Parameters of the functions Preparation and Transportation.

Figure 4. The instantiation of the functional interactions.
The aim of the study is to increase the safety of passenger road transport by developing an improved model of the transport process while minimizing the risk of accidents.

2. Materials and methods

Let’s define the transportation risk as a quantitative measure of potential danger or undesirable consequences, characterizing the possibility of getting into a road traffic accident. The result is a violation of the traffic schedule when transporting passengers. In the risk assessment we will adhere to the concept that recognizes the inevitability of accidents but assumes their minimization based on a thorough hazard analysis of the system design, prioritized safety measure funding, responsible compliance with safety legislation, rules etc.

For hazard risk management in the PRT it is necessary to scrutinize the influence of various transportation causal links at every stage, compare origins of hazards and action mechanisms, classify and rank potential sources of danger according to their contribution to integral risk indicators.

To study the PRT model we will use FRAM and consider transportation as a set of interconnected functions, with six most influential aspects for each of them: input data, time, control, resources, preconditions, and output data. The process diagram displays the functions by hexagons (Figure 2). There is an interaction between them so that the components or the result of one function can be input parameters, a prerequisite, or a control aspect of another. FRAM used for analysing the PRT and assessing the unwanted incident risk includes four steps.

1. Identification of the main functions and their characteristics.
2. Determination of the variability of the functions.
3. Revealing functional resonance by assessing each function’s failure risk and the influence of such variability on other process components.
4. Change management. Search for management decisions to reduce accident risk.

3. Theory

We present PRT through five essential functions: Preparation, PB delivery, Boarding of passengers, Transportation, and Alighting of passengers at the destination. The output of some functions is input to the others (Figure 3).

We can elaborate each function by a set of its elements (Figure 4). Table 2 reflects other factors affecting transportation.

Currently, there are many methods and algorithms for risk assessment [30]. But there are no generally accepted methods that meet all the requirements of the transport industry among them. We will assess accident risk due to a combined action of several factors affecting passenger transportation using a phenomenological model. The model does not establish any rigid interaction regulations between risk factors and accidents but summarizes their cumulative effect on PRT.

We can characterize all PRT functions by the interaction between human, transport, and organizational factors. We can assess them

| Number of criteria | Indicator                                      | scenario 1 | scenario 2 |
|--------------------|------------------------------------------------|------------|------------|
| 1                  | Professional experience of the driver          | 12         | 2          |
| 2                  | Doctor’s experience                            | 5          | 7          |
| 3                  | Mechanic’s experience                          | 10         | 3          |
| 4                  | Service lifetime of the vehicle                | 8          | 15         |
| 5                  | Uninterrupted driving time                     | 4.5        | 3.5        |
| 6                  | Speed within the city                          | 60         | 65         |
| 7                  | Speed on the highway                           | 90         | 110        |

Figure 5. Graph of $K_1(x)$
according to criteria which, in turn, affect the safety of PRT. To identify weaknesses in the PRT scheme, among the numerous criteria affecting transportation we will consider the values which are regulated by the relevant standards, namely:

- a regulated professional driver's experience [31] is at least five years;
- a regulated uninterrupted driving time [32] is within 4.5 h;
- a regulated service lifetime of PB [33] is 10 years;
- a regulated speed of PB [31] in city is 50 km/h, on motorways is 90 km/h;
- regulated stress load [34].

It should be noted that these criteria are substantiated by the relevant national standards or international legislation governing the relevant requirements for the safety of the transport process PRT, which allows adaption of the proposed approach to the conditions of any country.

4. Results

Changes in the values of these criteria will, undoubtedly, affect the variability of the transportation functions. For example, an inexperienced driver, who controls PB, may need much downtime at stopping points, and the average PB speed may be lower [35, 36].

We will investigate the possibility of non-fulfilment of the passengers' transportation needs at the proper level (not delivering passengers to their destination on time) due to the deviation of the factors above from their regulatory requirements.

To assess the potential simultaneous impact of several risk factors on PRT we model two scenarios: "good", the base case with the most likely combinations, and the average PB speed may be lower [35, 36].

