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# FUNCTIONAL NETWORKS FOR ERGONOMICS AND RELIABILITY TASKS ON THE 90TH ANNIVERSARY OF A. GUBINSKY AND V. EVGRAFOV

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*SUMMARY: The paper considers the tasks of discovering ergonomic reserves for increasing the reliability and efficiency of automated systems. The authors show the necessity of using the Activity Approach and the Theory of Functional Networks, developed by the scientific school of Professor Anatoly Ilyich Gubinsky. The authors describe the history of Functional Networks approach and the current state of development of the functional networks models and show the possibilities for automating the assessment of reliability of human-machine interactions. The research describes the common ergonomics issues and its effective solution by the introduction of automated procedures for the analysis and evaluation of functional networks. The authors further present the ways of using the developed models in decision support systems in the automated systems design and operation.*

**Key words:** *information systems, reliability, human-operator, ergonomics, information technology, human factors, man-machine interaction, efficiency, computer simulation*

## INTRODUCTION

Despite the introduction of integrated automation systems and even artificial intelligence (*Radziwon et al., 2014, Wang et al., 2015, Zhong et al., 2017*), the number of security and reliability issues in information systems and manufacturing keeps increasing *(Hamdi et al., 2019, Kharchenko et al., 2019, Rotshtein, 2018)*.

In contemporary Man-Machine Systems (HMS) the number of accidents, threats to environment, health, and human lives also keeps increasing. Some statistical examples one can see in Figures 1-3 *(Database of chemical accidents…, Lavrov et al., 2021b, Zhao et al., 2017)*.

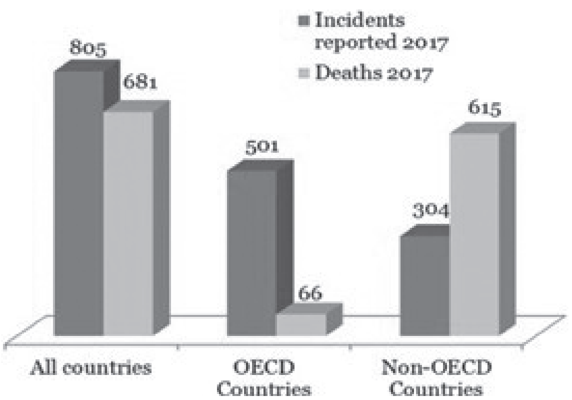


*Figure 1. Number of chemical incidents reported in mass media in 2017*

*Slika 1. Broj kemijskih incidenata prijavljenih u masovnim medijima u 2017.*

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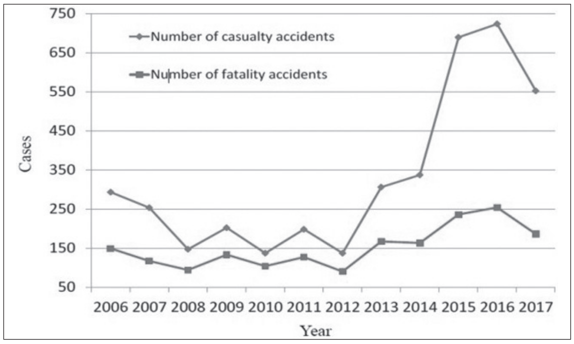



*Figure 2. Industrial accidents and fatalities in China (2006–2017) in chemical industry*

*Slika 2. Industrijske nesreće i smrtni slučajevi u Kini (2006.–2017.) u kemijskoj industriji*

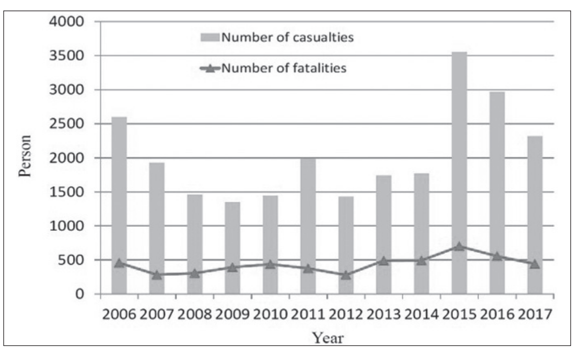



*Figure 3. Number of victims in industrial accidents and fatalities in China (2006–2017) in chemical industry*

