APARATURA
BADAWCZA I DYDAKTYCZNA

The concept of stream and system reliability on the example of the bakery industry

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ABSTRACT:

This article presents a new concept of technological system reliability based on the analysis of the relationship of associations of elements of energy streams, matter, information, time and finance. The method of stream specification and the method of determining the reliability values of significant and supporting relationships are given. Relevant relationships between elements of system streams were defined as having one-time reliability value. Supportive relationships have a value between zero and one. Relevant relationships are determined based on research, experience and knowledge. P_{ss} stream-system reliability is a scalar quantity, i.e. a number whose value lies between zero and unity. The size of P_{ss} characterizes the entire system without being denied. Its average value in standard time t_n expresses the efficiency of the production process. P_{ss} is the quotient of the number of significant relationships to the sum of the significant and supporting relationships. The form of expression on P_{ss} indicates how to optimize the process by increasing the number of relationships significant between the components of the system batch streams. The P_{ss} concept was used in research into the production efficiency of bakery X operating within the MSCBI group. System analysis of the bakery allows a significant increase in the bread baking process reliability after using robotization. The concept of P_{ss} stream-system reliability can be used to analyze the efficiency of technological processes and optimization in any production processes. This requires a detailed system analysis of such processes.

Koncepcja niezawodności strumieniowo-systemowej na przykładzie branży piekarniczej

Słowa kluczowe: niezawodność strumieniowo-systemowa

STRESZCZENIE:

W niniejszym artykule przedstawiono nową koncepcję niezawodności systemu technologicznego opartą na analizie relacji skojarzeń elementów strumieni energii, materii, informacji, czasu i finansów. Podano sposób specyfikacji strumieni i metodę ustalania wartości niezawodności relacji istotnych i wspomagających. Relacje istotne pomiędzy elementami strumieni systemu definiowano jako mające wartość niezawodności jeden w czasie. Relacje wspomagające mają zaś wartość pomiędzy zero i jeden. Relacje istotne określa się na podstawie badań, doświadczenia i wiedzy. Niezawodność strumieniowo-systemowa P_{ss} jest wielkością skalarną, to jest liczbą, której wartość zawiera się pomiędzy zerem i jednością. Wielkość P_{ss} charakteryzuje bezodmowną pracę całego systemu. Jej średnia wartość w czasie normowym t_n wyraża efektywność procesu produkcyjnego. Wielkość P_{ss} jest ilorazem liczby relacji istotnych do sumy relacji istotnych i wspomagających. Forma wyrażenia na P_{ss} wskazuje sposób optymalizacji procesu na drodze wzrostu liczby relacji istotnych pomiędzy komponentami strumieni wsadowych systemu. Koncepcję P_{ss} zastosowano w badaniach efektywności produkcyjnej piekarni X, działającej w ramach grupy MiMPBP. Analiza systemowa piekarni umożliwia istotny wzrost niezawodności procesu wypieku chleba po zastosowaniu robotyzacji. Koncepcja niezawodności strumieniowo-systemowej P_{ss} może być wykorzystana do analizy efektywności procesów technologicznych i optymalizacji w dowolnych procesach produkcyjnych. Wymaga to szczegółowej analizy systemowej takich procesów.

1. INTRODUCTION

The issue of reliability concerns mainly the technical, physical and organizational structure of the components of the system selected so that it fulfils the tasks set out [2, 4].

In general, a division is made into the concept of initial reliability at the start of operation and the reliability function distinguishing the impact of the operation time of a distinguished element on its reliability [1, 5].

The reliability function is constructed on the basis of experimental tests and practical knowledge of operation and characteristics of the system [3].

Active operation of the system until the first failure, i.e. refusal, is random. Therefore, reliability may be understood as probability to execute the specified commands (tasks) imposed on components that are in a specific relationship. Thus, active operation of the system is a set of interoperating components.

By definition, there are no non-interoperating components in the system.

