



Systemic analysis of a manufacturing process based on a small scale bakery

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Abstract

The main aim of the article is to present two new innovative concepts of reliability of a functioning manufacturing system in the process of making bread in small-scale bakeries. Reliability is understood as one of the representations of an operator acting on specific streams in time t_0 to t . One of these represents the global reliability of a system as a function of parallel action of all the streams of the system in time t_0 to t and is denoted as $P_g^{(t)}$. The second representation of reliability is a scalar value, P_{ss} . It shows a new function of global reliability of a manufacturing process as a product of system stream reliability. In order to plot the flow of the manufacturing process's global reliability function, we need to perform detailed calculations, computations, and analysis of the differences of individual values in real time, as well as plan an algorithm of the flow of system streams. This needs a lot of effort, translating however, to a detailed picture of the process. In the analysed example, measurements and research revealed an important increase of the value of reliability in a transition from a traditional to a robotised bakery. The article also presents a new concept of the reliability of a technological process, based on the analysis of relations of elements of the following streams: energy, matter, information, time, and finances. It shows the method of specifying streams and the method for defining the reliability of important and supportive relations. Important relations between stream elements are defined as having the reliability value of one in time. Supportive relations bear the reliability within a continuum between zero and one. Important relations are designated based on research, experience, and knowledge. Stream systemic reliability P_{ss} is a scalar value, i.e. a number from the continuum between zero and one. The P_{ss} value characterises failure-free operation of the whole system. Its average value in the normative time t_n expresses the efficiency of the manufacturing system. The value P_{ss} is a quotient of the number of important relation and the sum of important and supportive relations. The formula for P_{ss} shows the method of optimising the process through the increasing of the number of important relations between the input stream components. The concept has been applied to study the efficiency of operation of a small-scale bakery. Systemic analysis of a bakery allows for important increase in the reliability of baking bread if robotisation has been implemented. The concept of systemic-stream reliability P_{ss} may be applied to analyse the efficiency of any technological process and optimisation of any manufacturing process.

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Keywords Manufacturing process reliability · Bread baking · Analysis of relations streams · Quality

1 Introduction

Small-scale bakeries are of key importance to the economic development of the European Union (Ambroziak 2002; Sikora et al. 2005; Škrbić et al. 2008). They are indispensable in the sustainable economic development and facilitate the economic growth (Pijanowski et al. 2000; Ellis 2021; Dziugan 2006). The fourth industrial revolution as well as increased competitive pressure from the market caused the emergence of unprecedented technological development as a key element for the development of small-scale bakeries – both on the level of technical devices, auxiliary devices, and the systemic reliability of the manufacturing process (Gilchrist 2016; Schwab 2018; Kumar et al. 2019; Kabugo et al. 2020).

Growing competition in the baking industry causes an ever-growing demand for solutions that would increase the reliability of all manufacturing processes (including machines and devices) of small-scale bakeries, thus allowing for improved quality of their products (Thompson 2007; Chryssolouris 2015; Hawryluk 2019).

A breakthrough moment of qualitative influence on the changes in the robotisation of manufacturing lines can be seen in the emergence of industrial robots in small baking enterprises (Lasi et al. 2014; Miśkiewicz et al. 2020; Foidl et al. 2016). Robotisation is a major technological step for the branch under scrutiny in this paper (Bauernhansl et al. 2015; Bauer 2014; Santos et al. 2017). Definitive gains from its implementation and use of robotisation in manufacturing processes are seen in the aspects of direct impact of reliability in bakery manufacturing lines (Drozd 2021, Drozd 2020a, b, Drozd and Piwnik 2019a).

The definition of reliability may encompass varied requirements described with technical, economic, and sociological characteristics of objects (Fidelis et al., 2006; Macha 2001). In it, we see (Migdalski 2018; Nadolny 1999; Słowiński 2002)—technical reliability that takes into account technical characteristics,—technical-economic reliability that encompasses technical and economic characteristics,—global reliability which encompasses technical, economic, and social characteristics of its objects.

The goal of the article is to introduce two representations of reliability of a functioning manufacturing system in the process of making bread in small-scale bakeries. Reliability is understood as one of the representations of an operator acting on specific streams in time t_0 to t .

One of these represents the global reliability of a system as a function of parallel action of all the streams of the system in time t_0 to t and is denoted as $P_g^{(t)}$.

The second representation of reliability is a scalar value, P_{ss} . (Drozd and Piwnik 2019b).