*Slika 3. Broj žrtava industrijskih nesreća i smrtnih slučajeva u Kini (2006. – 2017.) u kemijskoj industriji*

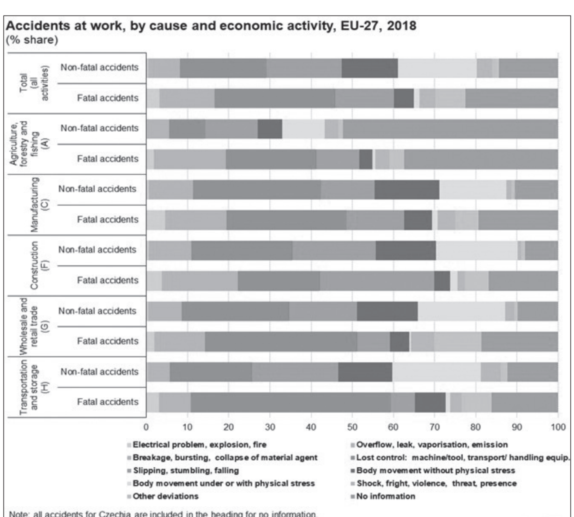



*Figure 4. Fragment of European statistics on the causes of accidents (2018)*

*Slika 4. Fragment europske statistike o uzrocima nesreća (2018.)*

It is a generally accepted that from 50 to 90 percent of accidents and problem situations in transport, industry, agriculture is caused by the human factors. One can see an example of official European statistics (fragment) in Figure 4 *(EUROSTAT Statistics Explained, 2021)*.

## RESEARCH ANALYSIS AND GOALS SETTING

Due to increasing number of issues associated with accidents and mortality of people in automated production, the number of scientific studies related to the adaptation of technology and the external environment to the human operator is also increasing, for example *(Zhirabok et al., 2018, Reason, 2009, Xu et al., 2017)*. We can mention many conferences held on the named issues, such as ERGONOMICS 2020 *(Croatia, December 2020)*, the Triennial Congress of the International Ergonomics Association *(Canada, June 2021)* and many others. The number of published papers related to the study of both general approaches that ensure the reliability of human-operator and the high level of ergonomics is also increasing in recent years *(Fesenko et al., 2018, Havlikovaa et al., 2015, Jongprasithporn et al., 2018, Levin et al., 2019, Li et al., 2017, Rotshtein, 2018, Wiboonrat, 2020)*. The research papers mainly consider the following topics:

- Working conditions,
- Usability of information systems,
- Operator's situational awareness and training.
- Operator's functional state (e.g., stress and tiredness).

The analysis of recent papers devoted to the risks in human-machine systems performance indicates that the main task is to integrate the methods of managing the ergonomics and reliability of operators in the overall quality management systems in manufacturing and information systems *(Bridges et al., 2010, Theophilus, et al., 2018)*. The approaches to solving the problem proposed in *(Bridges et al., 2010)* one can see in Figure 5.

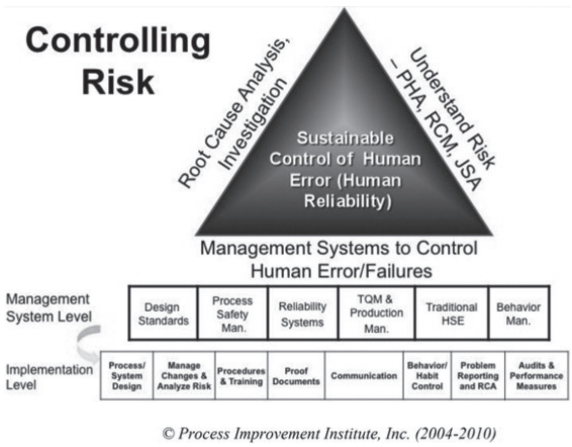



*Figure 5. The concept of human-operator reliability systems*

*Slika 5. Koncept sustava pouzdanosti čovjek-operater*

Unfortunately, despite the increasing number of research devoted to the human-operator reliability *(Asgari et al., 2017, Liaw et al., 2017, Shao et al., 2021)*, the problem of the ergonomic reserves identification to ensure the automated systems quality has not been fully resolved. The problem is associated with the need for a unified model of the human-operator activity that considers all its features and factors affecting it.

