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# SELECTION OF TRAIN TRAFFIC MANAGER’S ACTIVITIES IN TRAINING PROCESS USING FUNCTIONAL RESONANCE ANALYSIS METHOD

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## *Abstract:*

*In training process of rail traffic manager (controller) using virtual reality technology, selection of activities among those assigned to a workplace and scenarios that should be taken in training is an important issue. The selection method that is based on performance variability of her/his activities has been proposed in the paper. This variability has been characterized by timing and precision. The traditional reliability and safety analysis methods are not sufficient when building the training program for traffic managers. In the paper the train controller work has been modelled using Functional Resonance Analysis Method (FRAM) that is system oriented approach. Scales of values of timing and precision that are train transport driven have been presented. They are different when comparing with typical timing and precision scales given in FRAM literature. In the paper the estimation of probabilities of occurring of values of timing and precision scales for these activities has been calculated as the mean from the values obtained by questionnaire done in traffic manager community or using Analytic Hierarchy Process (AHP) method. In FRAM with AHP approaches presented in literature, AHP pairwise comparison is executed using natural numbers and their reciprocals what is typical in AHP method. In our paper the AHP is used for estimating the probabilities, so in pairwise comparing the rational numbers are applied, because natural numbers and their reciprocals would limit the set of values of probabilities. The activities and scenarios that the training should be concentrated on are selected from those with the greatest variability.*

**Keywords:** *function performance variability, precision, timing, Analytic Hierarchy Process (AHP)*

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## 1. Introduction

Nuclear energy, health care, transport: air, rail, road, sea systems are complex socio-technical systems that are safety related. Their safety depends on the following types of factors: environment, technical, organization and human. In complex systems the execution of function is variable because the conditions of the execution are changeable. In complex socio-technical systems, human being and organization are the main sources of performance variability. From one side the human factor is the cause of undesirable events, but from the other hand this factor is the reason of resilience because of her/his adaptability. In rail transport the traffic manager (controller) is one of crucial positions. It can be found that the improvement of people behavior in the system rises the safety and reliability (Jacyna and Żak, 2016, Jacyna-Gołda et al., 2017). Thus, the research problem studied in the paper is to select the activities among those assigned to the traffic manager position and scenarios that the training process should be concentrated on. In training process of rail staff using virtual reality technology, selection of activities among those assigned to a workplace and scenarios that should be taken in training is an important issue. The selection method of activities of the traffic manager that is based on performance variability of her/his activities has been proposed in the paper. The method is founded on the Functional Resonance Analysis Method (FRAM) and Analytic Hierarchy Process (AHP).

The structure of the paper is as follows. In Section 2. the literature associated with the paper has been given. The traffic manager's activities and interactions among them are modelled by FRAM in Section 3. The activities are represented by FRAM functions. For the functions, their performance variability is assigned in Section 4. The timing and precision that characterize the variability of activity are estimated by a questionnaire done in traffic manager community and by authors of the paper using AHP method. The activities and scenarios that the training should be concentrated on are selected from those with the greatest variability (Section 4). The discussion of results is given in Section 5. Finally there are conclusions.

## 2. Literature review

Rail transport is the topic of this paper. In rail system the following positions: train driver, traffic manager, rolling stock auditor, train manager are safety related ones. The railway is a complex socio-technical system with a high human influence on the safety (Gołębiowski, 2020). The safety influencing human factors result in uncertainty that is hard to take into account in modelling of transportation systems (Jacyna, 2009, Jacyna et al., 2014), where the traffic manager (controller) is one of crucial positions. In the paper the emphasis is put on activity performance variability of traffic manager.

A train traffic manager is a person who directs and controls the movement of all trains within the dispatching section. He makes quick decisions to ensure the punctuality of train services. Due to the complexity of this work, in scientific publications, the authors analyze the demand for training of train traffic managers based on surveys of employees.

In (Todorova et al., 2019), a survey was conducted on the form of training and its scope. According to the results of the surveys, practical training is important, and the training should cover issues related to: receiving and dispatching trains, taking over the working shift, unpredictable situations and events, managing traffic when conducting repairs. The practice should consist of a seminar, work on a simulator and work at an real traffic station. The publication (Dymitrov and Trendafilov, 2018) discusses contemporary aspects and perspectives on the conduct of vocational training of train traffic manager. Based on a survey, methodological recommendations were made on the necessity of building a training complex for training, testing and certification of employees and new cadres. Particular attention was paid to multimedia training and the need to build a simulator with special attention to handling shunting and emergency events. In (Hatakeyama et al., 2016), a training method for train traffic managers was developed to teach communication skills. The training includes hazard scenarios, points to remember in communication skills, and a training program. Based on a survey, a list of 45 key communication points to remember was also developed and designed to promote understanding of communication skills through regular use.