In each system, in particular production system, there are: ϕ_E energy streams, ϕ_M material streams (of technical measures), ϕ_I information streams, ϕ_T time streams and ϕ_F financial streams.

The system operation may be identified with an organised set of relationships between components of the aforementioned streams.

Knowledge of the rights of probabilities of non-refused operation within a specified time and relationships functioning in the system between components of streams, may form the basis for determining the reliability of the entire system. Therefore, reliability may be one of the metrizable measures of system operation.

The aim of the article is to demonstrate a new reliability concept that relates to the entire system. Reliability is understood here as one of the representations of the operator acting on the aforementioned streams.

The reliability measure will be the ratio of a certain number of relations between the components of the stream, with the probability of meeting the tasks with values, to the total number of relations ensuring system efficiency. Knowledge of the reliability of the relationship of components with the probability value equal to one is obtained from experimental tests and from practical and theoretical knowledge of the nature of the system.

This article presents the concept of stream and system reliability, based on the example of the bakery X operating within the MSCBI group.

2. STRUCTURE OF THE PROCESS (PRODUCTION) SYSTEM

The process system is referred to as a set of system streams: ϕ_E, ϕ_M, ϕ_I, ϕ_T, ϕ_F and operator $\hat{O}$ whose action on the streams results in the P* product and S losses.

Therefore, the process system is also an organised set of relationships between the components of the stream which leads to the formation of the P* product and unavoidable S losses. The relationships between the components of the streams are the system actions presented in Figure 1.

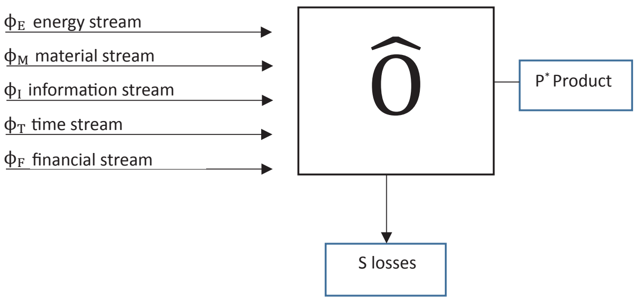

Figure 1 Structure of the tested bakery system (own study)

Symbolically, the actions of operator $\hat{O}$ may be specified as:

$$\hat{O}\,[\phi_E, \phi_M, \phi_I, \phi_T, \phi_F\,] \rightarrow P^* + S \qquad (1)$$

On the basis of the given definitions of the process system, Figure 1 and the distinguishing mark (1), the system may be identified with the operation. The process system does not exist without operation, i.e. without relationships between the stream components. These streams are "batch" collections of the system and differ in their role, form, function and number of components.

The energy stream $\phi_{i\,E}$ is a set of components related to the processing and transmission of electrical, mechanical, thermal and other energy necessary for the execution of the project tasks.

The material stream $\phi_{j\,M}$ is a set of components which guarantee full material protection of the implementation of the project objectives. These will be raw materials, machines and systems.

The information stream $\phi_{k\,I}$ is a set of components of properly organised instructions, algorithms, commands, guidelines and such segments of the state-of-the-art knowledge used which guarantee the highest efficiency of the process system operation.

The time stream $\phi_{l\,T}$ is a set of l- components of the principles of technological algorithms concerning the sequence of operations in time. The $\phi_{l\,T}$ components determine the duration of each operation, treatment and other actions regarding the operation duration.

The financial stream $\phi_{m\,F}$ is a set of components determining the operating costs of the system and the economic trends for the P* product demand.

Relationships between components of the process system streams mean the technological, organisational and economic relationships between individual components of the same stream or other streams which will ensure continuous operation of the system.