Since the modelling of risks in man-machine systems presented in the reports at ERGONOMICS 2020 conference *(Lavrov et al., 2021, 2021a)* aroused interest and many questions, and due to lack of papers in English on the fundamental approach developed in Ukraine and Russia, Prof. Davor Sumpor inspired the authors to further describe in the present article the features and the usage possibilities of functional networks (FN) as a model of human-machine interaction.

Thus, the purpose of the article is to present and describe:

- Fundamentals of FN theory,
- Current possibilities of modelling human-machine interaction using the FN apparatus,
- Examples and mechanisms of using FN in systems to ensure the reliability of automated systems.

## FN THEORY AND ITS USAGE

### Background and history of FN theory proposed to model human-machine interaction

Dr. of Technical Sciences, Prof. Anatoly Ilyich Gubinsky (1931-1990, St. Petersburg) was the ideologist and creator of the Functional-Structural Theory of Ergo-Technical Systems (FST ETS).

The prerequisites for the theory development were the low efficiency and adaptability of man-machine systems, which A. I. Gubinsky faced as a naval sailor (in 1959, he took part in the first cruise of a nuclear-powered submarine to the North Pole). Faced in practice the ergonomics and human factors (HFE) issues ubiquitously manifested in the Navy, A. I. Gubinsky devoted his whole life to solving these problems.

Solving the HFE issues for the Navy, A. I. Gubinsky considered the following approaches to determine a complex system:

- Systemic-technical – acknowledge a system as a set of technical elements *(machine)*, human-operator *(man)* is considered as a factor of the external environment,
- Equal Element – acknowledges a system as a combination of equal *man* and *machine* elements,
- Human-systemic – considers a human-operator *(man)* as a main element of a system, and a *machine* as a subordinate labour tool,
- Narrow-anthropocentric – considers a system as consisting of the *man* element, and the *machine* element as a factor of the external environment,
- Narrow-technical – acknowledges a system as consisting of technical elements *(machine)*, the *man* element is not considered.

A. I. Gubinsky had singled out the human-systemic approach as the only possible in terms of system performance efficiency. The human-systemic approach was later used as the basis of the emerging scientific school.

In 1963, A. I. Gubinsky together with Yu. P. Grechko, created and headed the first ever scientific laboratory for the ergonomic support of the Navy. In 1965, Dr. of Technical Sciences, Prof. Vladimir Georgievich Evgrafov (1931-2011) joined the research.

The joint activity of the scientists resulted in the creation of the FST ETS scientific school.

In 1963-1969 the scientists developed the integrated approach and methodology to analyse the efficiency, quality and reliability of operators' activities in Ship Control Systems; various algorithms were tested to optimize the number of crews.

Subsequently, numerous associates and students from different countries – Ukraine, Israel, Russia, Georgia, Armenia, Lithuania, Poland, Germany, Vietnam, etc. – extend the results to other different types of systems:

- Information systems,
- Technical systems,
- Aerospace systems,
- Command and control systems, and
- Others.

Applying in practice in the design of ship control systems the so-called "information theory" based on the assessment and optimization of the amount of information processed by an operator, A. I. Gubinsky and his colleagues became convinced of the low adaptability of purely informational models to solving practical HFE issues. Difficulties were associated with the lack of ability to analyse the structures of activity and the laboriousness of designing adequate models for real processes. The use of a purely informational approach did not allow solving numerous problems emerging in the real ship systems design and performance. These difficulties became the reason for the orientation towards the Activity Approach.

"If one adequately describes the human-machine interaction with the help of FN, taking into account the possibilities of occurrence and elimination of errors, malfunctioning, failures of any structural element (human, technology, information support, software, etc.), and taking into account many influencing factors, including external environment, it is possible to assess the reliability and optimize the man-machine interaction with sufficient accuracy for practice" became the main hypothesis.

Considering the requirements of the activity approach, researchers can describe the functioning processes by several formal systems *(Drakaki et al., 2017, Farah et al., 2019, Adamenko et al. 1993)*:

- Logical systems (formal grammars, Petri nets, logical automata, event algebras, logical algorithms, etc.),
- Algebraic systems (Markov and semi-Markov processes, semi-Markov service networks, etc.),
- Linguistic-algebraic systems (precedence networks, PERT, GERT, etc.).

