Applicability of the Functional Resonance Analysis Method in urban transport

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Abstract. Functional resonance is a novel approach of explaining how adverse events happen in complex socio-technical systems. It stresses the fact that such systems in most of the cases function without any negative consequences due to their internal adaptiveness, called resilience. Therefore, this approach is particularly suitable to domains with relatively high level of safety, where there is not much data on incidents and accidents form the past. It can also be used for describing other analyses domains in order to better understand their resilience mechanisms. The literature review performed with help of Scopus database shows clearly that the topic of functional resonance is getting more and more attention in the scientific world. The research aiming to develop the FRAM or using it as a tool for various kinds of safety analyses is being published in the best journals from a variety of disciplines, especially the Engineering. Transportation system was the domain of the research in four investigated papers; three times the aviation transport and once – maritime transport. There was no publication in the urban transportation, although the FRAM is applicable also in this domain.

1 Introduction

The widely-used definition of safety is "the state of the analysis domain with no hazards" [1], especially – hazards of unacceptable risk [2,3]. Measuring safety is therefore done through measuring risk of hazards; the lower the risk is, the higher safety level is expected. This approach leads to a paradox where safety interventions taken hinder the possibility of measuring their real impact on safety through limiting the measurable quantity. Therefore, defining safety through the negation of risk is being criticised by many safety science researches.

One of the most influential work in respect to understanding of safety was Hollnagel's book on so-called 'Safety-II' approach [4]. The difference between the 'Safety-I' (the traditional way of understanding safety) and the proposed 'Safety-II' has been graphically shown in Figure 1. However, as emphasised by Hollnagel, the 'Safety-II' approach is not intended to exchange the 'Safety-I', but should be seen as its supplement for complex systems.

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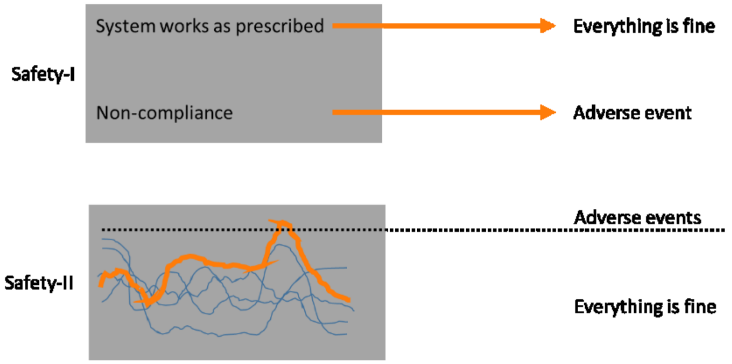

Fig. 1. Differences between Safety-I and Safety-II approaches to explain the nature of adverse events.

According to Hollnagel, the traditional approach to safety ('Safety-I') is driven by the assumption that systems' functioning is bimodal. As long as the system works as prescribed by the relevant specifications and procedures, there are no adverse events; the system's function is fulfilled. On the other hand, any adverse event can be tracked down to a non-compliance of some type, e.g.:

– the specification of the system was not detailed enough
– a technical element of the system does not conform to the specification
– a person was not following respective procedures.

With this approach, there is always a countermeasure possible, i.e. new specification, exchanging of faulty technical parts, more surveillance on people involved in the system's functioning.

'Safety-II' sees the functioning of complex systems as non-deterministic, their dependencies being too difficult to fully understand and track the initial reasons for the adverse events. Instead, a model is proposed where all the system's functions are fulfilled sometimes 'more'/'stronger', and sometimes 'less'/'weaker'. The overall functioning of the system is a superposition of all its functions. If this aggregated function exceeds some boundary, an adverse event happens. This situation is called 'functional resonance', per analogy to amplification of vibration in mechanics.

In most of the cases, however, the system is capable of keeping the function below the limit and it does not mean that inside of the system everything is performed as prescribed. With the proposed approach it becomes important to observe the system's functioning all the time, even if no adverse events happen. The captured variability of functions performance can help to predict scenarios when the functional resonance occurs. Such observation can be done with help of Functional Resonance Analysis Method (FRAM).

The aim of the article is to indicate the possibility of using the Functional Resonance Analysis Method for the implementation of the "Safety II" approach in selected urban / land transport domains.