P_{ss} is an average relation in time t_0 to t of the delivery of the process, a quotient of the important relations to the sum of all the relations between process elements. P_{ss} is called the stream-systemic reliability (Drozd and Piwnik 2021; Drozd and Wolniak 2021).

Reliability is mainly related to the technical, physical, and organisational structure of the elements of a manufacturing system established in a way that would ensure the fulfillment of the designated functions (Thoft–Christensen et al. 2000; Warszyński 2000).

Subject literature distinguishes the notion of initial reliability, at the point of the start of work, and the functional reliability, defined by the impact of time of the analysed element on its reliability (Powierża 2007; Bhowmik et al. 2018).

The reliability function is constructed on the basis of experimental data and practical knowledge of system work and properties (Pogorzelski 2009; Cempel 2006).

Active work of a system up to the first failure, or denial of service, is of random character. Therefore, reliability can be the probability of performing certain tasks (orders) issued to interrelated elements (Bijan et al. 2012; Blanchard et al. 2021). Active functioning of a system is therefore a set of its cooperating elements (Sienkiewicz 2008). A system, according to its definition, cannot contain elements that do not cooperate among themselves.

In each, system a manufacturing system in particular, there exist: energy streams ϕ_E , material (technical means) streams ϕ_M , information technology streams ϕ_I , time streams ϕ_T , and financial streams ϕ_F .

Activity of a system can be synonymous to an organised set of relations between the elements of the abovementioned streams (Drozd 2020a, b).

Knowledge of probability of failure-free work in a given time that functions in an inter-related system of stream elements can form a basis to determine the reliability of a whole system. Therefore, reliability may be one of the metrisable measures of the functioning of a system.

2 Materials and methods

In this section we have described the basis of the concept used in the paper to prepare our new innovative method of measure representation of reliability of a functioning manufacturing system in the case of process of bread production in small bakeries. We presented here the analysis of the mathematical symbols and its managerial representatives we have used in the paper. Also we have described method used in the analysis. The main method we use in this paper to analyse the scientific problem is stream analysis and the use of stream representation to technical and managerial problems.

A technological system is a set of system streams ($\phi_E, \phi_M, \phi_I, \phi_T, \phi_F$) and an operator, \hat{O} , whose activity on the system results in the product, P^* , and losses, S .

In different words, a technological system is an organised set of relations between the elements of streams, leading to the emergence of a product P^* and inevitable losses S .

To prepare the methodological basis for our future analysis we have prepared the model of structure of streams in the bakery. The relations between the stream elements are the activities of the system and are presented in Fig. 1.

Symbolically, we can write down the activity of the operator \hat{O} as:

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

From the definitions of the technological system, Fig. 1, and the Eq. (1) we deduce the synonymy of a system with action. A technological system does not function without actions, i.e. relations between the elements of the streams. The streams are inputs into the system and differ according to their role, form, subject, and number of elements.

The ϕ_{iE} energy stream is set of i -elements of converting and transmitting electric, mechanical, heat, and other energy needed to perform the tasks of the project. The ϕ_{jM} matter stream is a set of j -elements that guarantee the material security of the project. These are raw materials, machines, and installations.

The ϕ_{kI} information stream is a set of k -elements of organised instructions, algorithms, orders, guidelines, and the elements of the recent applied knowledge which guarantee the highest possible quality of the activity of a technological system.

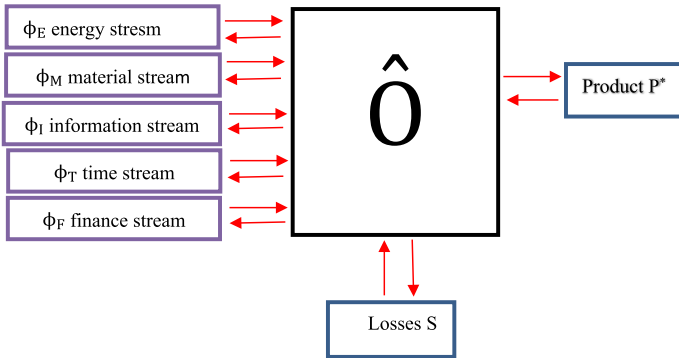


Fig. 1 Structure of the system of the analysed bakery. Source: Own elaboration

The ϕ_{IT} time stream is a set of l -elements of instructions for technological algorithms for sequence and timing of actions. The elements of ϕ_{IT} define durations for the individual operations, functions, and other tasks within the process.