Traditional reliability, safety, and resilience analysis methods as Fault Tree Analysis, Event Tree Analysis (Restel, 2021), Failure Mode and Effect Analysis, Hazard and Operability Study, Reason's swiss cheese method, Human Factors Analysis and Classification System (De Felice and Petrillo, 2011), Petri nets (Trowitzsch et al., 2005) or model checking approach (Lin and Min, 2022) are not sufficient when analyzing the human behaviour. An alternative in threat prediction and risk estimation are system oriented approaches like: System-Theoretic Accident Model and Process (STAMP) (Leveson, 2012), Functional Resonance Analysis Method (FRAM) (Hollnagel et al., 2014, Patriarca et al., 2020), AcciMap (Rasmussen and Svedung, 2000) or synthesis of STAMP and Human Factors Analysis and Classification System (HFACS) (Lower et al. 2018). The STAMP is stronger oriented on structure of the system than on behaviour, while FRAM is functionality oriented i.e. emphasis is put on functions and interactions among them. FRAM is applied in safety analysis of: air transportation (Hollnagel et al., 2008), health care (Hollnagel et al., 2014), (Magott and Wikiera-Magott, 2020) construction industry (Rosa et al., 2015), offshore oil well drilling (Franca et al., 2020). In FRAM method the emphasis is put on function (activity) performance variability that is the key feature of the traffic manager's work. The method we propose in this article is different from those currently used. We analyze in detail the activities performed by train traffic managers and their interrelationships using the FRAM method. A detailed selection of training activities using a survey in traffic managers community and AHP method adapted to railroad environments is given in the paper. The selection is founded on variability of the activities performed. Based on this, the activities that are important in the training of train traffic managers are selected.

In our paper the performance variability of the controller's activity (function) is characterized by performance precision and timing. In order to treat the FRAM function performance variability in quantitative way the following approaches: Monte Carlo simulation (Patriarca et al., 2017), fuzzy sets (Hirose et al., 2020), AHP (Franca et al., 2020), (Rosa et al., 2015) have been applied. In paper (Franca, 2020), AHP is used in comparing the timing and precision. In paper (Rosa et al., 2015), relative importance of aspects of function is analyzed using AHP. In our paper, AHP is used in estimating the timing and precision. However, scales of values of timing and precision are train transport inspired, and are different than typical values in FRAM as in (Franca et al., 2020), (Patriarca et al., 2017). In FRAM with AHP approach (Franca et al., 2020), (Rosa et al., 2015), when pairwise comparing the authors use natural numbers and their reciprocals what is typical in AHP. In our paper the AHP is used for estimating the probabilities, so in pairwise comparing the rational numbers are applied.

## 3. FRAM model of traffic manager's work

### 3.1. Typical and untypical situations in traffic manager's work

The main task of a traffic manager is to run trains through one or more traffic control points. Her/his activities consist of exchanging information about trains, preparing the route, receiving and releasing trains. The analysis in the paper is limited to the following infrastructure: electromechanical and relay. From this point of view it is possible to distinguish three possible operation situations.

The first one is a typical situation when the traffic manager runs trains in the easiest possible way according to the timetable. In this situation all traffic control devices work correctly and protect the traffic manager from implementing of wrong and dangerous decisions. This situation is illustrated by Fig. 1. Preparation of the train path is detailed by three activities on right.

The second situation is an unusual one. The traffic control devices work also properly, thus the traffic manager is protected against implementation of wrong dangerous decisions in a dangerous way. However, the train traffic is disturbed, and as a consequence the traffic manager has to make creative decisions about the order of receiving and releasing trains and assigning tracks and paths to them. This situation may result in displaying signal for a route that is inadequate to the current traffic situation. In order not to cause additional disruptions the traffic manager can cancel the locked route. Switching off the signal and cancelling the route without passing a train is possible before the train has entered the braking path to the signal. The traffic manager first switches off the signal, then verifies (visually, through CCTV (Closed-Circuit Television), or by devices) that the train has not passed the signal and will not pass, and then cancels the route.

The third situation is an unusual situation, where the traffic control equipment has malfunctions. This abnormal situation raises the risk of an accident.

The first subcase is the cancelling of a route when the train has not did it automatically. The traffic manager verifies (visually, through CCTV, with further equipment that works correctly) that the train has not broken up and is in full formation, then cancels the route.

The third abnormal situation may also be related to the inability to display the signal for the train. Due to a failure of equipment that:

- erroneously indicating the occupation of a track - occurs when the devices are defective; in this situation the traffic controller must determine visually (or through CCTV) whether the track is free; if such verification is not possible then he must go to the ground (or send someone) to check the status,
- switch position error - occurs when the equipment is defective; in this case the traffic manager must check visually (or by CCTV, but it is unlikely) if the switch is correct set up,
- semaphore error - occurs when the semaphore is defective; in this situation the traffic controller must check visually (or by CCTV) if the semaphore has the correct display,
- identifying the complete train arrival error – occurs when the equipment does not recognize that the complete train has arrived; in this case the traffic manager must visually check whether there is an end-of-train signal on the last train car.

In order to continue the operation of the system, the traffic manager can bypass the equipment and display a nonrestrictive (substitute) signal or give a written order. Before this action, the neighboring station shall be contacted by phone to introduce the emergency traffic procedures. The train driver shall be obliged to run on sight at reduced speed not exceeding 40 km/h within the station area, i.e. until he reaches the next correctly displayed signal or until he enters the open track.

The following conditions (terms) must be met to give a replacement information (written or displayed):

(1) the tracks and switches on which the train will run must be clear, from the time the path is set until the desired train movement takes place,
(2) switches are in proper positions for running on specified track together with protective switches and derailleurs,
(3) switches mentioned above must be immobilized in desired positions for the time of the train movement,
(4) excluding the possibility of other runs on the same track and on the same switches,
(5) the open track or station track on which the train will enter must be free, in most cases an agreement between traffic control points is required.

At present research stage, when the replacement information is used, observation of wrong operation of the traffic control equipment and the activities after train movement: switching the semaphore to “stop” after a train has moved, identifying the complete train arrival, clearing path, unlocking of switches have not yet been studied in their variability.

