Technological reliability of the production process of dietary supplements

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Abstract—

The aim of this paper is to explore the concept of technological reliability within the context of the dietary supplement production process. It introduces a novel approach to formulating the technological reliability function by utilizing the concept of technological stream, which amalgamates different elements including system streams, information quantity, and the cost of relations. The methodology proposed facilitates the evaluation of product quality, identification of failure sources, and has been effectively employed in the analysis of dietary supplement production at Company X.

Keywords-production process, reliability, model

I. INTRODUCTION

The aim of this publication is to introduce the concept of technological reliability in the production process of material goods as a novel and measurable representation of the product manufacturing system.

The technological reliability of the system concerns the analysis and calculation of all relationships of elements constituting the system streams:

- Streams of energy $E_i(t) = [E_1(t), E_2(t), \dots, E_i(t)]$
- Streams of matter $M_i(t) = [M_1(t), M_2(t), \dots, M_i(t)]$
- Streams of information $I_k(t) = [I_1(t), I_2(t), \dots, I_k(t)]$
- Streams of finance $F_l(t) = [F_1(t), F_2(t), \dots, F_l(t)]$
- Streams of time $T_n = [t_1, t_2, \dots, t_n]$

The technological reliability of the system of relations for unit production $P_{tch}^{R_i}(t)$ is a function of time over a segment Δt, in which the relation will be an active participant in the production of the product. Knowing the waveforms of $P_{tch}^{R_i}(t)$ for all real process relations, The technological reliability of the production of the entire process can be constructed $P_{tch}^{S}(t)$. This will be shown later in the paper.

The issues of reliability determination are described in the literature [1-7]. In them, a general analysis of issues related to technological reliability of the system can be found [8-14]. It is one of the metrizable representations between elements of streams at time t_0 to t_n and expresses the probability of readiness for reliable operation of the entire system at time t.

The technological reliability of the production system is associated with product quality and productivity. Its assessment necessitates experimental measurements of the actual relationships within the production process being studied. Figure 1 presents a diagram of the production system.

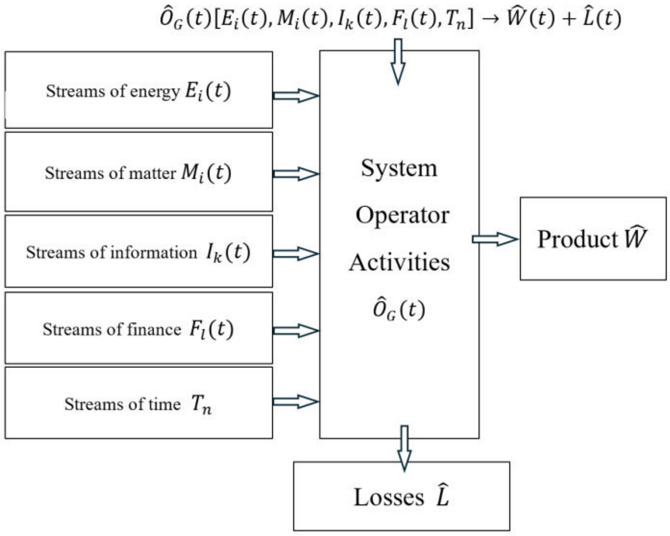

Figure 1. Diagram of the production system

Figure 2 shows a diagram of the technological structure. The concept of technological reliability described in the article is based on the presented structure.

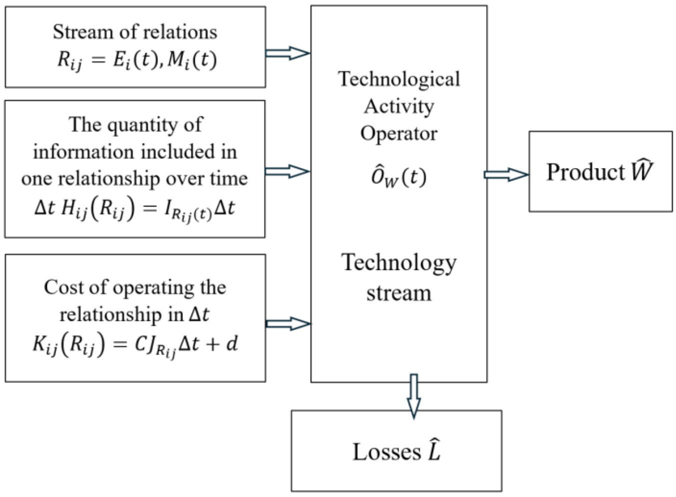

Figure 2. Diagram of the technological structure

The diagrams presented in Figure 1 and Figure 2, illustrating the production system and technological structure, will serve as the foundation for further elaboration on the concept of a technological reliability model.