We assume that even in the best circumstances unforeseen situations are possible. The zero value of the criterion indicates the lack of driving experience. And driver's experience of over 20 years can lead to the accumulation of fatigue, burnout, physiological changes, which means a gradual decreasing criterion.

For the indicators "Professional experience of a doctor" and "Professional experience of a mechanic" the criteria are described equally by the formula:

\[
K_{1}(x) = 0.42x^{0.5} \cdot e^{-1.6(x-5)/25}
\]

Where \(x\) is the actual driver's experience.

Figure 5 chooses it for the following reasons: the best experience according to the standards is 5+ years, so the highest values of the criterion (close to but not more than 1) must correspond to these values: \(K_{1\text{max}} = K_{1}(7.8) = 0.981, K_{1}(5) = 0.93\).

We assume that even in the best circumstances unforeseen situations are possible. The zero value of the criterion indicates the lack of driving experience. And driver's experience of over 20 years can lead to the accumulation of fatigue, burnout, physiological changes, which means a gradual decreasing criterion.

For the indicators "Professional experience of a doctor" and "Professional experience of a mechanic" the criteria are described equally by the formula:

\[
K_{i}(x) = 1 - \frac{0.7}{x+0.7} i = 2, 3
\]

where \(x\) is the actual employee's experience.

The more experienced the employee, the higher the value of the criterion (Figure 6).

Criteria for "Uninterrupted driving time", "Service lifetime of vehicles", "Speed within the city", "Speed on the highway" reflect that the greater the deviation from the standards, the worse the value using the appropriate formula:

\[
K_{4}(x) = \frac{394}{400 + (x+0.5)^2} K_{5}(x) = \frac{100}{100 + x^2},
\]

\[
K_{6}(x) = \frac{296}{300 + (x-50)^2} K_{7}(x) = \frac{296}{300 + (x-90)^2},
\]

where \(x\) is the actual indicators' values.

Figures 7, 8, 9, and 10 show the graphs of these functions.

We will also consider the driver's load, describing it by some value of \(K_{6}(x)\), which ranges from 0 to 1 and reflects the degree of the driver's mindfulness (control of technology, traffic, etc.). We will consider that...
the more carefully the inspection process is carried out (the greater the value of $K_8$), the better the conditions of passenger transportation are.

While the control function is the prerogative of the driver only (as provided in scenarios 1 and 2), the quality of its implementation depends, among other things, on external conditions, and the psychophysiological state of the driver (feelings of inner comfort/discomfort, fatigue, reaction speed, culture, driving skills, emotional load).

Table 4 presents the values of $K_i(x)$, $i = 1, 8$, corresponding to scenarios 1 and 2.

Let $\lambda_{ijk}$ to indicate that the $i$-th criterion impacts the $k$-th characteristic (time, resources, control etc.) of the $j$-th main transportation function:

$$F_j = \sum_{k=1}^{5} \omega_{jk} H_{jk} = \frac{\sum_{k=1}^{5} K_i \cdot x_k}{\sum_{i=1}^{8} \lambda_{ijk}},$$

where $F_j$ is $j$-th function output; $H_{jk}$ is the value, which determines the impact of $k$-th characteristic on $j$-th main function, $\omega_{jk}$ is the factor's

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### Table 4. The criteria values for the modelled scenarios.

| Number of criteria | Criteria | scenarios 1 | scenarios 2 |
|--------------------|----------|-------------|-------------|
| 1                  | Professional experience of the driver | 0.9296 | 0.7197 |
| 2                  | Doctor's experience | 0.8772 | 0.9091 |
| 3                  | Mechanic's experience | 0.8346 | 0.8106 |
| 4                  | Service lifetime of vehicles | 0.8343 | 0.6154 |
| 5                  | Uninterrupted driving time | 0.8316 | 0.8909 |
| 6                  | Speed within the city | 0.7400 | 0.5638 |
| 7                  | Speed on the highway | 0.9867 | 0.4229 |
| 8                  | Stress level | 0.9000 | 0.6500 |

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### Table 5. The variability of the transportation functions caused by changes in their characteristics.