However, the limited logic and the impossibility of implementing procedures for assessing the reliability and time performance indicators did not allow using these models for evaluating complex processes of human-machine interaction (considering failures and errors of different types, restoring operability and eliminating errors, cycles and complex logic of interaction between functional elements).

Subsequent long-term researches of pupils and colleagues on scientific school (professors, doctors of sciences A. T. Asherov, E. B. Tsoy, P. P. Chabanenko, V. V. Kobzev, A. P. Rothstein, P. I. Paderno, M. G. Grif, O. Y. Burov, E. A. Pavlov, G. K. Kozhevnikov, A. N. Adamenko, A. M. Kuchukov, S. D. Shtovba, N. B. Pasko, N. L. Bartcenko, S. N. Serdjuk, M. Vlodarchik and many others), which were also conducted after Professors A. I. Gubinsky and V. G. Evgrafov passed away, proved the constructiveness and efficiency of the approach.

The general crisis of Soviet science, caused by the collapse of the USSR and the problems of interaction of scientists from some countries (coinciding with the death of Prof. A. I. Gubinsky) conditioned problems of the scientific school, which lasted until about the end of the 90s of the 20th century, followed by a period of active work associated with the removal of some restrictions and assumptions.

The FN-based models obtained in recent years have made it possible to fully automate the assessment and optimization processes as well as to remove several restrictions associated with the characteristics of a human-operator as an element of a system.

## FN as a model for describing and evaluating human-machine interaction

The FN-based models obtained in recent years have made it possible to fully automate the assessment and optimization processes, as well as to remove some restrictions associated with the characteristics of a human-operator as an element of a system.

The process of functioning is "a set of human-operator actions and operations performed by automation, combined into a single purposeful sequence due to the control and support activities of human-operators, which form a coherent logical-temporal sequence from a disparate nomenclature of individual functions, resistant to disturbances and leading to the achievement of the set goal".

The resulting ergonomic quality is efficiency - the feature of the system to achieve its goal (e.g., to receive a product of labour) with a given quality under given conditions. The system-wide indicators also include quality indicators and operational reliability. Operational efficiency is determined by operational reliability, performance and functionality (Figure 6.), and the nomenclature of the main system (pragmatic) indicators of the process of functioning is presented in Table 1.

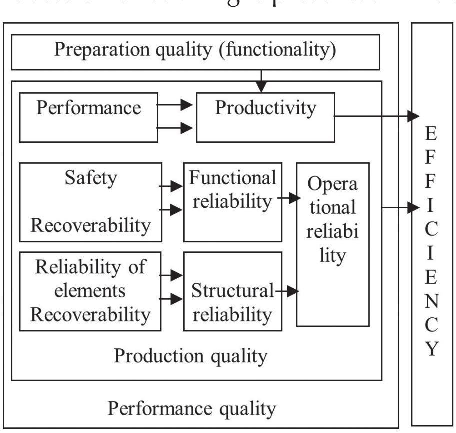



*Figure 6. Properties of a man-machine system that determine its effectiveness*

*Slika 6. Svojstva sustava čovjek-stroj koja određuju njegovu učinkovitost*

**Table 1. Key indicators of efficiency, quality and reliability of automated systems (pragmatic)**

**Tablica 1. Ključni pokazatelji učinkovitosti, kvalitete i pouzdanosti automatiziranih sustava (pragmatični)**

| Property | Indicator name |
|---|---|
| Efficiency | The probability of error-free and timely execution of the functioning process<br>The costs of the functioning process execution |
| Productivity | The distribution of the functioning process execution time and its moments: expected value and variance<br>The likelihood of timely execution of the functioning process |
| Structural reliability | The probability of failure-free operation of the system during the function execution<br>The probability that the system is in a state of readiness now of an application receipt to execute a function<br>The probability that the system is in a state of readiness at the moment of application receipt to execute a function and will perform the prescribed function if the interruptions arising from failures during the period of function execution do not exceed the allowable time |
| Functional reliability | The probability of error-free function execution |

The basic principles of the FST ETS:

- The principle of the functional basis (the structure of the functions executed, the F-structure is taken as the basis for constructing mathematical models for describing and evaluating the functioning process),
- The principle of the functioning units' typicality (to describe various processes, a small composition of Typical Functioning Units (TFU) is selected, with the help of which a wide class of systems can be modelled, each TFU is characterized by indicators of quality and performance reliability),
- The principle of multiple outcomes of system functioning,
- The principle of the finiteness of the functioning process,
- The principle of the typicality of the estimated indicators,
- The principle of equivalence (individual fragments or the entire functioning process

can be replaced by operations of a lower dimension, having the same quantitative values of indicators and quality of functioning as the original fragments),

- The principle of the mathematical models typicality (the most common blocks of the functioning process the TFU of form Typical Functional Structures (TFS), for each TFS mathematical models are displayed in advance, TFS are saved in the library and used when equivalent).