II. SYSTEM STRUCTURE OF THE PRODUCT MANUFACTURING PROCESS

In Figure 2, a diagram of the unit production structure is depicted. It consists of three basic batch elements:

Dimensionless stream of relations as:

$$R_{ij} = E_i(t)M_j(t) \tag{1}$$

1. The amount of information H_{ij}, contained in relation R_{ij} during its operation at time Δt is dimensionless:

$$H_{ij}(R_{ij}) = I_{R_{ij}}(\Delta t) \tag{2}$$

2. Dimensionless cost of operation of the relationship

$$K_{ij} = CI_{R_{ij}}(\Delta t)\Delta t + d \tag{3}$$

To determine the amount of information in relation R_{ij}, it is necessary to calculate N-element sets of combinations of energy and matter fluxes after q. It is important to note that the order of the elements is not relevant.

$$N_q^{i+j} = \binom{i+j}{q} = \frac{(i+j)!}{q![(i+j)-q]} \tag{4}$$

Sequentially, the amount of information $I_{R_{ij}}$ for the relationship R_{ij} operating in a unit of time as:

$$I_{R_{ij}} = log_2 N_q^{(i+j)},\ gdzie\text{: } q = 1, 2, 3, n \tag{5}$$

Formula (3) for the cost of the relationship includes coefficients *C* and *d*, which distinguish between the complexity of the operation and the depreciation of the infrastructure. The selection of these coefficients is based on the type of production process. In order to determine the technological reliability of unit production related to a single relation $P_{tch}^{R_{ij}}(t)$, the concept of dimensionless technological flux will be introduced $\varphi_{R_{ij}}(t)$ as:

$$\varphi_{R_{ij}}(t) = R_{ij}(t)H_{ij}(\Delta t)K_{ij}(\Delta t) \tag{6}$$

The technological flux of the system is the product of a relation of some measure $R_{ij} = E_{ij}M_j$, the information contained in the action at time $H_{ij}(\Delta t)$ and the cost of the relation $K_{ij}(\Delta t)$.

Further to the calculation, it is more convenient to introduce a dimensionless expression for time t_n as:

$$t_n = \frac{t_{R_{ij}}}{T_0} \tag{7}$$

Where $t_{R_{ij}}$ is the running time of the R_{ij} relationship, and T_0 is the total production cycle time.

A. *Technological reliability of the production system*

A dimensionless expression for the technological reliability of the system for a single relation is now formulated $R_{ij}(\Delta t)$ as:

$$P_{tch}^{R_{ij}}(\Delta t_n) = 1 - \frac{\left|\varphi_{R_{ij}}^r(\Delta t_n) - \varphi_{R_{ij}}^0(\Delta t_n)\right|}{\varphi_{R_{ij}}^0(\Delta t_n)} \tag{8}$$

The values of (8) are equal to unity at $t_n = 0$, by definition of reliability, and greater than 0 and less than or equal to unity at each point t_n. This is illustrated in Figure 3.

