SILESIAN UNIVERSITY OF TECHNOLOGY PUBLISHING HOUSE

SCIENTIFIC PAPERS OF SILESIAN UNIVERSITY OF TECHNOLOGY 2021
ORGANIZATION AND MANAGEMENT SERIES NO. 151

METRISABILITY OF MANAGING OF STREAM-SYSTEMIC PROCESSES

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Purpose: This paper pursuits the possibilities of applying a mathematical description to the management of a manufacturing process, based on a stream-systemic model.
Design/methodology/approach: To achieve the planned goal, in order to properly describe the manufacturing system management, six process stream functions were introduced. Non-dimensional flows of these functions in time can be empirically defined during the manufacturing process. They are interpreted as non-dimensional expenses. Maximum values for these functions in properly-managed processes equal one. Also, a global management function was introduced, being a sum of areas of circle sections delineated by functions of the streams and their respective weights. Stream weights in the manufacturing process signify the processes' roles and importance in the system. The paper also provides a vector representation of a manufacturing process as a sum of stream vectors with their associated weights.
Findings: The global function of process management and the process vector provide the possibility to optimize the process, allow for control, and are closely associated with final product quality. The structure of the suggested management functions allows for optimization and process control. It is also strictly associated with manufacturing quality. The presented metrizability method of manufacturing process management can also be applied to the analysis of non-metrisable product manufacturing.
Originality/value: The article may be a recommendation for manufacturing companies. The structure of the suggested management functions allows for manufacturing companies optimization, process control and manufacturing quality.

Keywords: metrizability, stream-systemic processes.

Category of the paper: Research paper.

1. Introduction

Both in Poland and on the international level, no subject literature exists so far which would be taking a complete view on the metrisability of managing stream-systemic processes (Sikora, Strada, 2005). The notion of metrisability of managing stream-systemic processes is new in itself, and may be found in subject literature on that part of the manufacturing process which is responsible for the stream outlays in the researched manufacturing process (Świderski, Waszkiewicz, Robak, 2010).

The important factors bearing major impact on the metrisability of managing stream-systemic processes in product manufacturing are:

a) raw material quality parametres and costs (Toko, 2000),
b) precision and control of dosing ingredients (Skolik, 2011),
c) technology recipe and composition of substitutes (Wiśniewska, Malinowski, 2011),
d) repetitiveneness of the design-specific features of products within the manufacturing process (Stewart, Feinle-Bisset, Golding, Delahunty, Clifton, Keast, 2010),
e) high reliability of the technological installation (Gawęcki, Baryłko-Pikielna, 2007).

Among the abovementioned factors which are closely related to metrisability, the quality of the final product is essential (Holm, Brun, 2000). As an example, let us take metrisability of product manufacture quality, which may be defined as a degree of healthiness, sensory attractiveness, and accessibility within a wide consumer and social scope (Dillon, Goldstein, 2000). This degree will be valid only within the boundaries of capabilities offered by the raw materials, technology, and price (Balon, Dziadkowiec, 2015).

Designing and delivering of manufacturing processes (Borkowski, Ulewicz, 2009), necessitates deciding upon the algorithms (Pająk, 2006) within the whole manufacturing process (Durlik, 2007).

A rational algorithm, i.e. a recipe for the shape of the process, order of steps (organisational, technological, and other) (Biazzo, Bemardi, 2003) is possible if, and only if, a mathematical model (Zwolińska,2016) exists for the part of the operator that acts on the streams within a system, which is responsible for the interconnections of stream expenses at specific times). This is the main of this paper. Therefore, the below mathematic equations for management are based on widely understood systems engineering (Zwolińska, 2016) with the natural consequences of relativism, complexity, and the resultant pragmatism and limitations. For this reason, we further discuss the metrizability (Ahire, Dreyfus, 2000) of the part of the system which is responsible for the distribution of stream expenses after a specific concept for manufacture has been adopted (Mehrabi, Ulsoy, Koren, 2009). Figure 1 presents the macroscopic sequence of steps in the system.

The acceptance of a concept entails defining detailed procedures for the order of mutual relations of the system components (Kleniewski, 2004); these ought to take into account the structure, technology, and manufacturing process organization (Romanowska, Trocki, 2004).

The below mathematical models for the $\widehat{O}_{DS}$ management operator (cf. Figure 1) can be applied to the manufacture of physical goods as well as production of non-material goods. Differences in management will only be related to the dominance of certain streams over others, with the resultant configuration of interconnections (Drozd, Piwnik, 2019).