For example, the following relationships may occur in the bakery X which operates within the MSCBI group:

Spiral mixer $\phi_{2\,E}$, flour $\phi_{1\,M}$, water $\phi_{3\,M}$

($\phi_{2\,E}$, $\phi_{1\,M}$, $\phi_{3\,M}$)

Proofer $\phi_{9\,E}$, heater $\phi_{c1\,E}$, water $\phi_{3\,M}$

($\phi_{9\,E}$, $\phi_{c1\,E}$, $\phi_{3\,M}$)

The numbers of components of individual streams were taken from the table of specifications of the structure of the bakery X presented further in item 5.

The probability of non-refused (continuous) operation in the time τ from 0 to t_n of the arrangement of components in their specific relationship is designated as, for example:

$P_{[0,tn]}\,(\varphi_{2\,E}, \varphi_{1\,M}, \varphi_{3\,M})$

$P_{[0,tn]}\,(\varphi_{9\,E}, \varphi_{c1\,E}, \varphi_{3\,M})$

More generally, the reliability may be designated in time [0 to t_n] as:

$P_{[0,tn]}\,(\varphi_{i\,E}, \varphi_{j\,M}, \varphi_{k\,I}, \varphi_{l\,T}, \varphi_{mF})$

The above designations refer to the knowledge of the probability of readiness for non-refused operation of the arrangement of components in relationships in t = 0.

For example: $P_{t=0}\,(\varphi_{2\,E}, \varphi_{1\,M}, \varphi_{3\,M}) = 1$.

This means full efficiency for the components of the mentioned relationship at the beginning of the production process.

3. STREAM AND SYSTEM RELIABILITY (P_{SS})

Reliable operation of the relationships of the associated components of the system streams in

the time τ from 0 to t_n is a function, hence:
P_{tn} [0,tn] determines the impact of the operating time of a set of associated components on its reliability.
The value of function P_{tn} [0,tn] falls within the range between 0 and 1.

$P_{tn}[0,tn] \in [0,1]$

Hence, the reliability function P_{tn} [0,tn] is a stochastic characteristics.
The stream and system reliability P_{ss} [0,tn] determines the probability of non-refused operation of the entire process system, i.e. a full set of component relationships.
The stream and system reliability P_{ss} [0,tn] is defined as the ratio of the sum of significant relationships to the total sum of significant and supporting relationships. Therefore, the stream and system reliability determines the average value of the probability of non-refused operation of the system during the process time $\tau \in [0,tn]$.
The numerical measure P_{ss} is contained between unity as:

$$0 < P_{ss} < 1 \tag{4}$$

The formula for P_{ss} is as follows:

$$P_{SS} = \frac{\Sigma_{s=1}^{r} P_s^i[0,t_n]}{\Sigma_{s=1}^{r} P_s^i[0,t_n] + \Sigma_{s=1}^{z} P_s^W[0,t_n]} \tag{5}$$

In formula (5), index s denotes the number of relationships, r indicates the number of significant relationships, whereas z is the number of supporting relationships.
The measure P_{ss} is not a reliability function, but a scalar value defining the average reliability values of the entire system over time $\tau \in [0,tn]$.
The structure of the formula (5) for stream and system reliability also provides guidance on how to optimise the system structure. This is significantly related to the number of supporting relationships, the increase of which lowers reliability, while the increase of significant relationships increases the system reliability.
Therefore, technical implementations and innovations should lead to an increase in significant relationships, for example through the introduction of robotizaton.