2 Material and Methods

2.1 Functional Resonance Analysis Method

Functional resonance is a novel approach of describing the mechanism of how adverse events happen in complex socio-technical systems. It stresses the fact that such systems in most of the cases function without any negative consequences due to their internal adaptiveness, called resilience. Therefore, this approach is particularly suitable to domains with relatively high level of safety, where there is not much data on incidents and accidents form the past. Instead of reasoning based on past events, detailed description and subsequent analysis of performance variability in everyday operation is used. The method is based on four principles [5]:

1. Equivalence of failures and successes. Failures and successes come from the same origin, i.e. everyday work variability. The variability is responsible for things that go wrong, but can also be the reason for things going the way they are intended to.
2. Principle of approximate adjustments. People individually and in groups adjust their everyday performance to match the partly intractable and underspecified working conditions of the large-scale socio-technical systems.
3. Principle of emergence. It is not possible to identify the causes of all the safety events. Many events appear to be emergent rather than resultant from a specific combination of fixed conditions. Some events emerge due to particular combination of time and space conditions, which could be transient, not leaving any traces.
4. Functional resonance. The functional resonance represents the detectable signal emerging from the unintended interaction of the everyday variability of multiple signals. This resonance is not completely stochastic, because the signals variability is not completely random but it is subject to certain regularities, i.e. recognizable short-cuts in fulfilment of procedures.

In brief, the steps for safety system analysis using FRAM are [5]:

1. Identification and description of system's functions
2. Identification of performance variability
3. Aggregation of variability
4. Management of variability.

The distinctive feature of the FRAM is the way how the functions are represented. The graphical form of this representation is shown in Figure 2.

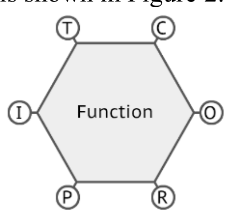

Fig. 2. A hexagon characterising function in FRAM [6].

As shown in Fig. 2, each function is characterised through six aspects [7]:

1. Input (I): what the function transforms or processes or what starts the function
2. Output (O): the result of the function, either an entity or a state change
3. Preconditions (P): conditions that must exist before a function can be executed
4. Resources (R): what the function needs when it is carried out or consumes to produce the Output
5. Time (T): temporal constraints influencing the function (with regard to starting time, finishing time or duration)
6. Control (C): how the function is controlled.

The function hexagons are connected with each other according to the aspects of these connections. The graphical form can be obtained e.g. with help of the FRAM official software [6]. The results of such modelling can be impressive in terms of number of functions and connections, but – due to the generic nature of FRAM – there are no solutions to issues resulting from application of this method to specific analyses domains. Therefore, research is being made to establish ways of customisation for FRAM.

2.2 Literature review

An inquiry in the Scopus database has been made to examine the number of publications that include ‘Functional Resonance Analysis Method’ phrase in the title, abstract or as a keyword. The result shows that 60 papers have been published since 2008. This number includes also papers with the status ‘in press’. Slightly less than half of the papers have been published in journals indexed in the Journal Citation Reports database (i.e. journals with Impact Factor). The distribution of the number of papers in years has been shown in Figure 3. The number of papers classified to different subject areas has been shown in Figure 4.

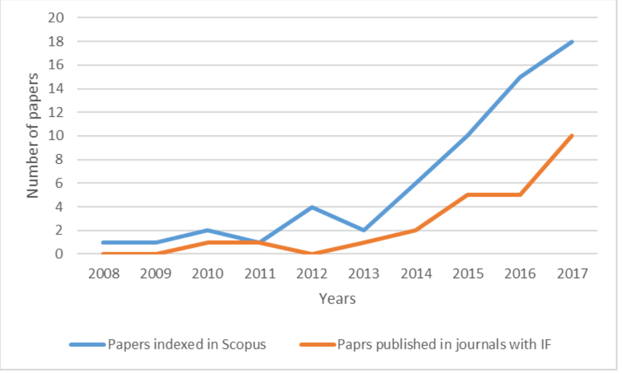

Fig. 3. Scientific papers on Functional Resonance Analysis Method indexed in Scopus.

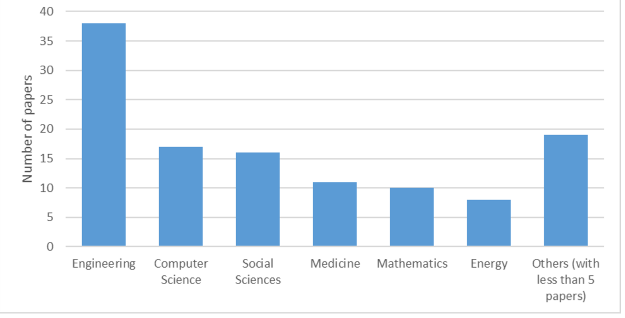

Fig. 4. Scientific papers on Functional Resonance Analysis Method indexed in Scopus according to the subject area (multiple answers possible).