### 3.2. FRAM model

FRAM (Hollnagel et al., 2014) model consists of functions and interactions (couplings) between them. The function is illustrated in Fig. 2 taken from (Magott and Wikiera-Magott, 2020).

In order to get a FRAM model of a fragment of reality, functions of FRAM model are connected from aspects O into aspects I, C, T, P, R of the functions. One coupling connects two aspects only, e.g. in Fig. 3 aspect O of function *Preparing the information about the state of the track by infras.* is connected with aspect P of *Verification and protection of switch positions – locking.*

*Functional resonance* (Hollnagel et al., 2014) is the detectable signal that is the outcome of multiple approximate adjustments that are the basis for everyday work activities.

### 3.3. FRAM model of typical and untypical situations

In first situation listed in Subsection 3.1 and presented in Fig. 1 which is typical, the sequence of FRAM functions in Fig. 3 is as follows:

- Traffic controller activities A1 – A7 according to notation in Table 1.,
- Train movement,
- Switching the semaphore to “stop” (automatically),
- Identifying the complete train arrival (automatically),
- Clearing path, unlocking of switches (*A9*).

Coupling from aspect output (O) of a function to the aspect input (I) of the next one indicates order of execution of the functions, see activities *A1, … , A7*.

Function *Preparing information about the state of the track* is performed by rail infrastructure and it delivers information that is required for execution of activities *A2, A4, A5, A6, A7, A10, A13, A14*. Hence, there are couplings from aspect O of function *Preparing information about the state of the track* to aspects P of these activities.

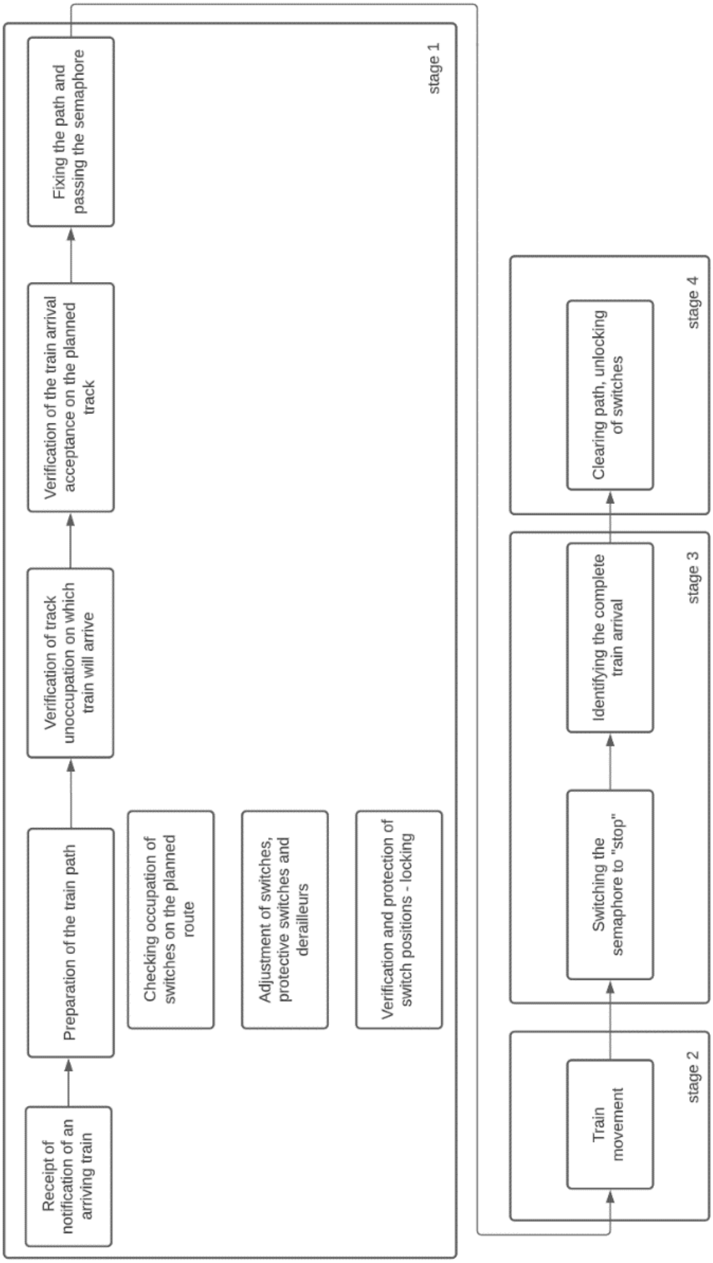

Fig. 1. Train traffic manager's activities in typical situation

In second situation from description in Subsection 3.1, the activity *Procedure in case of route cancelling* (*A8*) is executed by train controller when the train cannot arrive or a specified difference, between current time and time when permission to move had been sent, has been reached. Causal relation between functions *Preparation of information that the train cannot arrive, Preparation of information about the current time* and function *A8* are expressed by two couplings of aspects O of these preparations with aspect I of *A8*. The time instant when permission to move had been sent is expressed by couplings with aspect T of *Procedure in case of route cancelling*.

In third situation for the first subcase when the train has not cancelled the route automatically, activity *A8* is performed too.

Trains are moved using replacement information (displayed or written) after *Observation of wrong operation of the traffic control equipment* (*A10*) which has occurred in typical situation. Seven couplings from aspect O of activities *A1, ... ,A7* with aspect I of function *A10* illustrate that the wrong operation of the traffic control equipment can be noticed during the execution of functions *A1, ... ,A7* for typical situation, and it activates the *A10* execution. The other couplings with aspect I of *A10* from aspects O of: *Procedure in case of route cancelling*, activities after *Train movement* are not represented in Fig. 3 because of readability of this figure.