The essence of the method is as follows *(Adamenko et al., 1993, Chabanenko, 2012, Grif et al., 2018)*:

1. Description of the human-operator activities:

- Set of functionaries of TFU type (see examples in Table 2):
  - Working operations,
  - Correct functioning control operations,
  - Performance control operations,
  - Organizational control operations,
  - Alternative operations (decision making),
  - Delay (wait) operations.
- Set of composers (which describe the logical-temporal connections between functionaries) of TFU type:
  - Starters (with different logic for parallel processes - AND, OR, OR exclusive, etc.),
  - Finishers (with different logic for parallel processes - AND, OR, OR exclusive, etc.),
  - Cycle limiters,
  - Cycloformer.

See examples of functionaries in Table 2.

2. Indicators of reliability and execution time characterized each functionary.
3. The set of TFU forms the TFS. The structure of the TFS and the content of the TFU included in it determine the reliability and time characteristics of the TFS. There is a TFS library, which contains calculation formulas for determining the main time and reliability characteristics of the TFS. See example in Table 3.
4. By sequentially combining TFU into TFU, replacing TFU with an equivalent TFU and the next combination of equivalent TFU into new TFU, you can get a complete assessment of the quality of the entire activity (the demonstration is shown in Fig. 7.).

**Table 2. Functionaries (library fragment)**

**Tablica 2. Funkcionari (ulomak iz knjižnice)**

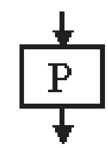
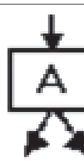
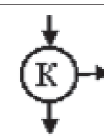
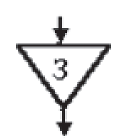
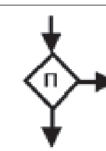
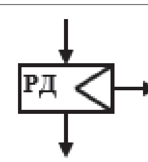
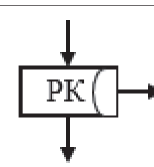
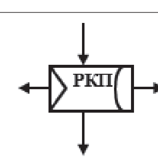
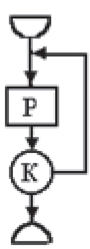
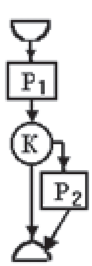
| Typical Functioning Units (TFU) | Symbol |
|---|---|
| 1 | 2 |
| Work operation |   |
| Alternative operation |   |
| Functioning control |   |
| Delay |   |
| Performance control |   |
| Work operation with performance self-control |   |
| Work operation with functioning self-control |   |
| Work operation with both performance and functioning self-control |   |

**Table 3. TFS models (library fragment)**

**Tablica 3. TFS modeli (ulomak iz knjižnice)**

| TFS | Model |
|---|---|
|  | $B = \prod_{i=1}^{n} B_i$ |
| | $M(T) = \sum_{i=1}^{n} M(T_i)$ |
| | $D(T) = \sum_{i=1}^{n} D(T_i)$ |
|  | $B = B^1 * K^{11} * \frac{1}{1-(B^1*K^{10}+B^0*K^{00})}$ |
| | $M(T)=(M(T_p)+M(T_K))*M(L)$ <br> $M(L) = \frac{1}{1-(B^1*K^{10}+B^0*K^{00})}$ |
| | $D(T)=D(T)*(M(T_p)+M(T_K))^2 +(D(T_p)+D(T_K))*M(L)$ <br> $D(L) = \frac{B^1*K^{10}+B^0*K^{00}}{(1-(B^1*K^{10}+B^0*K^{00}))^2}$ |
|  | $B = B_1^1*K^{11}+ (B_1^0*K^{00}+B_1^1*K^{10})*B_2^1$ |
| | $M(T) = M(T_{p1})+M(T_K)+ (B_1^0*K^{00}+B_1^1*K^{10})*M(T_{p2})$ |
| | $D(T) = D(T_{p1})+D(T_K)+ (B_1^0*K^{00}+B_1^1*K^{10})*D(T_{p2})+ (B_1^0*K^{00}+B_1^1*K^{10})* (B_1^1*K^{11}+B_1^0*K^{01})*M^2(T_{p2})$ |