4. SIGNIFICANT AND SUPPORTING RELATIONSHIPS

The stream and system reliability (P_{ss}) is one of the metrizable measures of the system operator Ô acting on the streams of energy, material, information, time and finance.
The stream and system reliability is the ratio of the number of reliability of significant associations and the relationships of system components to the sum of significant and supporting relationships.
Significant relationships are directly related to the system operator Ô acting in turn on the streams of energy, material, information, time and finance.
On the other hand, supporting relationships apply only to those relationships that support the process of significant relationships.
Significant relationships are characterised by the reliability of unit value, while supporting relationships have the reliability between zero and unity.
When examining and comparing the significant relationships between different streams, several criteria with dominating influence should be included. The following characteristics of these relationships are listed below:
1. Consistency. The system should be defined as to know what to do. The system definition may even be very general, but cannot be vague.
2. Invariability. The system definition should remain constant throughout the course of the discussions. It is unacceptable for some components to be sometimes treated as belonging to the system, whereas sometimes as not belonging to the system.
3. Completeness. The division of the system into subsystems should be complete. This means that the system cannot contain components not belonging to any of its subsystems.
4. Separation. The division into systems should be separable. This means that the system cannot contain components belonging to several systems at a time. The allocation of some components to one system must therefore be equivalent to the fact that they do not necessarily belong to any other system.
5. Functionality. The systems should be separated due to the functions performed and not due to spatial separateness.
Significant relationships $P^I_{[0,tn]}$ are associations of such components of the previously listed components of production streams, the cooperation of which during the process standard time $\tau = (0,t_n)$ is performed with the value of probability of non--refused operation as:

$$P^I_{[0,tn]} = 1 \tag{2}$$

Reliability of significant relationships with a value equal to unity is requested, based on research regarding the system, experience, achievements, tradition and the latest, verified technological practice and other knowledge, taking into account innovative elements.

Reliability of some part of significant relationships may be determined without testing. The knowledge is a result of experience. The identification of those significant relationships which do not require special tests requires extremely high competence of professional engineering personnel.

Supporting relationships $P^{W}_{[0,tn]}$ contain values of probability of non-refused operation of relationship of components of associated production streams in process time [0,tn] as:

$$0 < P^{W}_{[0,tn]} < 1 \qquad (3)$$

Supporting relationships should be partially necessary to ensure continuity of the full functionality of the system. Therefore, supporting relationships apply to such associations of process stream components, the refusal to operate of which will cause only a deterioration of the system operation.

It is assumed that such a refusal will not affect the operation of the system as a whole.

A collection of full set of system support relationships requires high qualifications of engineering personnel.

5. ANALYSIS OF STREAM AND SYSTEM RELIABILITY BASED ON AN EXAMPLE OF THE BAKERY X OPERATING WITHIN THE MSCBI GROUP

In order to illustrate the usefulness of the system of calculations of the stream and system reliability of the production plant, the bakery X operating within the MSCBI group was analysed.

The system analysis showed the need to introduce robotization.

The layout diagram of facilities and production halls is illustrated before robotization in Figure 2 and after robotization in Figure 3.