The ϕ_{mF} finance stream is a set of m -elements defining the costs of the activity of the system as trends for the demand of the product P^* .

Relations of the components of the technological system are marked by a technical-organisational-economic interrelations of the individual components of the same stream or of different streams that assure constant functioning of the system.

In one of the bakeries within a group of small bakeries, the following relations were observed:

Spiral mixer ϕ_{2E} , flour ϕ_{1M} , water ϕ_{3M}

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

Proofing cabinet ϕ_{9E} , heater ϕ_{c1E} , water ϕ_{3M}

$$(\phi_{9E}, \phi_{c1E}, \phi_{3M})$$

The number assignments of the individual elements were taken from the specification of the subject structure of the analysed bakery, shown later in Sect. 5.

The probability of failure-free work in time τ from t_0 to t_n of the set of elements in their relation is marked as e.g.:

$$P_{[t_0, t]}(\phi_{2E}, \phi_{1M}, \phi_{3M}),$$

$$P_{[t_0, t]}(\phi_{9E}, \phi_{c1E}, \phi_{3M})$$

More generally, reliability in time $[t$ to $t_n]$ can be marked as:

$$P_{[t_0, t]}(\phi_{IE}, \phi_{jM}, \phi_{kI}, \phi_{IT}, \phi_{mF})$$

The above take into the account knowledge of probability of the related elements to work failure-free at the time $t=0$.

For instance, $P_{t=0}(\phi_{2E}, \phi_{1M}, \phi_{3M}) = 1$.

The above means complete readiness of the elements of the described relation to work at the onset of the manufacturing process.

The actual streams: $\phi_{iE[t_0, t]}$, $\phi_{jM[t_0, t]}$, $\phi_{kI[t_0, t]}$, $\phi_{lT[t_0, t]}$, $\phi_{mF[t_0, t]}$ acting in time t_0 to t in the manufacturing process differ from their normative values, i.e. values that are designated with the use of algorithms and that represent theoretical activity, resulting from current state of knowledge of manufacturing the resultant product.

Normative streams are designated as: $\phi_{iE[t_0, t]}^n$, $\phi_{jM[t_0, t]}^n$, $\phi_{kI[t_0, t]}^n$, $\phi_{lT[t_0, t]}^n$, $\phi_{mF[t_0, t]}^n$. Differences between the normative and actual values of the streams in relation to their actual values in the same timespan t will be further referred to as a non-dimensional arguments of the global reliability function $P_g(t)$ of the manufacturing system.

The second part of this chapter will concentrate on analysis of global reliability of manufacturing system. We put there the methodology how the particular streams will be calculated in the paper. In the following part of the paper we use those conception to calculate mentioned strings on the example of an bakery.

Global reliability of a manufacturing system will be assigned to a metrisable measure of activity of elements of a stream in time t_0 to t , which represents the probability of the readiness to perform failure-free work of the whole system in time t .

Therefore, global reliability of a manufacturing system is a function in time t and will be marked as $P_g(t)$. The function $P_g(t)$ has a value of one at time t_0 , which denotes the system's readiness at the beginning of the process, and a value of less or equal to one at any given time of the manufacturing process.

The function $P_g(t)$ in its meaning as the global reliability of a manufacturing system is defined as a product of reliability of each of the system's streams. Therefore:

$$P_{g [t_0, t]}^t = P_E^{(t)} P_M^{(t)} P_I^{(t)} P_T^{(t)} P_F^{(t)} \tag{2}$$

Individual stream reliabilities are marked as:

(a) energy stream reliability

$$P_E^{(t)} = 1 - \frac{|\phi_{iE}^{(t)} - \phi_{iE}^{n(t)}|}{\phi_{iE}^{n(t)}} \tag{3}$$

(b) material stream reliability

$$P_M^{(t)} = 1 - \frac{|\phi_{jM}^{(t)} - \phi_{jM}^{n(t)}|}{\phi_{jM}^{n(t)}} \tag{4}$$

(c) information stream reliability

$$P_I^{(t)} = 1 - \frac{|\phi_{kI}^{(t)} - \phi_{kI}^{n(t)}|}{\phi_{kI}^{n(t)}} \tag{5}$$

(d) time stream reliability

$$P_T^{(t)} = 1 - \frac{|\phi_{lT}^{(t)} - \phi_{lT}^{n(t)}|}{\phi_{lT}^{n(t)}} \tag{6}$$

(e) finance stream reliability

$$P_F^{(t)} = 1 - \frac{|\phi_{mF}^{(t)} - \phi_{mF}^{n(t)}|}{\phi_{mF}^{n(t)}} \quad (7)$$

Reliability of the streams: $P_E(t)$, $P_M(t)$, $P_I(t)$, $P_T(t)$, $P_F(t)$ is defined as a difference between the value of one and the fraction of the modules of differences between the real and normative values of the streams at a given time t , in reference to their nominal values.