When the trains are moved using replacement information, the following functions are executed:

- Traffic controller activities A11-A15 according to notation in Table 1.,
- Train movement (performed by the train driver),
- activities after train movement for this untypical situation.

Additionally, observation of wrong operation of the traffic control equipment can be required for train movement with replacement information.

When the replacement information is used, the model of the behavior: observation of wrong operation of the traffic control equipment and activities after train movement is not represented according to the comment from the last paragraph of Subsection 3.1.

The couplings from function *Training of traffic managers* to control aspects of activities of the managers represent procedures for execution of these activities. The coupling from function *Organization of train traffic* to aspect T of manager's activity *Receipt of notification of an arriving train* expresses e.g. the time intervals between subsequent arriving trains.

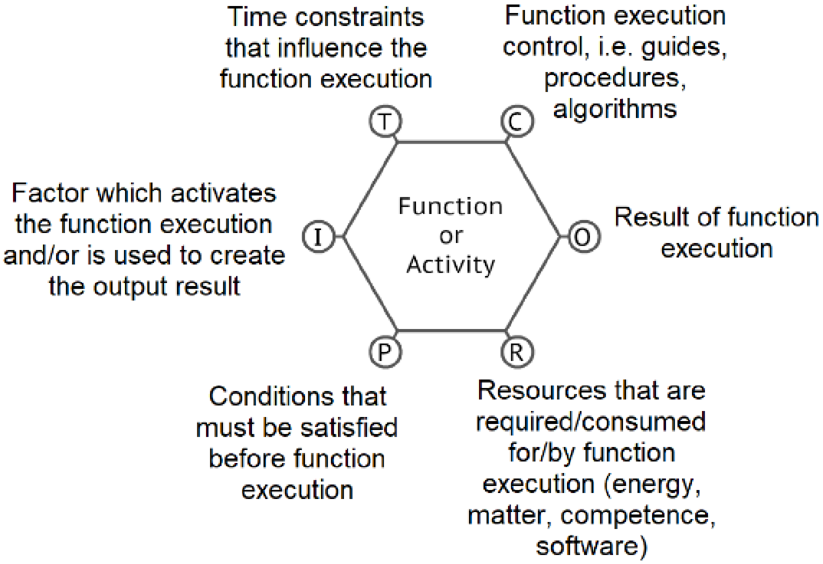

Fig. 2. Function of FRAM model with its six aspects: Input, Control, Time, Precondition, Resources, Output