| Number of function, $j$ | Characteristics, $k$ | Weight, $\omega_{jk}$ | Quantitative evaluation of parameters under conditions | Quantitative assessment of the performance of the basic function under conditions |
|-------------------------|----------------------|-----------------------|--------------------------------------------------------|--------------------------------------------------------|
|                         |                      |                       | The best | Scenario 1 | Scenario 2 | The best | Scenario 1 | Scenario 2 |
|                         |                      |                       |          |            |            |          |            |            |
| Preparations            |                      |                       |          |            |            |          |            |            |
| 1 Input                 | 0.07                 | 1.00                  | 1.00     | 1.00       | 1.00       | 0.0697   | 0.0697     | 0.0697     |
| 2 Time                  | 0.13                 | 1.00                  | 0.93     | 0.81       | 0.1310     | 0.1224   | 0.1062     |
| 3 Precond.              | 0.07                 | 0.99                  | 0.99     | 0.99       | 0.0690     | 0.0690   | 0.0690     |
| 4 Resource              | 0.26                 | 1.00                  | 0.93     | 0.81       | 0.2616     | 0.2445   | 0.2121     |
| 5 Control               | 0.47                 | 1.00                  | 0.88     | 0.91       | 0.4679     | 0.4105   | 0.4254     |
| 6 Output                | $F_1$                |                       |          |            |            | 0.9993   | 0.9161     | 0.8825     |
|                        |                      |                       |          |            |            |          |            |            |
| PB delivery             |                      |                       |          |            |            |          |            |            |
| 1 Input                 | 0.15                 | 1.00                  | 0.93     | 0.81       | 0.1507     | 0.1408   | 0.1222     |
| 2 Time                  | 0.15                 | 1.00                  | 0.93     | 0.72       | 0.1507     | 0.1401   | 0.1085     |
| 3 Precond.              | 0.08                 | 0.99                  | 0.99     | 0.99       | 0.0794     | 0.0794   | 0.0794     |
| 4 Resource              | 0.08                 | 1.00                  | 0.93     | 0.72       | 0.0802     | 0.0745   | 0.0577     |
| 5 Control               | 0.54                 | 1.00                  | 0.90     | 0.65       | 0.5382     | 0.4844   | 0.3498     |
| 6 Output                | $F_2$                |                       |          |            |            | 0.9992   | 0.9193     | 0.7176     |
|                        |                      |                       |          |            |            |          |            |            |
| Boarding of passengers  |                      |                       |          |            |            |          |            |            |
| 1 Input                 | 0.07                 | 1.00                  | 0.83     | 0.62       | 0.0735     | 0.0613   | 0.0452     |
| 2 Time                  | 0.08                 | 1.00                  | 1.00     | 1.00       | 0.0771     | 0.0771   | 0.0771     |
| 3 Precond.              | 0.10                 | 0.99                  | 0.99     | 0.99       | 0.1017     | 0.1017   | 0.1017     |
| 4 Resource              | 0.38                 | 1.00                  | 0.93     | 0.72       | 0.3810     | 0.3541   | 0.2742     |
| 5 Control               | 0.37                 | 1.00                  | 0.90     | 0.65       | 0.3656     | 0.3291   | 0.2377     |
| 6 Output                | $F_3$                |                       |          |            |            | 0.9990   | 0.9234     | 0.7399     |
|                        |                      |                       |          |            |            |          |            |            |
| Transportation          |                      |                       |          |            |            |          |            |            |
| 1 Input                 | 0.19                 | 1.00                  | 0.83     | 0.62       | 0.1933     | 0.1613   | 0.1190     |
| 2 Time                  | 0.09                 | 1.00                  | 0.99     | 0.42       | 0.0947     | 0.0935   | 0.0401     |
| 3 Precond.              | 0.13                 | 0.99                  | 0.99     | 0.99       | 0.1305     | 0.1305   | 0.1305     |
| 4 Resource              | 0.19                 | 1.00                  | 0.74     | 0.56       | 0.1933     | 0.1431   | 0.1090     |
| 5 Control               | 0.39                 | 1.00                  | 0.90     | 0.65       | 0.3867     | 0.3480   | 0.2514     |
| 6 Output                | $F_4$                |                       |          |            |            | 0.9987   | 0.8764     | 0.6500     |
|                        |                      |                       |          |            |            |          |            |            |
| Allighting passengers at the destination |                      |                       |          |            |            |          |            |            |
| 1 Input                 | 0.31                 | 1.00                  | 0.83     | 0.89       | 0.3143     | 0.2614   | 0.2800     |
| 2 Time                  | 0.15                 | 1.00                  | 0.74     | 0.56       | 0.1535     | 0.1136   | 0.0866     |
| 3 Precond.              | 0.15                 | 0.99                  | 0.83     | 0.62       | 0.1520     | 0.1281   | 0.0945     |
| 4 Resource              | 0.23                 | 1.00                  | 0.93     | 0.72       | 0.2251     | 0.2092   | 0.1620     |
| 5 Control               | 0.15                 | 1.00                  | 0.90     | 0.65       | 0.1535     | 0.1382   | 0.0998     |
| 6 Output                | $F_5$                |                       |          |            |            | 0.9985   | 0.8505     | 0.7228     |
weight in the corresponding function, calculated in advance by analysing relationships in the transportation scheme.