* – rectangle – work operation (TFU), circle –correctness control (TFU), subscript shows the sequential number of TFU,

where:

$B^1$ – probability of correct execution (for a working TFU-P),

$K^{10}$ – the probability of correctly performed actions to be recognized as performed correctly during control operation (for the control operation -*K*), $K^{11}=1-K^{10}$,

$K^{00}$ – the probability of incorrectly performed actions will be recognized as performed incorrectly (for the control operation - *K*), $K^{01}=1- K^{00}$,

*T* – execution time random variable,

*M(T)* – execution time expected value (TFU or TFS),

*D(T)* – execution time variance (TFU or TFS),

*B* –probability of no errors.

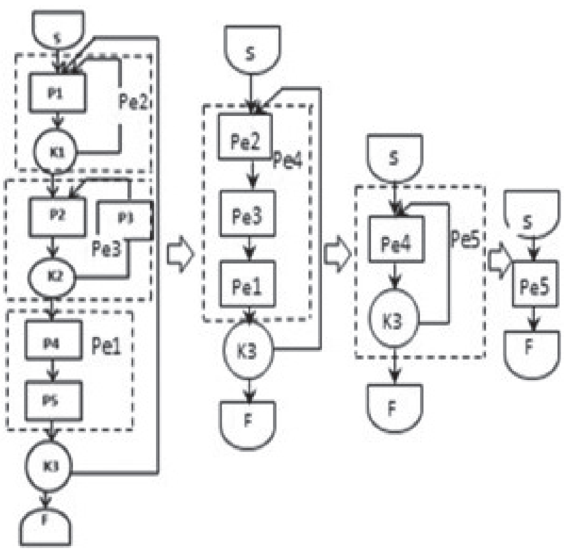



*Figure 7. Demonstration of the "folding" ("reduction") technology for FN*

*Slika 7. Demonstracija tehnologije "preklapanja" ("redukcije") za FN*

One can see an example *of the "folding" ("reduction") technology for FN, where:*

*S* – starter,

*F* – finisher,

*Pei* – equivalent working operation obtained at the *i*- th step of folding.

The characteristics of the final *Pe5* equivalent working operation are equivalent to characteristics of the entire activity algorithm.

**Automation of the human-machine interaction reliability assessment**

By 1996, researchers and practitioners developed about 10 different software systems for assessing and optimizing human-machine interaction (e.g., A. N. Adamenko, A. P. Rotshtein, A. V. Koshman, A. M. Kuchukov, M. G. Grif).

Despite the obvious advantages over other methods mainly based on humanitarian and expert methods, automation by the time ceased to meet the new requirements such as:

- Usability of the human-operator activities information input,
- Full automation of the assessment process,
- Ability to use the assessment tool in on-line systems to support the HFE decisions making.

The new requirements reduced the interest of HFE practitioners in Functional Networks. On the other hand, it stimulated the development of new tools and models (Table 4) related to the assessment automation and the initial data design based on Data Mining (DM) approach – data prediction according to data accumulated in specific information systems databases, considering various factors (e.g., working conditions, human-operator individual characteristics, interface usability, etc.).

As a Data Mining method, the authors use fuzzy approximation models, and machine learning algorithms, including neural networks *(Barchenko, 2019, Lavrov, Lavrova, 2019, Lavrov et al., 2020b, Rotshtein, 2018, Rotshtein et al., 2019, 2019a)*.

**Table 4. Models and tools development for the FN usage in decision support systems**

**Tablica 4. Razvoj modela i alata za korištenje FN-a u sustavima za podršku odlučivanju**

| Model year | 1996 | 2021 |
|---|---|---|
| Number of TFS | 18 | 55 |
| Natural-language FN structure input | - | + |
| FN models automatic generation, convenient for the human-operator activity parsing | - | + |
| TFS automatic recognition in the activity model | - | + |
| FNautomatic reduction (reliability assessment of the activity model) | - | + |
| Initial data generation for each operation in the activity model | Expert assessments (EA), HFE data bank (HFEDB) | EA, HFEDB, databases for specific systems based on DM algorithms |

Figure 8 demonstrates the principles of the developed methods and models that provide automatic assessment of human-operator activity *(Lavrov et al., 2017, 2020a)*.