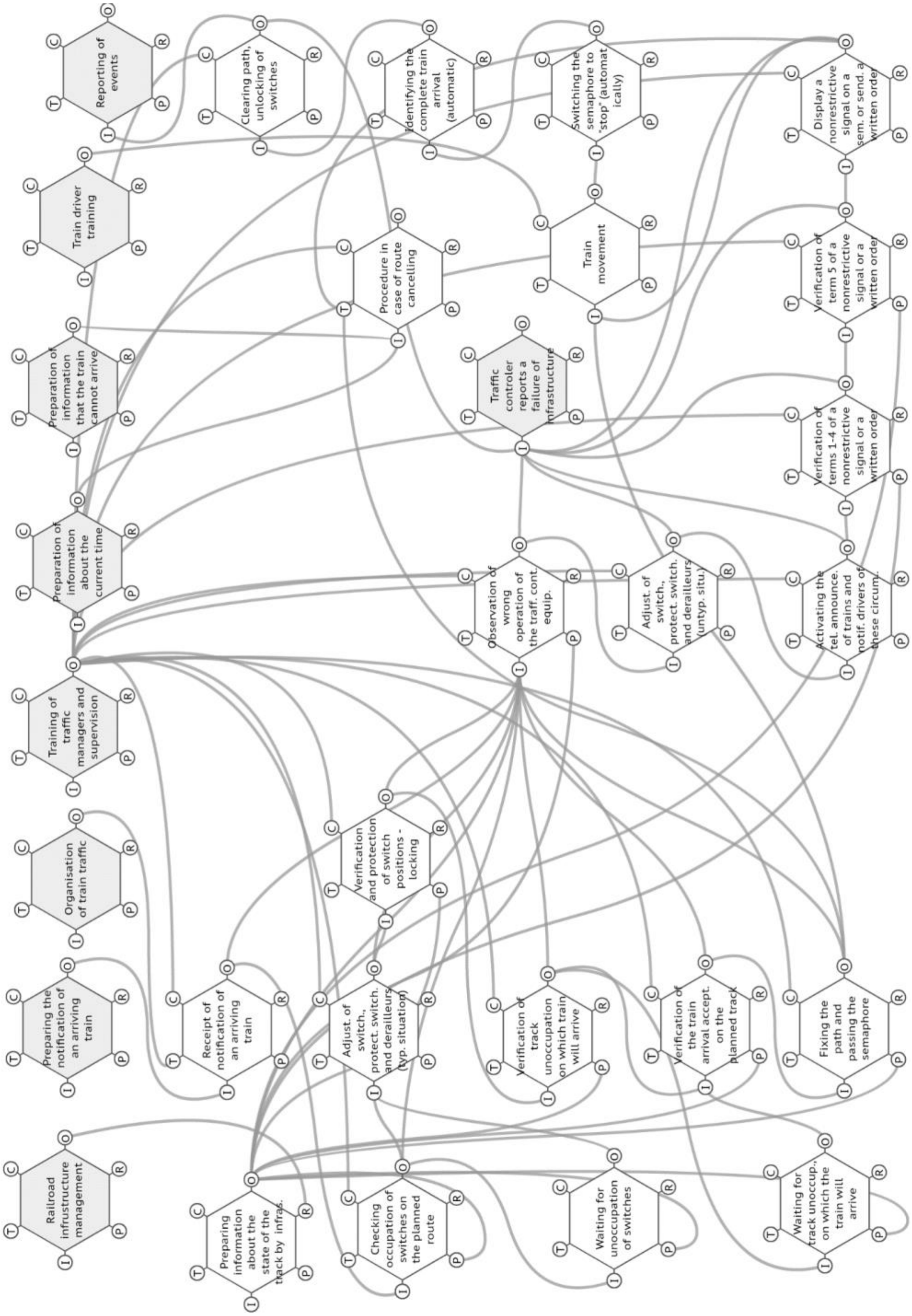

Fig. 3. FRAM model of traffic controller's work prepared using FMV tool (Hill)

## 4. Selection of activities of traffic manager in training process

In FRAM the activity performance timing is estimated using e.g. the following values (Franca et al., 2020), (Patriarca et al., 2017):

- on time,
- too early,
- too late,
- not at all.

The precision is graded using e.g. the following values (Franca et al., 2020), (Patriarca et al., 2017):

- precise,
- acceptable,
- imprecise,
- wrong (in (Patriarca et al., 2017) only).

In our paper, the set of values that seems to be better adapted to traffic manager's work is used. In the questionnaire in traffic controllers community, for the timing (*T*) the task was: select the worst occurring variant for the activity performance timing in your work among the values:

- on time (1),
- delayed activity and train on time (2),
- delayed activity and delayed train (3).

In the questionnaire, for the precision (*P*) the task was: select the ability of the activity performance in your work among values:

- correct (1),
- incorrectly but acceptable (2),
- dangerously (3).

In order to quantify uncertainty, for both scales the above numbers 1, 2, 3 in parenthesis have been assigned according to the principle:

*Greater the "distance" from the required value: "on time" for timing, "correct" for precision – greater the number is.*

Activity performance variability (*V*) is given by the formula:

$$V = T \cdot P \qquad (1)$$

In Table 1. there are traffic controller's activities with their symbols *Ai*, timing, precision and variability. For nine activities *A1 – A8, A10*, the *Timing* and *Precision*, respectively, are the mean arithmetic values of timing and precision (according to the above numbers 1,2,3) obtained from the questionnaire done in traffic manager community of 92 persons. The traffic controllers that work with electromechanical and relay infrastructure have been interviewed. Then for six activities *A9*, *A11 – A15* their *Timing* and *Precision* have been estimated by three authors of the paper using Analytic Hierarchy Process (AHP) method. AHP (Manoy), (Saaty, 1980) is linear algebra based method that is used in expressing the expert opinion in multi-step multi-criteria decision process for comparison of relative importance of criteria. In the paper the method is used for estimating the probabilities of occurring of the values of timing and precision for traffic manager's activities. Before estimating these characteristics for *A9*, *A11 – A15*, the authors have learned the estimation using the results of the questionnaire for *A1 – A8, A10*.

Now AHP method will be outlined. Examples of AHP tables with pairwise comparison of probabilities of occurring of the timing, precision, respectively, values for activity A14 and estimations of these probabilities delivered by an author of the paper are given in Tables 2., 3. In traditional AHP in pairwise comparison, natural values 1,2,3, … ,8,9 and their reciprocals are used. In our paper the AHP is used for estimating the probabilities, so in pairwise comparison the rational numbers are applied. The value $a_{ij}$, where $i,j \in \{1,2,3\}$, which is associated with timing or precision values, is the ratio of probabilities of occurring of these values $i,j$. The following condition $a_{ji} = {}^{1}/_{a_{ij}}$ need to be satisfied. Elements $a_{ii} = 1$, because they are the ratio of probabilities of occurring of the timing or the precision value $i$ with itself.

Then normalized values $b_{ij}$, where $i,j \in \{1,2,3\}$, of pair-wise comparisons of probabilities of occurring of the timing, precision values, are calculated according to formula:

$$b_{ij} = a_{ij} / \sum_{i \in \{1,2,3\}} a_{ij} \qquad (2)$$

i.e. elements $a_{ij}$ from Tables 2., 3. are divided by sums of entries in columns. Next, mean values of entries in the rows are calculated (last columns in Tables 2., 3.) according to:

$$e_i = \left(\sum_{j \in \{1,2,3\}} b_{ij}\right)/3 \qquad (3)$$

These means are estimations of probabilities of occurring of the timing (precision) values 1, 2, 3.

Then *Consistency ratio* (Manoy), (Saaty, 1980) is calculated. It should be smaller than 0,1. Sometime, value 0,15 is accepted as the upper bound. If the requirement imposed on Consistency ratio is not satisfied then the above pair-wise comparisons need to be done once more. For Table 2., consistency ratio is 0.016.

Timing $T_i$ delivered by $i$-th analyzer (author) is calculated according to the formula:

$$T_i = p_{t1} + 2 \cdot p_{t2} + 3 \cdot p_{t3} \tag{4}$$

where $p_{tj}$ is the estimation of probability of occurring of the timing value $j \in \{1,2,3\}$. According to the last column of Table 2. $T_i = 2.237$.

For Table 3. the consistency ratio is 0.008.