The formula $P_g^{(t)}$ as a function of global reliability of the manufacturing process, a product of five reliabilities of the system streams, combines the activities of all the elements of a system at the time t .

Global system reliability $P_g^{(t)}$ is derived from actual measurements of stream expenses in relation to their nominal values derived from a theoretical model.

Functions of global reliability need to be presented in non-dimensional time in reference to the actual process time T_p as:

$$t_b = \frac{t}{T_p} \quad (8)$$

The research we described in the paper was conducted in the year 2021 in small bakeries in Pomerania region in Poland. To calculate all the streams we have measured all the parameters. The extensive analysis of the organization we have made the research and the data to calculate strings are in the chapter 4.

The presented global reliability of the production system—supported by the formulas for individual flow reliability—assumes the further part of their research and its implementation to small enterprises in the baking industry.

3 Stream-systemic reliability of a manufacturing process

Stream-systemic reliability P_{ss} is defined as the probability of failure-free work of the whole technological system, i.e. the full set of component relations.

Stream-systemic reliability P_{ss} is defined as the quotient of the sum of important relations to the sum of important and auxiliary relations. Therefore, stream-systemic reliability is defined as the average probability of failure-free work of a system in technological time $\tau \in [t_0, t]$.

Numerical value P_{ss} is found on a continuum between zero and one:

$$0 < P_{ss} < 1 \quad (9)$$

The formula for P_{ss} is as follows:

$$P_{SS} = \frac{\sum_{s=1}^r P_s^I[t_0, t]}{\sum_{s=1}^r P_s^I[t_0, t] + \sum_{s=1}^z P_s^W[t_0, t]} \quad (10)$$

In the formula (10) the index s denotes the number of the relation, t stands for the number of important relations, and z stands for the number of supportive relations.

The value of P_{ss} is not a function of reliability but rather a scalar value representing averages of reliability of the whole system in time $\tau \in [t_0, t]$.

The construction of the stream-systemic reliability formula (10) also provides guidelines as to the optimisation of the structure of the system. This is related to the number of supportive relations whose growth lowers the reliability, while the increase of the number of important relations improves reliability. Therefore, implementations and technical innovations ought to be directed at growing important relations, e.g. through the introduction of robotisation.

3.1 Important and supportive relations

Stream-systemic reliability (P_{ss}) is one of the metrisable values of the system operator \hat{O} acting on streams (energy, matter, information, time, and finances). Stream-systemic reliability is a ratio of the number of reliabilities of important associations and system element relations on one side and the sum of important and supportive relations on the other.

Important relations are related to the direct \hat{O} system operator relations, where the operator acts on individual streams: energy, matter, information, time, and finances.

Supportive relations are related to only those relations that support the process of important relations. Important relations are characterised by reliability of one, while supportive relations bear the reliability of zero to one.

While studying and comparing important relations between the individual streams, we need to take into account a few criteria which are dominant on their activity. We may enumerate the following properties of such relations:

1. *Strict character* A system ought to be defined so as for an observer to be able to say what forms part of the system and what does not. A definition of a system may be set in general terms, but not too vague.
2. *Invariability* The definition of a system ought to be invariable all along the course of scrutiny. It is not permitted for some elements to be treated as part of the system at one time and not belonging to the system at another.
3. *Completeness* The division of a system into subsystems ought to be complete. This means the system may not include elements that do not belong to any of its subsystems.
4. *Separation* Division into subsystems ought to be separate. This means the system may not contain elements that form part of different subsystems at the same time. Belonging of elements to a subsystem must therefore be synonymous with them not belonging to any other subsystem.
5. *Functionality* Systems ought to be defined by the functions they perform, not by their spatial separation. Important relations $P^I_{[t_0,t]}$ are associations of elements of the above-mentioned manufacturing stream components whose cooperation in normative technological time $\tau \in [t_0,t]$ is delivered with the value of expected non-failure operations:

$$P^I_{[t_0,t]} = 1.$$

Reliability of important relations, with the value of 1, is postulated based on the study of the system, experience, tradition, and the newest verified technological practice with the implication of innovations. Reliability of some of the important relations can be even defined without studies. Knowledge is derived from experience in such cases. Defining those important relations which do not require specific research needs high expertise of the management.