We can interpret the value $K_i(x)$, $i = 1, 8$ as PRT reliability in time. All of them are chosen so that their values decrease with an increasing deviation of process parameters from the standards. Therefore, we can consider the values $F_p$, $j = 1, 5$, as reliability of corresponding basic function, and the value $(1 - F_p)$ as the risk of an undesirable result. And since the functions are sequential, we will assume that the transportation reliability can be expressed, by analogy with [37], by the multiplication $F_p$, $j = 1, 5$ (Eq. (2)):

$$S = \prod_{j=1}^{5} F_j,$$

and the risk of an undesirable situation will be calculated by the formula (Eq. (3)):

$$R = 1 - S.$$

We calculate the weights $\omega_{jk}$, $j = 1, 5$, $k = 1, 5$ according to the algorithm. For each $k$-th characteristics of the $j$-th function (($j, k$)-factor), we form the matrix $A^{jk} 5 \times 5$, elements of which are

$$a^{jk}_{ps} = \begin{cases} 1, & \text{if } (j, k) - \text{factor impacts } - \text{th factor of } p \text{-function } \sum_{l=1}^{5}, s = j, 5 \\ 0, & \text{otherwise} \end{cases}$$

Then

$$\omega_{jk} = \frac{\sum_{s=1}^{3} \sum_{p=1}^{5} a^{jk}_{ps} / \sum_{s=1}^{3} \sum_{p=1}^{5} a^{jk}_{ps}}{1, j, 5, k = 1, 5}$$

The results of the quantitative evaluation of the basic functions of the PRT transport process for scenarios 1 and 2 are shown in Table 5. According to the results of the analysis of the obtained results it is possible to trace the variability of the values of the specified functions of the PRT transport process, caused by a change in their characteristics. We can trace the variability of their values caused by changes in characteristics. Total estimates for the whole passenger transportation process for the best conditions and the parameters provided in scenarios 1, 2 are 0.995, 0.58, and 0.219, respectively. Consequently, even under ideal conditions, there is a risk of an undesirable outcome. The increase in the deviation of the process indicators from the normative values increases this risk significantly. The results of calculations allow us to conclude that all the considered criteria together significantly affect transportation.

Analysis of the data in Table 2 and Table 5 identifies the most influential characteristics of each of the basic functions that ensure their timely and quality completion. For Preparation input data on external conditions, appropriate route, schedule, and resources are important. For the Transportation function quality of infrastructure, technical characteristics of vehicles, and physical and psychological state of the driver are critical. But the most critical component at all stages of the passenger transportation process is control over the performance. And this is unquestionable because the occurrence of accidents is closely related to the imperfect inspection of the technical condition of vehicles at the preparation stage and human error caused by either psychophysiological condition or inappropriate driving experience [2].

Thus, the functional resonance in passenger transportation may be caused by imperfections or lack of proper control over all participants of the process, from carriers to drivers.