Precision $P_i$ delivered by $i$-th analyzer (author) is calculated according to the formula:

$$P_i = p_{p1} + 2 \cdot p_{p2} + 3 \cdot p_{p3} \tag{5}$$

where $p_{pj}$ is the estimation of probability of occurring of the precision value $j \in \{1,2,3\}$. According to the last column of Table 3. $P_i = 1.669$.

The timing $T$ and precision $P$ of the activity performance are calculated as the mean arithmetic values from estimations delivered by three authors, and activity performance variability $V$ is calculated according to expression (1). When estimating the activity performance variability for an activity using AHP, two tables for: timing and precision by each of three authors have been prepared. Hence, 6 tables have been created for one activity.

Process *for estimating timing and precision of activities was as follows:*

(1) *Estimation of timing and precision of* A1 – A8, A10 and two other activities (that are not contained in FRAM model) using the questionnaire in traffic controllers community,

(2) 66 AHP tables for A1 – A8, A10 and two other activities (in total 11) analyzed in the questionnaire have been created in learning process of three authors and then obtained estimations *of timing and precision* have been compared with those from the questionnaire,

(3) 36 AHP tables for A9, A11 – A15 have been prepared by three authors and required estimations have been calculated.

Table 1. Traffic manager's activities with their timing, precision and variability

| Symbol of activity | Activity | Timing | Precision | Variability |
|---|---|---|---|---|
| A1 | Receipt of notification of an arriving train | 1.522 | 1.326 | 2.018 |
| A2 | Checking occupation of switches on the planned route | 1.543 | 1.609 | 2.483 |
| A3 | Adjustment of switches, protective switches and derailleurs (typical situation) | 1.75 | 1.62 | 2.834 |
| A4 | Verification and protection of switch positions - locking | 1.489 | 1.489 | 2.218 |
| A5 | Verification of track unoccupation on which train will arrive | 1.359 | 1.283 | 1.743 |
| A6 | Verification of the train arrival acceptance on the planned track | 1.272 | 1.25 | 1.59 |
| A7 | Fixing the path and passing the semaphore | 1.674 | 1.315 | 2.202 |
| A8 | Procedure in case of route cancelling | 1.478 | 1.402 | 2.073 |
| A9 | Clearing path, unlocking of switches | 1.342 | 1.357 | 1.820 |
| A10 | Observation of wrong operation of the traffic control equipment | 1.511 | 1.261 | 1.905 |
| A11 | Adjustment of switches, protective switches and derailleurs (untypical situation) | 2.033 | 1.532 | 3.114 |
| A12 | Activating the telephone announcement of trains and notifying drivers of these circumstances | 1.925 | 1.651 | 3.177 |
| A13 | Verification of terms 1-4 of a nonrestrictive signal or a written order | 1.845 | 1.518 | 2.801 |
| A14 | Verification of term 5 of a nonrestrictive signal or a written order | 1.992 | 1.618 | 3.222 |
| A15 | Display a nonrestrictive signal on a semaphore or sending a written order | 1.395 | 1.471 | 2.052 |

Table 2. Pairwise comparison $a_{ij}$ of probabilities of occurring of the timing values (second, third and fourth columns) for activity A14 and estimations of these probabilities given by an author

| **A14 Timing** | **On time (1)** | **Delayed activity and train on time (2)** | **Delayed activity and delayed train (3)** | **Estimation of probabilities of occurring of the timing values 1, 2, 3** |
|---|---|---|---|---|
| On time (1) | 1.00 | 3.00 | 0.50 | 0.320 |
| Delayed activity and train on time (2) | 0.33 | 1.00 | 0.25 | 0.123 |
| Delayed activity and delayed train (3) | 2.00 | 4.00 | 1.00 | 0.557 |

Table 3. Pairwise comparison $a_{ij}$ of probabilities of occurring of the precision values (second, third and fourth columns) for activity A14 and estimations of these probabilities given by an author

| **A14 Precision** | **Correct (1)** | **Incorrectly but acceptable (2)** | **Dangerously (3)** | **Estimation of probabilities of occurring of the precision values 1, 2, 3** |
|---|---|---|---|---|
| Correct (1) | 1.000 | 1.000 | 4.000 | 0.458 |
| Incorrectly but acceptable (2) | 1.000 | 1.000 | 3.000 | 0.416 |
| Dangerously (3) | 0.250 | 0.333 | 1.000 | 0.126 |

According to variabilities of activities given in Table 1., the emphasis in training process should be put on those with greatest variabilities. In typical situation there is one activity A3 with variability greater than 2,8. In the case of train movement using replacement information (displayed or written) there are four activities A11 – A14 with variability greater than 2.8. The highest value of variability (above 3) is characterized by situations related to emergency situations. These are: *Adjustment of switches, protective switches and derailleurs (untypical situation)*, *Activating the telephone announcement of trains and notifying drivers of these circumstances*, *Verification of term 5 of a nonrestrictive signal or a written order*. The biggest problem in these three activities is timing. It points out that the execution of these activities by traffic managers is prolonged. This is due to the low experience of employees in handling this type of situation. This should be taken into account in job training. The lowest value of variability is shown by the routine activities performed by traffic duty officers. These are: *Verification of the train arrival acceptance on the planned track*, *Verification of track unoccupation on which train will arrive*. Employees are very experienced in performing these activities therefore in terms of timing they do not cause train delays and rarely the activity is itself delayed. In terms of precision, they are acceptable. It is worth to analyze the sequences of activities with more than one element. For example, the sequences of three activities with the greatest and the smallest, respectively, sums of variabilities are A12 A13 A14 with 9.2 and A5 A6 A10 with 5.2.