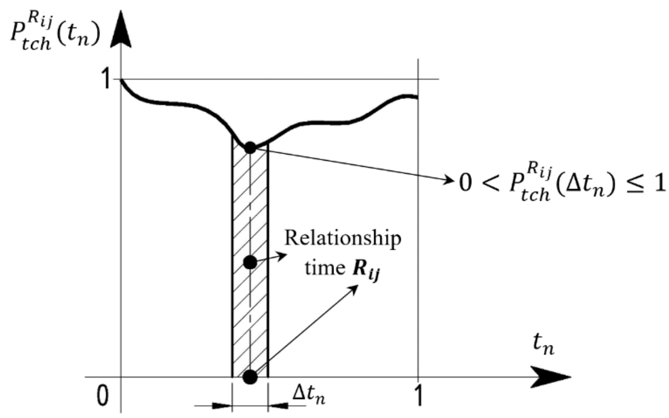

Figure 3. Technological reliability for the relationship R_{ij} operating over the time interval Δt_n

The index "r" in $\varphi_{R_{ij}}^r(\Delta t_n)$ of formula (8) denotes the actual, measurable value of technological flux and is determined experimentally. The index "0" in $\varphi_{R_{ij}}^0(\Delta t_n)$ of formula (8) denotes the calculated design value of the technological flux. It is derived from the form of the technological algorithm.

Technological reliability of the system for all time $P_{tch}^s(t_n)$

the definition can be expressed as a linear combination or another reliability function related to individual components

The most convenient way is to define $P_{tch}^{s}(t_n)$ as the arithmetic average of all "S" quantities of $P_{tch}^{s}(\Delta t_n)$ for the total system operation time T_0, then as $0 \leq t_n \leq 1$.

Hence, at time t_n:

$$P_{tch}^{S}(t_n) = \frac{\sum_{l=1}^{S} P_{tch}^{R_{ij}}(\Delta t_n)}{S} \quad \text{and} \quad P_{tch}^{R_{ij}}(\Delta t_n) > 0 \quad (9)$$

The magnitude of $P_{tch}^{S}(t_n)$ will always be equal to unity at $t_n = 0$ and greater than zero and less than or equal to unity at each point t_n. This is illustrated in Figure 4.

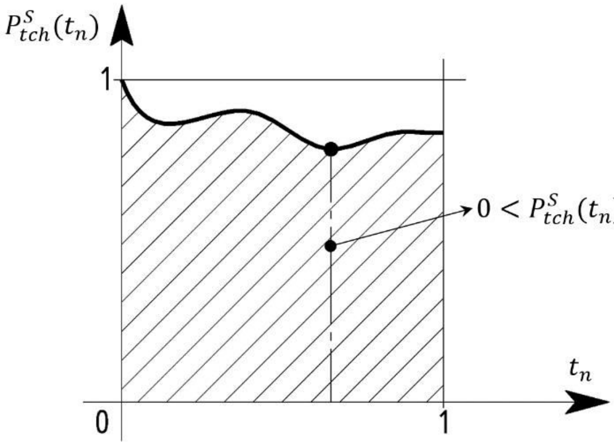

Figure 4. Time t_n waveforms of technological reliability of the system

Another computational variant is to formulate an expression for the process reliability function as the product of the reliability of the component process steps. This means using the process diagram directly, as shown in Figure 5.

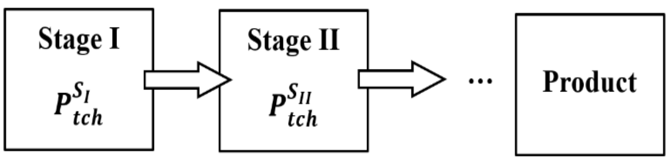

Figure 5. Block diagram of the technological and organizational structure of the process.

It illustrates the process components set as: $S_I, S_{II}, \ldots, S_K$. The sequence of activities of the stages leads to the product. Hence, the process reliability function of the whole process can be the product of the reliability of the component stages of the process. Thus, the reliability of stage I is expressed as:

$$P_{tch}^{S_I}(\Delta t_n) = \frac{\sum_{l=1}^{S_I} P_{tch}^{R_{ij}}(\Delta t_n)}{S_I} \quad (10)$$

And for stage two is:

$$P_{tch}^{S_{II}}(\Delta t_n) = \frac{\sum_{l=1}^{S_{II}} P_{tch}^{R_{ij}}(\Delta t_n)}{S_{II}} \quad (11)$$

The reliability of subsequent stages of the process is calculated in the same way.