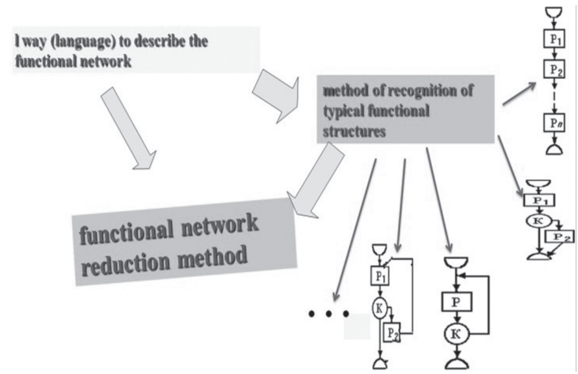
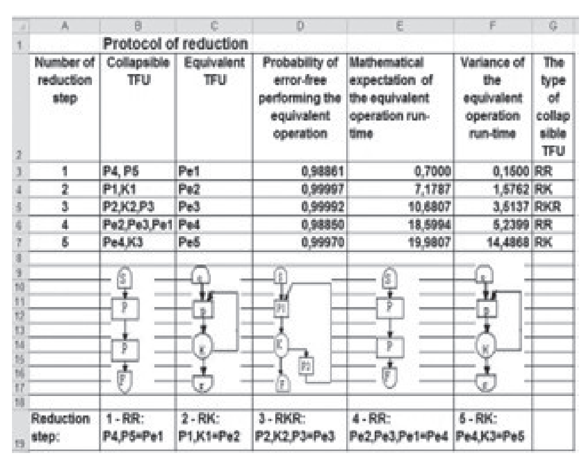



*Figure 8. The basis for modeling automation is the FN description followed by FN analysis, recognition and reduction*

*Slika 8. Osnova za automatizaciju modeliranja je opis FN-a nakon čega slijedi analiza, prepoznavanje i redukcija FN-a*

N. B. Pasko et al. *(Lavrov et al., 2018, 2020b)* developed the automation mechanisms incorporated in a software. In Fig. 9 one can see an example of the automatic human operator activity model assessment for a Banking Information System *(Lavrov et al., 2020)*.



Protocol of reduction

| Number of reduction step | Collapsible TFU | Equivalent TFU | Probability of error-free performing the equivalent operation | Mathematical expectation of the equivalent operation run-time | Variance of the equivalent operation run-time | The type of collapsible TFU |
|---|---|---|---|---|---|---|
| 1 | P4, P5 | Pe1 | 0,98861 | 0,7000 | 0,1500 | RR |
| 2 | P1,K1 | Pe2 | 0,99997 | 7,1787 | 1,5762 | RK |
| 3 | P2,K2,P3 | Pe3 | 0,99992 | 10,6807 | 3,5137 | RKR |
| 4 | Pe2,Pe3,Pe1 | Pe4 | 0,98850 | 18,5994 | 5,2399 | RR |
| 5 | Pe4,K3 | Pe5 | 0,99970 | 19,9807 | 14,4868 | RK |
| Reduction step: | 1 - RR: P4,P5=Pe1 | 2 - RK: P1,K1=Pe2 | 3 - RKR: P2,K2,P3=Pe3 | 4 - RR: Pe2,Pe3,Pe1=Pe4 | 5 - RK: Pe4,K3=Pe5 | |

*Figure 9. An example of automatic TFS recognition, and activity model assessment for the algorithm in Fig. 10 developed by N. B. Pasko*

*Slika 9. Primjer automatskog TFS prepoznavanja i procjene modela aktivnosti za algoritam na slici 10 koji je razvio N. B. Pasko*

**Functional networks in decision support systems for the HFE support of automated systems**

Functional networks can and should be the central element for decision support systems to find ergonomic reserves for increasing the efficiency of automated systems. The use of such models and mechanisms for evaluating the human-operator activities adapted and tested by us in solving all the main problems of ergonomics (Figure 10)