*Correlation coefficient* between activity performance variability for activities A1 – A8, A10 (from the questionnaire) and length of activity scenario description measured in signs is equal to 0.858, while for the other activities is significantly smaller.

## 5. Results and discussion

FRAM model of rail traffic manager’s work has been proposed in the paper. At next research stage, for the case when the replacement information is used, observation of wrong operation of the traffic control equipment and the activities after train movement should be studied in detail with their variability. According to paper (Patriarca et al., 2020), FRAM has been applied in railway domain in: accident study, integration of human factors with technology change in traffic management, risk assessment, but not in traffic manager training as it is done in the paper.

To extend the conclusions the CREAM - Cognitive Reliability and Error Analysis Method (Hirose et al., 2020) can be included in the FRAM model analysis. Common Performance Conditions used by CREAM can represent external conditions that impact on FRAM function’s behavior. The list of Common Performance Conditions (CPCs) is as follows:

1. Adequacy of organization,

2. Working conditions,
3. Adequacy of Man-Machine Interface and operational support,
4. Availability of procedures\plans,
5. Number of simultaneous goals,
6. Available time,
7. Time of day (Circadian rhythm),
8. Adequacy of training and experience,
9. Crew collaboration quality.

In Fig. 3 the couplings from background function *Training of traffic managers and supervision* directed to controller's activities can be used to incorporate the CPCs with numbers 4, 8, 9. The connections from background function *Organization of train traffic* oriented to controller activity *Receipt of notification of an arriving train* (and the connections to the other activities that are not shown in the figure) can represent influence of the CPCs with numbers 1, 2, 5, 6, 7. Impact of CPC 3 can be taken into account in connections from activity *Preparing information about the state of the track by infrastructure* to aspects P of functions: *Checking occupation of switches on the planned route*, *Verification and protection of switch positions – locking*, *Waiting for unoccupation of switches*, *Verification of track unoccupation on which the train will arrive*, *Waiting for track unoccupation on which the train will arrive*, *Verification of the train arrival acceptance on the planned track*, *Fixing the path and passing the semaphore*, *Verification of terms 1-4 of a nonrestrictive signal or a written order*, *Verification of term 5 of a nonrestrictive signal or a written order*, to aspects I and P of function: *Observation of wrong operation of the traffic control equipment.* A part of couplings have not been presented in Fig. 3, due to readability of the figure. The identified CPCs can be used in the next stages of research for elaborating of safety barriers as well as training scenarios.

The used scales of timing and precision that are adapted to train traffic controller's work are different than typical ones in FRAM, as in (Franca et al., 2020), (Patriarca et al., 2017). In our paper, the variabilities of activities in terms of timing and precision have been estimated with the help of questionnaire done in traffic managers community and by authors of the paper using AHP method. When comparing with other FRAM AHP approaches our paper differs in scales of compared values and values in pairwise comparison in AHP. In FRAM with AHP approaches (Franca et al., 2020), (Rosa et al., 2015) in pairwise comparing the authors use natural numbers and their reciprocals what is typical in AHP. In our paper the AHP is used for estimating the probabilities, so in pairwise comparison the rational numbers are applied. Estimating the variabilities using AHP has been preceded by learning of estimation applying AHP for activities considered in the questionnaire. Such selection method of activities for training the managers that is based on activity performance variabilities have been proposed. The selection can be done for single activities or for the sequences of activities.

Now some limitations and possible extensions of the paper will be discussed. In the questionnaire the traffic controllers that work with electromechanical and relay infrastructure have participated. The authors of the paper do not know whether the proportions of questionnaire participants that work with both infrastructure are consistent with these proportions in Poland. Assignment of natural numbers 1, 2, 3 to values of scales for timing and precision enables quantitative comparison of different timing values, precision values, and variabilities of train manager's activity performance. However, this assignment is arbitrary. It can be questioned that value 3 is assigned to precision equal “dangerous”. Variability has been defined as the multiplication of timing and precision. What other operations can be considered?

Next let us outline possible extensions of the paper. In Fig. 3 the couplings from background function *Training of traffic managers and supervision* directed to controller's activities represent an influence of the training on quality of controller's work. The efficiency of the training process using a training simulator can be measured as a change of variability of activities. In this figure the couplings from background function *Organization of train traffic* oriented to controller activity *Receipt of notification of an arriving train* (and the couplings to the other activities that are not shown in this figure) can represent influence of different controller workload in training using the training simulator. Additionally, description of events: accidents and incidents as structures of executions of activities can be used in statistical analysis of events.

## 6. Conclusions

The Functional Resonance Analysis Method and Analytic Hierarchy Process based method for preparing the rail controller training program has been proposed in the paper. The differences between this FRAM and AHP method and other FRAM and AHP approaches described in literature have been shown. Moreover, the method can be used after adapting activities for other groups of railway employees that are highly responsible for system safety. Beside other groups of railroad personnel, further research will be also oriented on investigation of the traffic manager's model using additional methods, like the suggested Cognitive Reliability and Error Analysis Method. The questionnaire in controllers community and AHP method are applied to select activities for the training of train traffic managers on the base of variability. It is worth to distinguish the training according to the main cause of variability: timing or precision. In addition, it is planned to develop a system for evaluating training conducted according to our proposed method. In this evaluation process, statistical analysis of: a survey conducted among employees and results of traffic managers training will be performed.