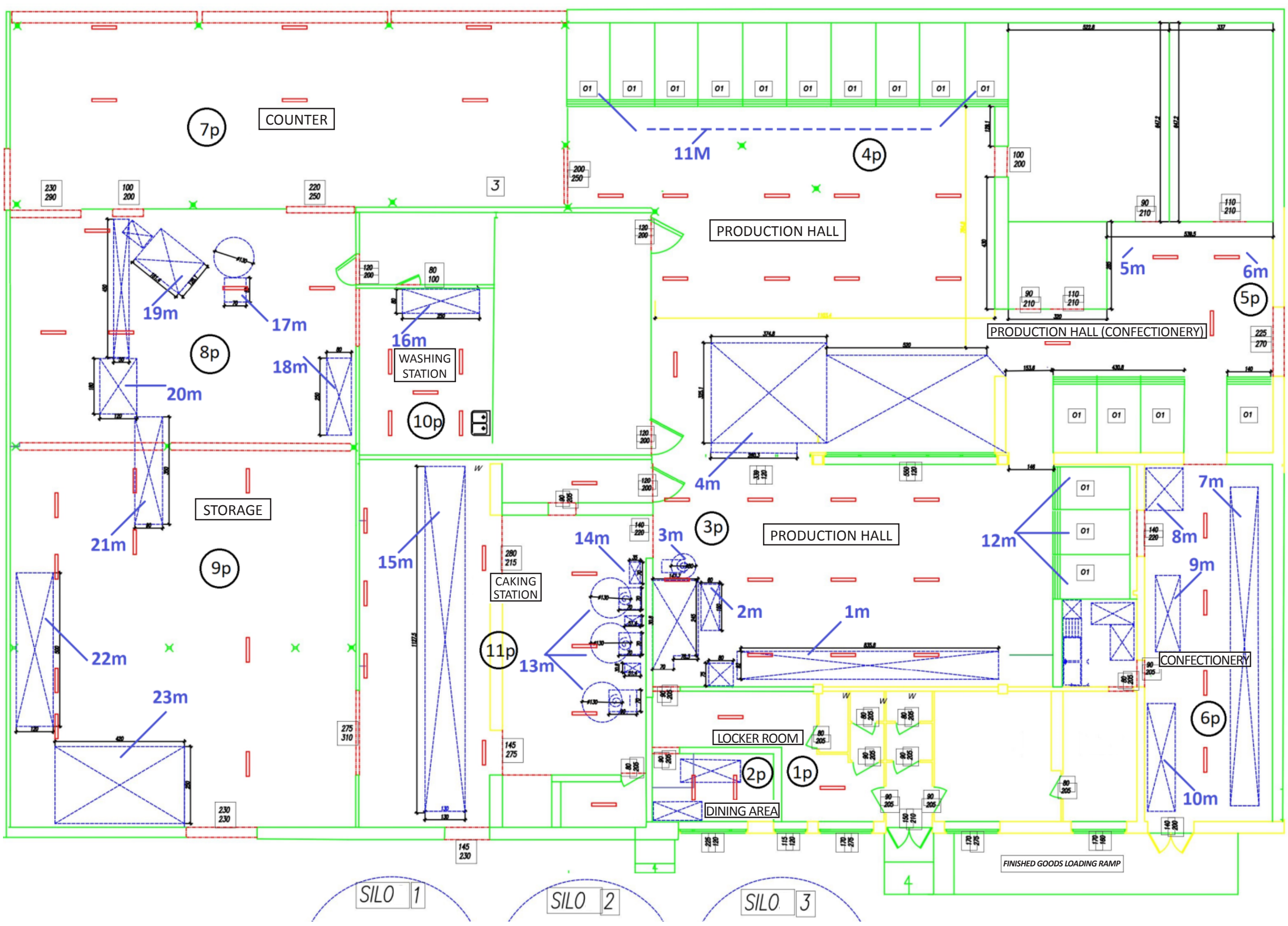

Figure 2 Layout diagram of facilities and production halls before robotization in the bakery X.
Source: Own study based on tests performed in the bakery X

Table 1 Information to the drawing of the bakery X before robotization

Symbol	Room	Symbol	Machine
1p	Locker room	1m	roll line
2p	Dining area	2m	work table
3p	Production hall 1	3m	mixer
4p	Production hall 2	4m	WPH1 bread line
5p	Production hall 3	5m	fryer
6p	Confectionery	6m	packaging machine
7p	Counter	7m	product lamination line
8p	Storage 1	8m	confectionery compactor
9p	Storage 2	9m	work table
10p	Washing station	10m	dough sheeter
11p	Caking station	11m	thermal and oil ovens
		12m	thermal and oil ovens
		13m	mixer
		14m	stool with gas burner(s)
		15m	WPH2 second bread line
		16m	work table
		17m	bread slicer
		18m	work table
		19m	slicer
		20m	slicer
		21m	clipper
		22m	raw material cold store
		23m	raw material cold store