The technological reliability of the entire process consisting of several stages can be determined as the product of the reliability of these stages. Thus, the reliability function for the entire process takes the form:

$$P_{tch}^{Global} = P_{tch}^{S_I} \cdot P_{tch}^{S_{II}} \cdot \ldots \cdot P_{tch}^{S_K} \quad (12)$$

This approach makes it possible to use the process flowchart directly, along with documentation that includes treatment and process charts.

B. Application of the method of determining the technological reliability of the system in the production of dietary supplements

At company X, the production of a wide range of dietary supplements is realized. Further shown are the waveforms of the technological reliability function at time t_n for the production of one of the selected elements of a dietary supplement packed into one sachet. The sum of the elements of energy fluxes E_i and matter flux M_j $(i + j = 27)$. All values of other quantities were taken from standards and research-proven procedures. The course of the technological reliability function $P_{tch}^{S}(t_n)$ related to one sachet of dietary supplement is illustrated in Figure 6, where the weak spots of the process are indicated. This made it possible to eliminate shortages and reduce the failure rate of the production cycle.

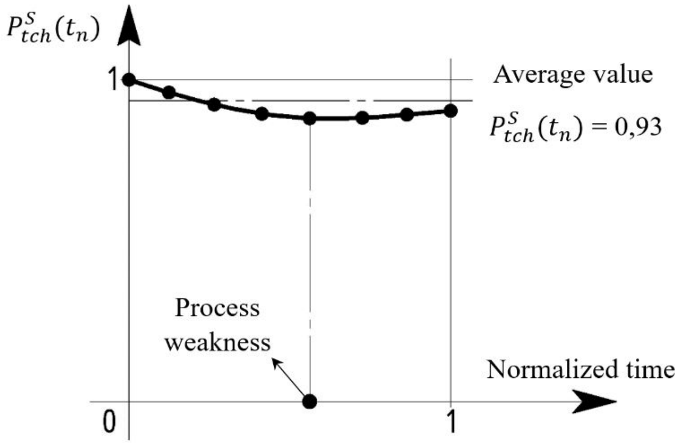

Figure 6. Time course of technological reliability in the production of dietary supplements in the amount of one sachet at company X

III. CONLUSIONS

The paper presents a new concept of technological reliability of the manufacturing process based on a system analysis of product manufacturing technology. The technological reliability function is shown in its essence to have both local and global characteristics for the process. It provides insight into the technological history of the production cross-section, enabling the detection of weak spots and facilitating the assessment of product quality and costs. This activity is very important from the point of view of the reliability of the production process, as it allows for the increase of profits by eliminating weak points.

Determining the course of the technological reliability function requires a lot of work and professional staff. The example shown regarding the production of a dietary supplement confirmed the importance and profitability of such a study for Company X's resources.

Due to commercial secrecy, the paper presents a general model of technological reliability of the production process. In order to carry out a full analysis of the technological process, detailed data about it are needed, which are sensitive company data.

Potential avenues for further research could include:

- Validation and Verification: Conducting further validation studies to verify the accuracy and effectiveness of the proposed technological reliability model across diverse manufacturing processes and industries.
- Enhanced Methodologies: Refining and enhancing the proposed methodologies for assessing technological reliability by incorporating advanced data analytics techniques, machine learning algorithms, or simulation models.
- Case Studies: Conducting additional case studies in different industrial settings to gain more insights into the practical application of the proposed technological reliability framework and its impact on production processes.
- Longitudinal Studies: Undertaking longitudinal studies to analyze the evolution of technological reliability over time and identify trends or patterns in system performance and failure rates.
- Cost-Benefit Analysis: Performing cost-benefit analyses to evaluate the economic implications of implementing technological reliability measures and identifying optimal strategies for resource allocation.
- Integration with Industry 4.0 Technologies: Exploring opportunities to integrate technological reliability concepts with emerging Industry 4.0 technologies such as Internet of Things (IoT), Big Data analytics, and cyber-physical systems to enhance production efficiency and reliability.
- Risk Management Strategies: Developing risk management strategies based on the insights gained from technological reliability assessments to mitigate potential disruptions and enhance overall system resilience.
- Collaborative Research: Collaborating with industry partners to conduct joint research projects aimed at addressing specific challenges related to technological reliability in real-world manufacturing environments.

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