Scenario 2 traces the nature of "human error" – not a one-time act, but a systematic inconsistency caused by the organizational culture of the enterprise: the lack of certain resources, preconditions, and control over traffic only by the driver. Therefore, to reduce accident risk during transportation it is necessary to strengthen these elements of functions.

At the stage of "Change Management," we propose an improved version of the transportation process, which provides remote control (RC) over the technical conditions of the vehicle and the driver – from the PB preparation to alighting of passengers at the destination. In Figure 11,
we present interrelationships between the components of the improved PRT process with the introduced elements of control over the vehicle and the driver's health and psychophysiological state.

The new feature in the proposed PRT process is the RC function with four control measures over driver admission, passenger safety, and the driver's psychological and physical state.

By strengthening the control over the functions' performance, we improve their characteristics. Within the proposed approach to assessing PRT reliability, some quantitative indicators may increase. We assume that because of RC, the criteria Speed within the city, Speed on the highway, and Load increase by 70, 70, and 60 percent compared to the normative values. Such changes cause variability in main functions and transportation in general. The results of new quantitative estimate calculations are given in Table 6.

Quantitative assessments of the reliability of PRT at the appropriate level and the risk of violation of the transportation schedule for scenarios 1 and 2 under the conditions of RC are calculated by formulas: Equation (1) and Equation (2), and respectively are equal to \( S_1 = 0.378 \), \( R_1 = 0.622 \) and \( S_2 = 0.6657 \), \( R_2 = 0.3343 \). Evidently, the risk is almost halved.

Therefore, the introduction of enhanced control over transportation increases reliability and reduces risk to a certain degree. Table 7 provides comparative information on quantitative estimates of all main functions corresponding to scenarios 1 and 2, considering the absence and implementation of RC over transportation.

Figure 12 shows the comparison of the transportation functions' variability according to scenarios 1 and 2. Figures 13 and 14 demonstrate the increase in the variability with the introduction of the RC function with and without violation standards.

### Table 6. The variability of the transportation functions caused by changes in their characteristics, subjected to RC.