Source: Own study based on tests performed in the bakery X

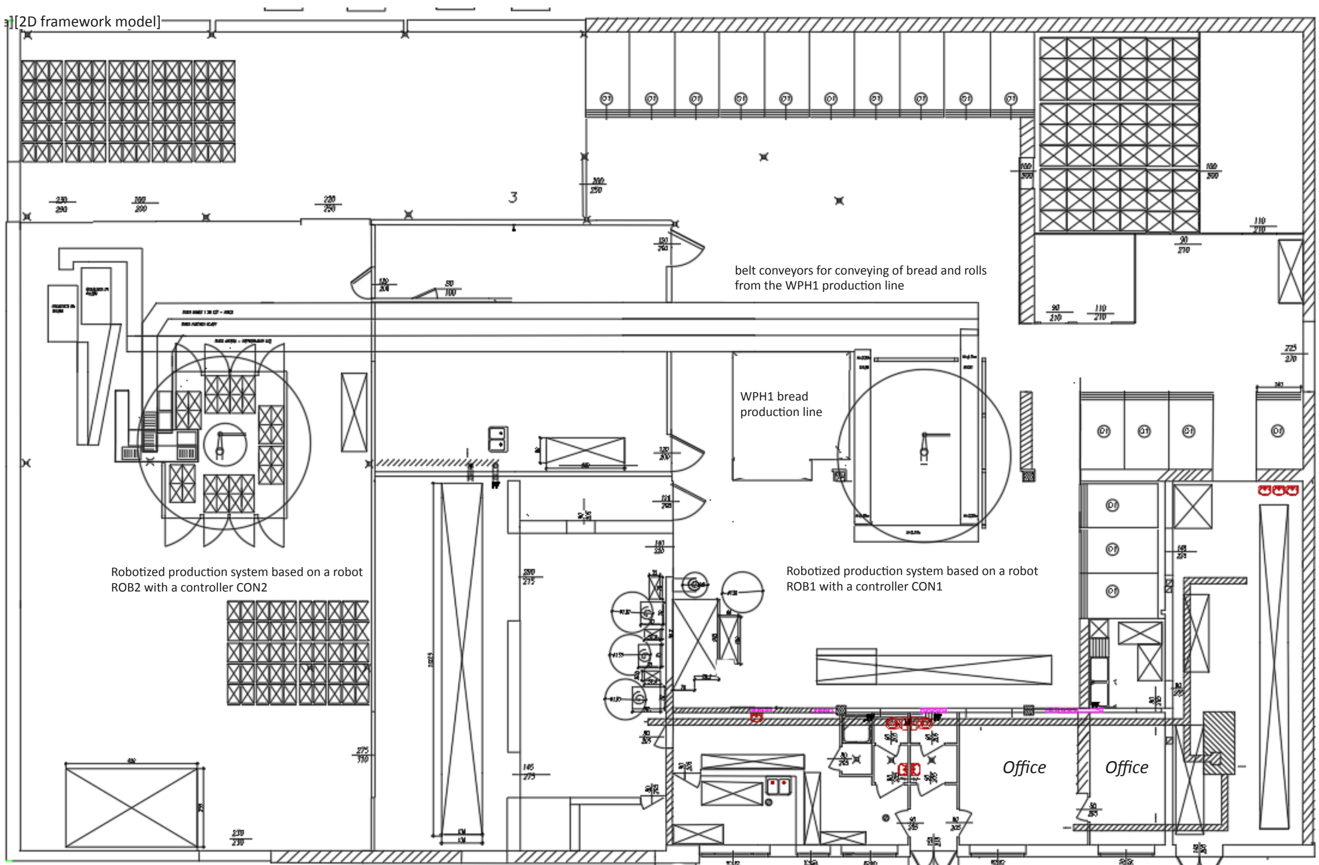

Figure 3 Layout diagram of facilities and production halls after robotization in the bakery X.
Source: Own study based on tests performed in the bakery X

The structure of the production system may sometimes be covered by process secrecy.
In the case in question, a detailed process specification of production streams was performed.
Selected components are shown in Tables 2, 3, 4, 5, 6.