For this study, the content of the most recent papers published in journals with Impact Factor in year 2017 has been analysed and summarised in Table 1 (papers where FRAM is used to describe real socio-technical systems) and Table 2 (papers that further explore the FRAM).

3 Results

The literature review shows clearly that the topic of functional resonance is getting more and more attention in the scientific world. The research aiming to develop the FRAM or using it as a tool for various kinds of safety analyses is being published in the best journals from a variety of disciplines, especially the Engineering.

Six of the analysed papers (Table 1) present research that had the aim to describe existing socio-technical systems. In four cases, transportation system was the domain of the research: three times the aviation transport and once – maritime transport. The research methodology used was based mainly on review of literature, operation manuals, existing documentation related to the analysis domain etc. This theoretical study was than enriched by observations and/or interviews with experts and people involved in the respective socio-technical system. Once, in paper [8], the methodology contained also analysing of accidents reports.

Table 1. Content of the newest papers on the Functional Resonance Analysis Method used to describe real socio-technical systems that were published in journals with Impact Factor in year 2017.

Title of the paper	Impact Factor 2016	Domain
A systemic modelling of ground handling services using the functional resonance analysis method [9]	3.805	Ground Handling Services at airports
The Functional Resonance Analysis Method for a systemic risk based environmental auditing in a sinter plant: A semi-quantitative approach [10]	3.094	Sinter plant (steel factory)
A Monte Carlo evolution of the Functional Resonance Analysis Method (FRAM) to assess performance variability in complex systems [5]	2.246	Air Traffic Management system
Safety is an emergent property: Illustrating functional resonance in Air Traffic Management with formal verification [7]	2.246	Air Traffic Management system – Minimum Safe Altitude Warning
Blood sampling - Two sides to the story [8]	1.866	Operation of taking blood in Scottish hospitals
Modelling complexity in everyday operations: functional resonance in maritime mooring at quay [11]	1.105	Maritime mooring operation

Four of the papers being analysed (Table 2) were devoted to the further development of the FRAM.

Table 2. Content of the newest papers exploring the Functional Resonance Analysis Method that were published in journals with Impact Factor in year 2017.

Title of the paper	Impact Factor 2016	Domain
An application of the Functional Resonance Analysis Method (FRAM) to risk analysis of multifunctional flood defences in the Netherlands [12]	3.153	Multifunctional flood defences in the Netherlands – capturing unexpected dependencies
Defining the functional resonance analysis space: Combining Abstraction Hierarchy and FRAM [13]	3.153	Theoretical study; its applicability shown on a case of railway accident at Esher on 25 November 2005
Proposing leading indicators for blood sampling: application of a method based on the principles of resilient healthcare [14]	1.105	Theoretical study; its applicability shown on blood sampling
Hazard/threat identification: Using functional resonance analysis method in conjunction with the Anticipatory Failure Determination method [15]	1.084	Theoretical study; its applicability shown on lifting operation

Most of the papers address the problem that occurs in the last step of the FRAM, when the way of management of the performance variability is to be proposed. Anvarifar et al. [12] notice that further work is required to test the applicability of the FRAM for detailed risk analysis in more complicated and data demanding case studies. Patriarca et al. [13] add that a comprehensive FRAM analysis might generate a representation, which is impressive in terms of its sheer number of functions and couplings, but hard to make interpretive sense for further analytical purposes. The solutions used to overcome this problem consists of decomposition schemes and various original computer software based on Monte Carlo simulation.

4 Final remarks

Four out of ten papers on FRAM published in the top scientific journals in 2017 were devoted to the topic of transportation, but none of them dealt with either urban or even road transportation. However, the subject of the published works and the FRAM description itself indicate the possibility of applying this method also to the analyses of these specific modes of transport.

This applies above all to the urban transport system, which has a particularly large number of dependencies between the infrastructure elements (e.g. traffic lights, ITS), vehicles (cars, buses, trams) and their drivers, as well as pedestrians. Despite this complexity, this system very often is able to use its internal adaptiveness, thanks to which adverse events do not occur even after breaking the applicable procedures (mostly traffic code) by several participants at the same time.

It has to be noted though, that correct and purposeful identification of individual functions for FRAM analysis would require performing relevant field tests and / or using driving simulators. The analysis can also be supported by a computer simulation of the system described by the FRAM diagram [16]. As a result it should be able to identify and strengthen resilience mechanisms in urban transportation.

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