| Number of function, \( j \) | Characteristics, \( k \) | Weight, \( \omega_{jk} \) | Quantitative evaluation of parameters under conditions | Quantitative assessment of the performance of the basic function under conditions |
|-----------------------------|-----------------------------|---------------------------|--------------------------------------------------------|--------------------------------------------------------|
|                             |                             |                           | Scenario 1 | Scenario 2 | Scenario 1 | Scenario 2 |
| Preparation                 |                             |                           |            |            |            |            |
| 1                           | Input                       | 0.07                      | 0.99       | 0.99       | 0.0690     | 0.0690     |
|                             | Time                        | 0.13                      | 0.93       | 0.81       | 0.1224     | 0.1062     |
|                             | Precond.                    | 0.07                      | 0.99       | 0.99       | 0.0690     | 0.0690     |
|                             | Resource                    | 0.26                      | 0.93       | 0.81       | 0.2445     | 0.2121     |
|                             | Control                     | 0.47                      | 0.88       | 0.91       | 0.4105     | 0.4254     |
|                             | Output \( F_1 \)            |                           |            |            | 0.9154     | 0.8818     |
| PB delivery                 |                             |                           |            |            |            |            |
| 2                           | Input                       | 0.15                      | 0.93       | 0.81       | 0.1408     | 0.1222     |
|                             | Time                        | 0.15                      | 0.93       | 0.72       | 0.1401     | 0.1085     |
|                             | Precond.                    | 0.08                      | 0.99       | 0.99       | 0.0794     | 0.0794     |
|                             | Resource                    | 0.08                      | 0.93       | 0.72       | 0.0745     | 0.0577     |
|                             | Control                     | 0.54                      | 0.97       | 0.90       | 0.5221     | 0.4817     |
|                             | Output \( F_2 \)            |                           |            |            | 0.9569     | 0.8495     |
| Boarding of passengers      |                             |                           |            |            |            |            |
| 3                           | Input                       | 0.07                      | 0.83       | 0.62       | 0.0613     | 0.0452     |
|                             | Time                        | 0.08                      | 1.00       | 1.00       | 0.0771     | 0.0771     |
|                             | Precond.                    | 0.10                      | 0.99       | 0.99       | 0.1017     | 0.1017     |
|                             | Resource                    | 0.38                      | 0.93       | 0.72       | 0.3541     | 0.2742     |
|                             | Control                     | 0.37                      | 0.97       | 0.90       | 0.3547     | 0.3272     |
|                             | Output \( F_3 \)            |                           |            |            | 0.9490     | 0.8255     |
| Transportation              |                             |                           |            |            |            |            |
| 4                           | Input                       | 0.19                      | 0.83       | 0.62       | 0.1613     | 0.1190     |
|                             | Time                        | 0.09                      | 1.00       | 0.83       | 0.0944     | 0.0783     |
|                             | Precond.                    | 0.13                      | 1.00       | 1.00       | 0.1319     | 0.1319     |
|                             | Resource                    | 0.19                      | 0.92       | 0.87       | 0.1783     | 0.1680     |
|                             | Control                     | 0.39                      | 0.95       | 0.83       | 0.3674     | 0.3190     |
|                             | Output \( F_4 \)            |                           |            |            | 0.9332     | 0.8163     |
| Alighting of passengers at the destination | | | | | | |
| 5                           | Input                       | 0.31                      | 0.83       | 0.89       | 0.2614     | 0.2800     |
|                             | Time                        | 0.15                      | 0.74       | 0.56       | 0.1136     | 0.0866     |
|                             | Precond.                    | 0.15                      | 0.83       | 0.62       | 0.1281     | 0.0945     |
|                             | Resource                    | 0.23                      | 0.93       | 0.72       | 0.2092     | 0.1620     |
|                             | Control                     | 0.15                      | 0.95       | 0.83       | 0.1459     | 0.1267     |
|                             | Output \( F_5 \)            |                           |            |            | 0.8582     | 0.7497     |
| Remote control              |                             |                           |            |            |            |            |
| 6                           | Input                       | 0.31                      | 1.00       | 1.00       | 0.0612     | 0.0612     |
|                             | Time                        | 0.15                      | 0.83       | 0.89       | 0.0924     | 0.0990     |
|                             | Precond.                    | 0.15                      | 0.99       | 0.99       | 0.0785     | 0.0785     |
|                             | Resource                    | 0.23                      | 1.00       | 1.00       | 0.3455     | 0.3455     |
|                             | Control                     | 0.15                      | 1.00       | 1.00       | 0.4027     | 0.4027     |
|                             | Output \( F_6 \)            |                           |            |            | 0.9805     | 0.9871     |
6. Discussion

It is known that the main task of passenger transport is to provide an optimal plan for the transportation of passengers from departure points to arrival points [38]. This contributes to the improvement of the level of transport service, the spread of new technologies, the growth of population mobility, etc. [39]. However, for the high-quality performance of the transport task it is necessary to ensure the implementation of a number of conditions, one of which is to reduce the variability of the transportation process. There is a need to study external and internal factors that, in accordance with the requirements of ISO 45001, lead to the active development of systems and methods of management of occupational safety and health of employees [40]. In particular, they can be attributed to: the professional experience of the driver, the time of work (driving) by the driver on the route, the period of operation of the PB, speed of movement, and stress. And, although the above factors are an incomplete list of all factors that affect the result of transport work, the study showed that if the requirements are met (the best option), the occurrence of an accident (for example, a violation of the transportation schedule) is reduced by 15–20%, in contrast to the worst case, when the latter are violated for some reason. The obtained result clearly indicates that the totality of the effects of various factors of the transport process, which is demonstrated using the FRAM method, leads to an increase in variability and an increase in the risk of an accident. At the same time, the study of the magnitude of the risk of a traffic accident by other methods would lead to experts ignoring some of them due to the influence of the specified factors. This is due to the fact that the value of the risk of a dangerous event, calculated separately for each factor, will not be significant.

The results of the calculations of the variability of the PRT process for the given scenarios of the transportation process indicate the need to implement additional remote control over certain actions of the participants of the transport process, which can significantly improve the result of the task of transporting passengers. However, as noted by the authors of the study [41], the best result for reducing variability is the improvement of working conditions.