Supportive relations $P^w_{[t_0,t]}$ contain values for failure-free operation of the associated manufacturing stream elements in technological time $[t_0,t]$ as:

$$0 < P^w_{[t_0,t]} < 1 \quad (11)$$

Supportive relations can be partially necessary, providing the continuity of the full functionality of the system, therefore they are related to such associations of technological stream components whose failure will only worsen the operation of a system.

It is assumed that such failure will not result in the failure of the system as a whole. A full set of supporting relations requires high expertise of engineering staff.

4 Analysis of the global reliability and stream-systemic reliability of a manufacturing system based on small-scale bakeries

In order to illustrate the applicability of the calculations of the flow of global and stream-systemic reliability of a manufacturing process for a manufacturing business, we analysed one of the bakeries operating in the Pomerania area of Poland. Systemic analysis of the business revealed the need to introduce robotisation. The spatial distribution of manufacturing facilities in halls before the robotisation process has been implemented is shown in Fig. 2, while the same facilities and halls after the robotisation process has been completed are shown in Fig. 2.

Table 1 shows the information related to Fig. 2 that detail all the rooms, machines, and facilities in the analysed bakery.

The structure of a manufacturing process is most often kept under a secrecy clause.

In this case, a detailed technological specification of the manufacturing process was prepared. The select elements are shown in Tables 2, 3, 4, 5, 6.

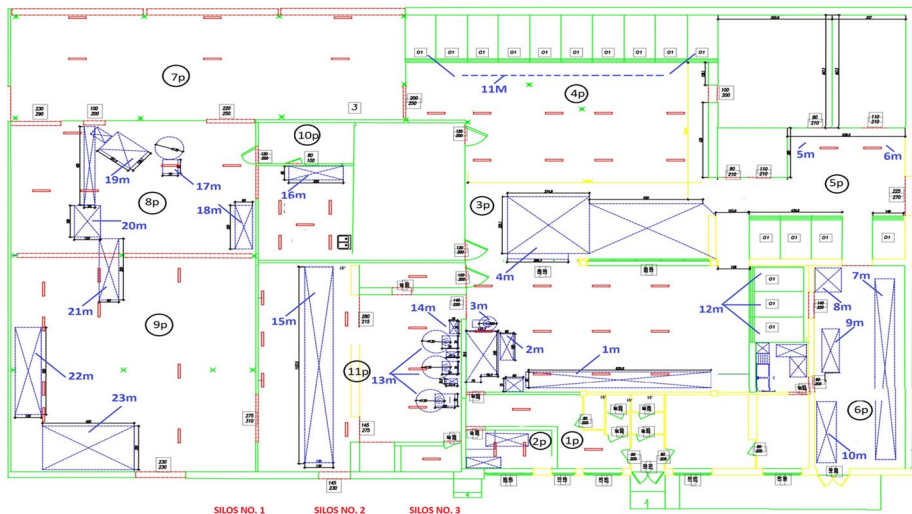


Fig. 2 Spatial distribution of manufacturing facilities and halls before the robotisation process in the analysed bakery. Source: Own elaboration on the analysed bakery

Table 1 A list of rooms, machines, and facilities in the analysed bakery

Symbol	Room	Symbol	Machine
1p	Dressing room	1 m	Bread roll manufacturing line
2p	Mess	2 m	Working table
3p	Production hall No. 1	3 m	Mixer
4p	Production hall No. 2	4 m	Bread manufacturing line 1
5p	Production hall No. 3	5 m	Frier
6p	Confectionery	6 m	Packing machine
7p	Distribution space	7 m	Lamination line
8p	Warehouse 1	8 m	Confectionery beater
9p	Warehouse 2	9 m	Working table
10p	Washing room	10 m	Dough roller
11p	Dough room	11 m	Thermal-oil ovens
		12 m	Thermal-oil ovens
		13 m	Mixer
		14 m	Gas stool
		15 m	Bread manufacturing line 2
		16 m	Working table
		17 m	Bread slicer
		18 m	Working table
		19 m	Slicer
		20 m	Slicer
		21 m	Clipping machine
		22 m	Material cooler
		23 m	Material cooler

Source: Own work on the analysed bakery

Table 2 ϕ_{iE} Energy stream elements (fragment)