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## References

[1] De Felice, F., Petrillo, A. (2011). Methodological approach for performing human reliability and error analysis in railway transportation system. *International Journal of Engineering and Technology*, 3(5), 241-253.

[2] Franca, J.E.M., Hollnagel, E., Luquetti dos Santos, I.J.A.: Haddad, A.N. (2020). FRAM AHP approach to analyse offshore oil well drilling and construction focused on human factors. *Cognition, Technology and Work*, 20, 653-665.

[3] Dimitrov, D., Trendafilov, Z. (2018). About the need for performing training and increasing the qualification of dispatchers and movement managers in railway transport. *International Journal of Innovative Technologies in Economy*, 5(17), p. 68-72.

[4] Gołębiowski, P., (2020). Method of Planning the Work of Conductor Crews Taking into Account the Polish Conditions, in: *ISCT21 2019: Research Methods and Solutions to Current Transport Problems*, 154-163. DOI: 10.1007/978-3-030-27687-4_16.

[5] Hatakeyama, N., Okada, Y., Hayama, K., Kaburagi, T., Miyachi, Y. (2016). Training Method of Communication Skills for Train Dispatchers in Abnormal Situations. *Quarterly Report of RTRI*, 57(2), 138-143.

[6] Hill, R., (2016) FRAM Model isualiser (FMV) version 0.4.3.

[7] Hirose, T., Hideki, N., Hollnagel, E., Hill, R., Sawaragi, T., Slater, D. (2020). Treating variability formally in FRAM. Preprint, DOI: 10.13140/RG.2.2.26507. 72485.

[8] Hollnagel, E., Hounsgaard, J., Colligan, L. (2014). FRAM – the Functional Resonance Analysis Method – a handbook for the practical use of the method. *Centre for Quality, Region of Southern Denmark*.

[9] Hollnagel, E., Pruchnicki, S., Woltjer, R., Etcher, S. (2008). Analysis of Comair flight 5191 with the functional resonance accident model. In: *8th International Symposium of the Australian Aviation Psychology Association, Sydney, Australia*. 8 p. hal-00614254.

[10] Jacyna M., (2009). Modelling and evaluation of transportation systems (in Polish). *Oficyna Wydawnicza Politechniki Warszawskiej*, Warszawa.

[11] Jacyna, M., Wasiak, M., Kłodawski, M., Lewczuk, K., (2014). Simulation model of transport system of Poland as a tool for developing sustainable transport. *Archives of Transport*, 31(3), 23-35. DOI: 10.5604/08669546.1146982.

[12] Jacyna, M., Żak, J., (2016). Simulation Models in Testing Reliability of Transport Process. *Journal of KONBiN* , 37(1), 203-230. DOI: 10.1515/jok-2016-0010.

[13] Jacyna-Gołda, I., Gołębiowski, P., Izdebski, M., Lewczuk, K., Kłodawski, M., Jachimowski, R., Szczepański, E., (2017). The evaluation of the sustainable transport system development with the scenario analyses procedure. *Journal of Vibroengineering*, 19(7), 5627-5638. DOI: 10.21595/jve.2017.19275.

[14] Leveson, N. (2012). Engineering a Safer World, Systems Thinking Applied to Safety. *MIT Press*.

[15] Lin, Y., Min, X. (2022). Quantitative safety analysis of train control system based on statistical model checking. *Archives of Transport*, 61(1), 7-19.

[16] Lower, M., Magott. J., Skorupski, J. (2018). A system-theoretic accident model and process with human factors analysis and classification system taxonomy. *Safety Science*, 110(Part A), 393-410.

[17] Magott, J., Wikiera-Magott, I. (2020). Patient safety analysis in general practitioner's work using Functional Resonance Analysis Method (FRAM). *Journal of KONBiN*, 50(3), 217-236.

[18] Manoy, M.: Multicriteria decision making, Analytic hierarchy process (AHP) method. https://www.youtube.com/watch ?v=J4T70o8gjlk, accessed 2021/01/05.

[19] Patriarca, R., Di Gravio, G., Costantino, F. (2017). A Monte Carlo evolution of the Functional Resonance Analysis Method (FRAM) to assess performance variability in complex systems. *Safety Science*, 91, 49-60.

[20] Patriarca, R., Di Gravio, G., Woltjer, R., Costantino, F., Praetorius, G., Ferreira, P., Hollnagel, E. (2020). Framing the FRAM: A literature review on the functional resonance analysis method. *Safety Science*, 129, Article number 104827.

[21] Rasmussen, J., Svedung, X. (2000). Proactive Risk Management in a Dynamic Society. Swedish Rescue Services Agency.

[22] Restel, F. (2021). The railway process evaluation method in terms of resilience analysis. *Archives of Transport*, 57(1), 73-89.

[23] Rosa, L.V., Haddad, A.N., De Carvalho P.V.R. (2015). Assessing risk in sustainable construction using the Functional Resonance Analysis Method (FRAM). Cognition, *Technology and Work*, 17.

[24] Saaty, T. L. (1980). The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation. McGraw-Hill.

[25] Todorova, M., Kirchev, T., Trifonov, K. (2019). A survey on needs and possibilities of training in acquiring "Train dispatcher" qualification. *BulTrans-2019 Conference Proceedings*, Sozopol.

[26] Trowitzsch, J., Zimmermann, A., Hommel, G. (2005). Towards quantitative analysis of real-time UML using stochastic Petri nets. Proc. *19th IEEE International Parallel and Distributed Processing Symposium*, 7.