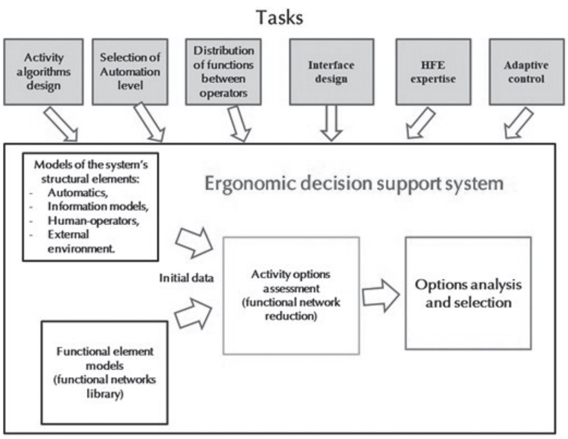



*Figure 10. Functional networks in HFE decision making systems*

*Slika 10. Funkcionalne mreže u HFE sustavima odlučivanja*

For the details on techniques for system models design to support the initial data generation for the FN one can see in *(Rotshtein, 2019a)*.

**Approbation**

The developed models and software have been repeatedly used to solve HFE problems in automated systems for various purposes *(Barchenko, 2019, Lavrov et al., 2017, 2018, 2019a, 2020, 2020a, 2020b, 2021a, 2021b)*, such as:

- Information service systems,
- Banking systems,
- Automated technological complexes (chemical production, flexible industrial systems for machining parts, gas pipelines control systems)
- E-learning systems, and
- Others.

The use of functional networks makes it possible to analyze competing options and make quick decisions, as well as justify the need to develop ergonomic measures and show the feasibility of investments into HFE, which is not always obvious for business.

## CONCLUSIONS

Increasing accidents and threats in automated production systems are forcing system designers and users to pay more and more attention to solving problems associated with the human factors and ergonomics.

Ensuring the efficiency and reliability of automated systems is mostly efficient when the quality management system embeds the two as subsystems to ensure the high-level of ergonomics of human-machine interaction and procedures.

The identification of ergonomic reserves will be effective within the human-system activity approach based on a quantitative assessment of the reliability indicators and the operations execution time.

The Functional Networks methodology, developed by prof. A. I. Gubinsky's scientific school, is a convenient tool for ensuring high-level of ergonomics, and makes it possible to describe and evaluate the procedures of human-machine interaction.

The models proposed in the article for describing FN and automatic reduction allow for rapid real-time evaluation of alternatives.

Human-machine interaction modeling software is a handy tool for use as part of decision support systems to address the full range of current HFE tasks, such as:

- Ergonomic expertise,
- Designing algorithms for activities,
- Designing information models,
- Choice of the degree of automation (distribution of functions between the human operator and automation),
- Determination of a rational number of operators and distribution of functions between operators,
- Adaptive control of processes of human-machine interaction.

The reliability of the proposed approach, methodology, and software were confirmed in the design and operation of computerized systems for various purposes.

## LITERATURE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## *FUNKCIONALNE MREŽE ZA ERGONOMIJU I ZADACI POUZDANOSTI U POVODU 90. GODIŠNJICE A. GUBINSKYJA I V. EVGRAFOVA*

*SAŽETAK: U radu se razmatraju zadaci otkrivanja ergonomskih rezervi za povećanje pouzdanosti i učinkovitosti automatiziranih sustava. Autori pokazuju nužnost korištenja pristupa aktivnosti i teorije funkcionalnih mreža, koje je razvila znanstvena škola profesora Anatolyja Ilyich Gubinsky. Autori opisuju povijest pristupa funkcionalnih mreža i trenutno stanje razvoja modela funkcionalnih mreža te prikazuju mogućnosti automatizacije procjene pouzdanosti interakcija čovjek-stroj. Istraživanje opisuje uobičajena pitanja ergonomije i njezino učinkovito rješenje uvođenjem automatiziranih postupaka za analizu i evaluaciju funkcionalnih mreža. Autori nadalje predstavljaju načine korištenja razvijenih modela u sustavima za podršku odlučivanju u projektiranju i radu automatiziranih sustava.*

***Ključne riječi:*** *informacijski sustavi, pouzdanost, čovjek-operater, ergonomija, informacijska tehnologija, ljudski faktori, interakcija čovjek-stroj, učinkovitost, računalna simulacija*

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