Designation	Element number (i)	Name of element	Type of energy
ϕ_{1E}	1	Spiral mixer	Mechanical
ϕ_{2E}	2	Proofing room	Thermal
ϕ_{3E}	3	Thermal-oil oven	Natural gas

Source: Own elaboration on the analysed bakery

Table 3 ϕ_{jM} matter stream elements (fragment)

Designation	Element number (j)	Name of element	Type of matter
ϕ_{1M}	1	Wheat flour	Powder
ϕ_{2M}	2	Water	Liquid

Source: Own elaboration on the analysed bakery

Table 4 ϕ_{kI} information stream elements (fragment)

Designation	Element number (k)	Name of element	Type of information
ϕ_{1I}	1	Material storage instruction	Instruction
ϕ_{2I}	2	Material measurement	Measurements

Source: Own elaboration on the analysed bakery

Table 5 ϕ_{1T} time stream elements (fragment)

Designation	Element number (l)	Name of element	Type of time
ϕ_{1T}	1	Silo operation time	Technological time for the machine(s)
ϕ_{2T}	2	Bread cooling	Technological time for the product

Source: Own elaboration on the analysed bakery

Table 6 ϕ_{mF} finance stream elements (fragment)

Designation	Element number (m)	Name of element	Type of finances
ϕ_{1F}	1	Flour unit costs	Material costs
ϕ_{2F}	2	Proofing room work	Machine working cost

Source: Own elaboration on the analysed bakery

Examples of stream fragments are derived from the studied bakery—a small-scale manufacturing business—before and following the robotisation process.

The flow of the global reliability of a manufacturing system for selected bakery products in non-dimensional time $P_g^{(l)}_{[t_0, t_1]}$ for the traditional and robotised bakery are shown in Figs. 3, 4

The measurements and study showed in a definite way that the value of the global reliability $P_g^{(tb)}$ in non-dimensional time of manufacturing t_b in a robotised bakery is higher than the corresponding values for a traditional bakery by an average of 9%.

Tables for important and supportive relations were implemented.

The research clearly shows that the important relation for a traditional bakery count $P^i = 1292$ while for supportive relations it is $P^w = 920$.

In a robotised bakery, the count of important relations is $P^i = 2756$ and for the supportive relations it is $P^w = 573$.

The robotisation of the bakery under study increased the number of important relations by more than twofold.

Stream-systemic reliability in a traditional bakery is 58.41%.

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

Stream-systemic reliability in a robotised bakery is 73.61%

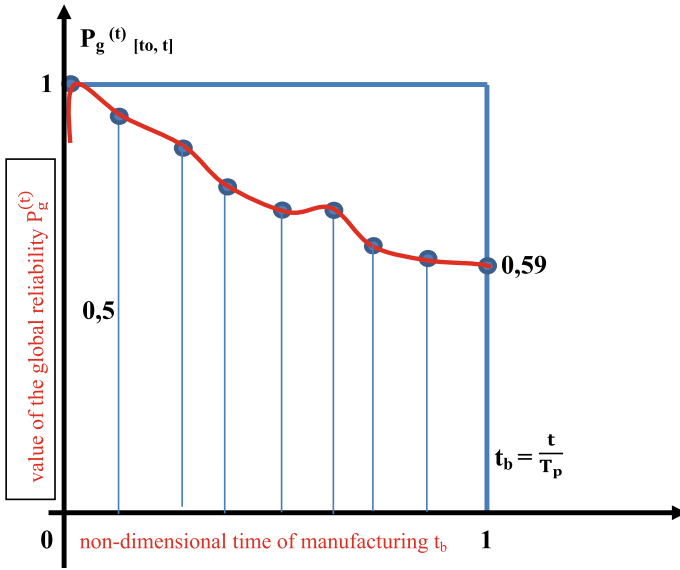


Fig. 3 Flow of the global manufacturing reliability function for a traditional bakery Source: Own work