Table 2 Components of energy stream $\varphi_{i\,E}$ (examples)

Designation	Component number (l)	Component name	Type of energy
$\varphi_{1\,E}$	1	Spiral mixer	mechanical
$\varphi_{2\,E}$	2	Proofer	thermal
$\varphi_{3\,E}$	3	Thermal and oil oven	natural gas

Source: own study

Table 3 Components of material stream of $\varphi_{j\,M}$ (example)

Designation	Component number (l)	Component name	Type of material
$\varphi_{1\,M}$	1	Bread wheat flour 750	loose material
$\varphi_{2\,M}$	2	Water	liquid

Source: own study

Table 4 Components of information stream $\varphi_{k\,I}$ (examples)

Designation	Component number (l)	Component name	Type
$\varphi_{1\,I}$	1	Ingredient storage instructions	instructions
$\varphi_{2\,I}$	2	Measuring of ingredients	measurements

Source: own study

Table 5 Components of time stream $\varphi_{1\,T}$ (example)

Designation	Component number (l)	Component name	Type
$\varphi_{1\,T}$	1	Silo(s) operating time	Machine(s) processing time
$\varphi_{2\,T}$	2	Cooling down of bread	Product processing time

Source: own study

Table 6 Components of financial stream of $\varphi_{m\,F}$ (example)

Designation	Component number (m)	Component name	Type
$\varphi_{1\,F}$	1	Flour unit costs	Raw material costs
$\varphi_{2\,F}$	2	Proofer operating costs	Machinery operating costs

Source: own study

Examples of stream fragments refer to the bakery X which operates within the MSCBI group before and after robotization.
Tables of significant and supporting relationships were used successively.
The tests clearly indicate that in a conventional bakery the number of significant relations is $P^i = 1292$ and the number of supporting relationships is $P^w = 920$.
In the robotized bakery, the number of significant relations is $P^i = 2756$ and the number of supporting relationships is $P^w = 573$.
Robotization of the bakery X increased more than twice the number of significant relations.
The stream and system reliability in a conventional bakery is 58.41%.

$$P_{ss} = \frac{1292}{1292 + 920} = 0.5841$$

The stream and system reliability in the robotized bakery is 82.79%.

$$P_{ss} = \frac{2756}{2756 + 573} = 0.8279$$

The robotization of bakery substantially increases the reliability of the baking process and has a significant impact on the improvement of the efficiency of production and quality of products.

6. CONCLUSIONS

The study presents a new concept of stream and system reliability (P_{ss}). This is a scalar value whose mean value is between zero and unity.
The stream and system reliability (P_{ss}) is one of the metrizable measures of the system operator Ô acting on the streams of energy, material, information, time and finance. The stream and system reliability is the ratio of the number of reliability of significant associations and the relationships of system components to the sum of significant and supporting relationships.
Significant relationships are characterised by the reliability of unit value, while supporting relationships have the reliability between zero and unity. Knowledge of significant relationships on the basis of limited research is requested, and more importantly on the basis of experience and knowledge. This requires advanced qualification of the production system diagnostics personnel.
The stream and system reliability P_{ss} is characterised by the degree of non-refused operation of the entire process system. The determination of

P_{ss} in the system refers to standard time and does not require significant research efforts.

The structure of the form of the stream and system reliability P_{ss} demonstrates the means of optimisation of the system in relation to its selected effective macro indicators. This structure clearly confirms the enhancement in the system efficiency by increasing the number of significant relationships. This indicates more certainty of non-refused operation of important associations of component streams, for example via robot applications. This is one of the methods to improve innovation in production processes.

The system analysis of the bakery X operating within the MSCBI group presented in this article, based on the structure of the value of P_{ss}, confirmed the usefulness of such "diagnostics" to improve the efficiency of the bread baking process. An unequivocally significant increase in the value of P_{ss} in the bakery with robotized bread baking production was identified. This increase also results in an increase in the product quality. The presented stream and system reliability structure may be used in any process. This requires a detailed system analysis of such processes.

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