The strengthening of control over the driver's admission to driving a PB should be carried out in order to ensure an accident-free driving experience for a long time (at least 10 years of professional experience in the transportation of passengers). Unfortunately, this issue is not given enough attention nowadays. Usually, the main criterion on the ground is the admission of drivers with the appropriate category of driving license. To increase the safety of PRT, PB should be equipped with modern systems for monitoring the health and psychophysiological state of the driver. Such technical devices include a steering wheel with built-in sensors that monitor the driver's pressure and heart rate, systems for monitoring the driver's facial expressions, eye blinks, PB deviation from...
straight-line movement, etc. They are connected via GPS navigation with the dispatcher, who can monitor the process of PB movement on the route and, when the relevant indicators change to critical values, make a timely decision to stop the vehicle or replace the driver. Many PB manufacturers serially produce vehicles that are equipped with the specified devices, and such buses should be used to transport passengers.

To ensure an accident-free driving experience for a long time, the strengthening of the control over the driver's admission to the PB should be carried out (or just: the control over the driver's admission to the PB should be strengthened). Unfortunately, usually, the main criterion is the appropriate driver's category. Additional control of the driver's state can also be carried out using a particular checklist [8], which considers the ergonomic, psychosocial, individual, and discomfort factors. Wages and monetary rewards should also stimulate an Accident-free management experience.

Monitoring changes in the driver's state and inspecting the implementation of primary safety conditions at all transportation stages allows in-time intervention and management that improve passenger service.

The presented study has limitations that relate to the consideration of two extreme scenarios: when all factors are within regulatory requirements or all of them are violated. Such a situation does not happen often. However, the proposed approach makes it possible to assess the risk based on any initial data of the specified factors. Moreover, the number of factors can be expanded, and their main indicators for comparison can be taken from the corporate requirements of the company itself or other international or national standards.

7. Conclusions

- To study the mechanism of occurrence and development of adverse events during passenger transportation it is proposed to depict the transport process in the form of FRAM-diagram, and study the cumulative impact of various factors of man-made, natural and social origin on the process based on phenomenological model. Two possible scenarios are considered, good and bad, which differ in the values of indicators such as professional experience, duration of work shift, speed, service life of vehicles and stress load of the driver. In the PRT transport process five main functions were distinguished, and a method for quantifying their variability caused by changes in these parameters was developed. At the same time, criteria are proposed to assess the deviations of parameters from the normative values regulated by law, as well as the method of determining the priority of the component characteristics of each basic function. All this allows to identify the potential functionally resonant effect when the transport process cannot be carried out in normal operation due to changes in certain conditions, as well as to develop risk reduction mechanisms through optimal management of technical and organizational factors.

- The ability to predict the implementation of PRT at the appropriate level was demonstrated. Quantitative estimates of the reliability of the task at the appropriate level and the risk of scheduling traffic for scenarios 1 and 2 under the conditions of remote control are calculated by formulas: Equation (2) and Equation (3) and are, respectively $S_1 = 0.378$, $R_1 = 0.622$ and $S_2 = 0.6657$, $R_2 = 0.3343$. Obviously, the risk is almost halved. Therefore, the introduction of enhanced control over the transport task will increase reliability and reduce a certain amount of risk.

- The measures to improve road safety by monitoring the driver's psychophysiological condition throughout the route are proposed: a steering wheel with built-in sensors that monitor the pressure and heart rate of the driver, control of facial expressions of the driver, blinking eyes, evasion of PB from rectilinear traffic, etc. connected via GPS-navigation with the dispatcher, who monitors the process of PB movement on the route and, if necessary, makes management decisions.

Declarations

Author contribution statement

Oleg Bazaluk, Vasyl Lozynskyi: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Larysa Koriashkina, Serhii Cheberiachko, Oleg Deryugin: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Mykola Odnovol, Olha Nesterova: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Funding statement

This work was supported by Guangdong University of Petrochemical Technology.

Data availability statement

Data included in article/supporting material/referenced in article.

Declaration of interest’s statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgements

The authors are thankful to the editors for providing the opportunity to present the research results on the pages of this respectable journal as well as the reviewers for providing valuable assistance in improving the scientific article representation quality.

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