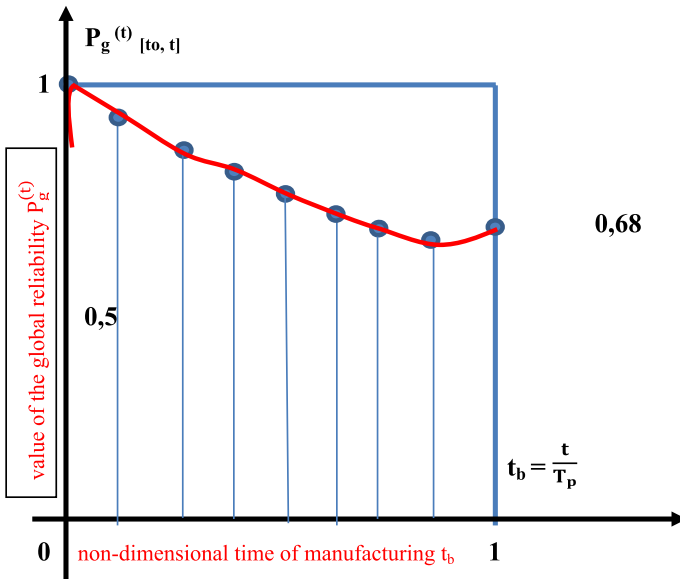


Fig. 4 Flow of the global manufacturing reliability function for a robotic bakery. Source: Own work

$$P_{ss} = \frac{2156}{2156 + 773} = 0.7361$$

Robotisation of a bakery significantly improves the reliability of the bread baking process and is of significant importance to the increase of manufacturing efficiency and quality of the final product.

5 Discussion

Formulating the reliability of a manufacturing process as a function in time is of fundamental importance to the formulating the description of the connection of the reliability with the final product, therefore, seeking the way of defining such functions, which are based on the assessment of the reliability of individual system streams. This allows for an analysis of the individual streams' impact on overall quality. The presented approach is empirical and analytical in nature, as it requires detailed measurements with the real and algorithmic expenses of the streams. This requires a lot of work, calling for further improvement in automation and the application of artificial intelligence.

Analysis of the important and supportive relations of the system elements are less resource consuming and leads to the simplified variant of calculations, P_{ss} . In each case, as the paper shows, the averages for both ways of calculating reliability do not differ from one another. Therefore, for the baking industry, either of the solutions is recommended, depending on the company's capabilities and needs.

The results of reliability analysis in manufacturing processes show the applicability of vector and stream analysis to the issues of quality within a manufacturing process. In this context, vector methods have so far not been practiced. Nonetheless, this concept was previously applied especially in technical sciences to solve problems. For instance, vector methods were applied in: nanostructure analysis (Zhao et al. 2021), forecasting in the energy sector (Yousaf et al. 2021; Aslam et al. 2021], e-business modelling (Sun et al. 2021), machine learning (Shahpouri et al. 2021), or issues related to the COVID-19 pandemic (Alghazzawi et al. 2021; Scuttari et al. 2021; Ting et al. 2020).

The paper's proposed solutions require a digitisation of the manufacturing process. Only this process will allow to obtain data that in turn allows the implementation of stream analysis in the manufacturing process. Digitisation of processes (Gajdzik et al. 2021; Kordel et al. 2021; Liu et al. 2021; Akazi et al. 2020; Pirocá et al. 2021) in a manufacturing business is employed increasingly often and forms one of the key factors of introducing Industry 4.0 (Miśkiewicz et al. 2020; Gajdzik et al. 2021; Stawiarska 2021; Pirocá et al. 2021). Also, robotisation is a prerequisite element for implementing Industry 4.0 in business (Botlíková et al. 2020; Siderska 2021; Marinoudi et al. 2021).

It seems that this paper's proposed solutions may allow bakeries to adjust themselves to the requirements of Industry 4.0. Ideas in implementing Industry 4.0 in the baking industry were voiced by e.g. A. Lindhal (Lindhal 2019). The author emphasises that issues of data digitisation and analysis in manufacturing processes are the most crucial element for the implementation of Industry 4.0 in a bakery. She also points to the importance of robotising the manufacturing processes (Lindhal 2019).

According to the presented theoretical concepts, we may conclude that full implementation of stream and vector analysis in the practice of operational management of a bakery will result in us being able to speak of new quality in a fully digitised Bakery 4.0 (Paulíková et al. 2021). This approach will allow for better management of the said bakery and

will create competitive advantage in the market. Bakery 4.0 has not been frequently cited in subject literature (Bordel et al. 2021), however, business-related publications have raised this concept. The concept of a Bakery 4.0 may be defined as the implementation of the methods and concepts of Industry 4.0 in a baking business. The implementation of this paper's proposed calculation methods may be an important step (article—Bakery 4.0 2021; Ting et al. 2021; Lachance 2021) of the transformation of a Bakery 3.0 into a Bakery 4.0.

As analysis of research of digitisation processes by G. Garcia shows, in this area, that the implementation of digitisation and robotisation leads to the possible improvement of quality (Garcia et al. 2021). Results from this paper's research also confirm that robotisation of a bakery has positive influence on the reliability of bread baking and the improvement of quality of the final product. Analysis of research in optimization of bakery processes (Babor et al. 2021) suggests the current insufficient methods that allow detailed analysis of the functioning of the baking process; this gap is addressed in this paper.

Our main achievements based on the data analyzed in the presented paper concentrate on development and usage of innovative new method of implementation of mathematical concept of stream analysis to managerial problems. We tried to implement this mathematical concept to prepare the set of strings which is most important to build and calculate the model of stream for bakery. We think it's one of the pioneering uses of this mathematical concept in management. Also we have not found any usages of the stream concept in bakery industry. We think that solution proposed in our paper give the theoretical basis to the use of this concept to any production.

The practical achievement of the paper is connected with the potential better adjustment of the bakery industry to the demand of XXI century business. Using the concept organization can digitalize it's operation and implement the Industry 4.0 rules within the organization. Also our solution is one of the first concept how to fully digitalize the quality concept in industrial enterprise and how to use mathematic representation to calculate all stream connected with quality in industrial firm.

6 Conclusions

The paper presents two new concepts of reliability of a manufacturing process, on the basis of a bakery. We have used two concepts to compare stream-systemic reliability in traditional bakery and stream-systemic reliability in robotized bakery. Each situation need using slightly different approach to analysis. This twofold analysis give as possibility to find how big was the effect on implementing robotization on the all processes in the organization, especially those related to quality of product. On the basis of our research we have observed that the implementation of robotization in the bakery can significantly improve the reliability of the bread baking process and can have positive impact on efficiency of organization and especially the quality of the final product. It is not possible to link those two concept into one because each of them can be used in various situation and to various problems. We think that two proponed approaches can be useful for the organization. The paper presents global reliability of a manufacturing process as a function in time, defined by the reliability of the individual manufacturing process streams. Reliability of streams was presented as a quotient of the difference of real and planned values of streams, and planned values.

The global reliability of a manufacturing process is the product of input stream reliabilities.

Values of streams and their variation in time has been defined empirically, in the course of the process. From the flows of the individual stream reliability functions, definitely higher reliability values of robotised bakeries can be deduced.

Smaller businesses require the computation of stream-systemic reliabilities.

This paper presents a new concept of stream-systemic reliability P_{ss} . It is a scalar value, whose average is between zero and one. Stream-systemic reliability is one of the metrisable values of the system operator \hat{O} acting on energy, matter, information, time, and finance streams.

Stream-systemic reliability is the ratio of reliabilities of important associations and relations of the elements of the system to the sum of important and supportive relations.

Important relations are characterised by reliability of one, while supportive relations bear the reliability in the continuum between zero and one.

The knowledge of important relations relies less heavily on research, and more heavily on knowledge and experience. Therefore, qualification of the staff who diagnose the manufacturing system needs to be high.

Stream-systemic reliability P_{ss} measures the degree of failure-free operation of a technological process. The designation of P_{ss} in a system relates to normative time and does not require high research overheads.

The structure of stream-systemic reliability P_{ss} points at paths of optimising the system according to the selected macro-indicators. The structure definitely confirms increased efficiency of the system through increasing the number of important relations. This means the introduction of higher probability of failure-free work of important relations of stream elements through robotisation. This is one of the ideas for improving the innovative character of manufacturing processes.

The analysis in the paper, a systemic analysis of a small-scale bakery, based on the structure of the function $P_g^{(t)} [t_0, t_1]$ and the value of P_{ss} has confirmed the usefulness of such “diagnostics” in the improvement of the efficiency of baking bread.

There has been an observable increase of the value of P_{ss} in a robotised bakery. The said increase also results in the improvement of the final product quality.

The presented structure of global stream-systemic reliability may also be applied to other manufacturing processes, which, however, requires detailed systemic analysis of those processes.

We think that in the future our research can go in two directions. One possible future research could be strictly connected with the bakery industry. We could use our method in more bakeries in Poland maybe not only small ones to have the bigger base of the data. The extensive statistical analysis could be give us the insight what are the differences according to various types of bakeries in the case of robotization implementation and advancement in product quality. Also we think that the method could be seen as universal and because of that can be used to analyses product quality in others industries. It is the interesting, perspective field of the future research. We think that we could try to modify the model of strings and the whole concept to analyze others industry and production systems.

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Declarations

Conflict of interest The author declare there is no competing interest.

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