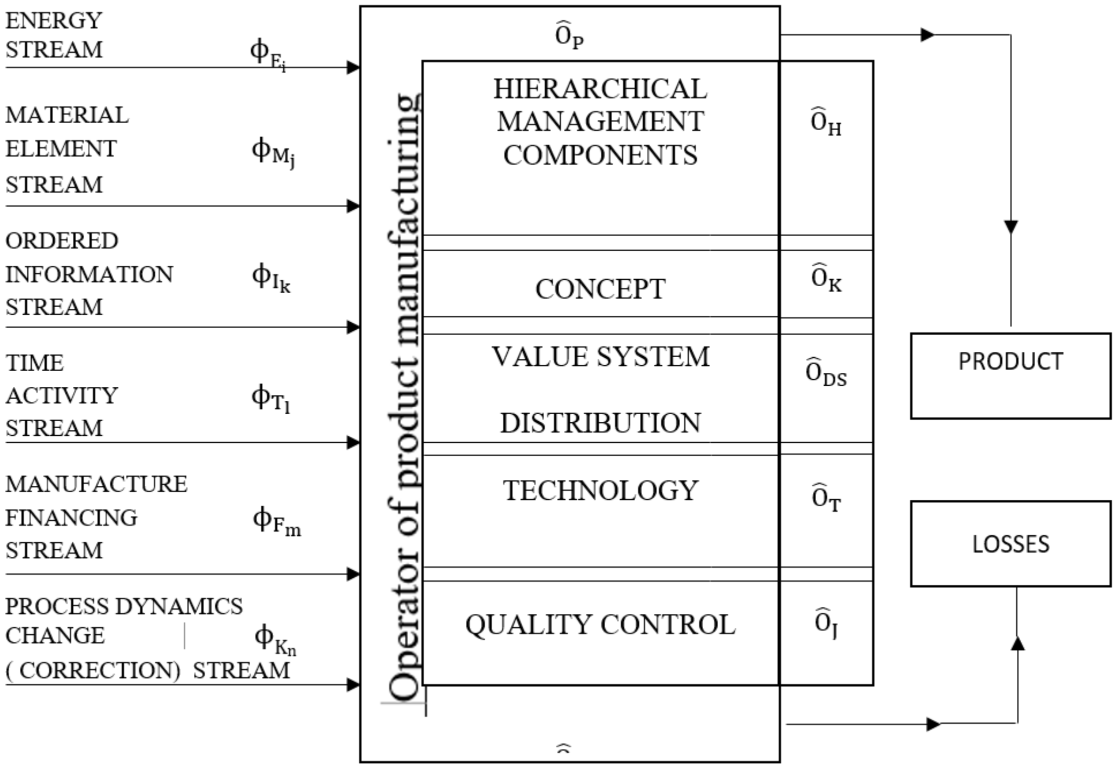

Figure 1. $\widehat{O}_P$ manufacturing structure $\widehat{O}_P = \widehat{O}_H + \widehat{O}_K + \widehat{O}_{DS} + \widehat{O}_T + \widehat{O}_J$. Source: own study.

Subject literature as well as industry practice lack ideas for management that apply a mathematical representation to a combination of process streams. The below mathematical models of the management process allow the assessment of such representation, both in a scalar and vector manner, which in turn enables mathematical description of the interconnections between management and manufacturing quality (Drozd, Piwnik, 2019).

2. Structure of technological (manufacturing) process

A general overview of the technological (manufacturing) system analysed in this article can be seen in Figure 1.

The manufacturing operator's $\widehat{O}_P$ activity area is supplied by six streams, "supply inputs". The ϕ_{E_i} energy stream is a necessary i-element set converting energy and is expressed by the amount of energy in time. Therefore, it is a set of elements that convert various types of energy (mechanical, electrical, heat, chemical, etc.). All the elements are described with kilowatt amounts.

The ϕ_{M_j} material stream is a j-element set that guarantees complete support of materials to deliver a project. These will be raw materials, machines, installations, and other objects. It is expressed by the number of elements in time.

The ϕ_{I_k} ordered information stream is a k-element set of specialist knowledge. These are instructions, guidelines, orders, analytical formulas, heuristic elements, and other segments of modern knowledge that translate to the highest efficiency of the system. This stream is described using amounts of information in time.

The ϕ_{T_l} time activity stream is an l-element set of the sequence of activity order relations between streams in time. The elements of this set also define timespans for individual operations and tasks as well as those of other events that result in the delivery of ϕ_{T_l} concept and design stream assumptions. The stream is quantified by a number of ordered operations in time.

The ϕ_{F_m} manufacture financing stream is an m-element stream describing the cost of individual stream relations, tide trends, and other costs of reliable system operation. The stream is quantified by sums of expenses in time.

The ϕ_{K_n} correction stream is an n-element set containing forced and unexpected changes to the defined concept of manufacturing process dynamics. It is characterised by high sensitivity to the correct flow of the five abovementioned streams. The elements of this stream are corrections of faulty relations and those of the interconnections between the elements of the (Drozd, 2019):

- ϕ_{E_i} energy stream,
- ϕ_{M_j} material component stream,
- ϕ_{I_k} ordered information stream,
- ϕ_{T_l} time activity stream,
- ϕ_{F_m} manufacturie financing stream.

The ϕ_{K_n} stream is quantified by the number of corrections to relations and order in time.

Taking into account the above stream characteristics, we shall proceed to our understanding of a system and definition thereof.

A technological (manufacturing) or production process is a directed activity of an operator, driven at streams that produce an ordered set of relations between stream elements; all results in the emergence of P^* product as well as inevitable losses. Therefore, the central idea of a system is the set of relations between stream components.

Within the system, all the relations are active, i.e. each has their own tasks to perform. Therefore, a system is an intentional set of active relations between the elements of its streams.

The further part will be devoted to the process of managing the said system. This is visualised in Figure 1, following the concept phase.

Management of the manufacturing system is performed by the $\widehat{O}_{DS}$ operator, an integral part of the $\widehat{O}_{P}$ global system operator. The $\widehat{O}_{P}$ can be represented using the following symbols:

$$\widehat{O}_{P} = \widehat{O}_{H} + \widehat{O}_{K} + \widehat{O}_{DS} + \widehat{O}_{T} + \widehat{O}_{J} \quad (1)$$

where:

$\widehat{O}_{H}$ - operator acts on hierarchical management,

$\widehat{O}_{K}$ - operator defines the concept of product manufacture, including the complete design that contains construction, technology, and quality control,

$\widehat{O}_{DS}$ -operator is related to management,

$\widehat{O}_{T}$ - operator is linked to manufacturing technology,

$\widehat{O}_{J}$ - operator is associated with quality control and monitoring.

Placement and marking of the individual operators are shown in Figure 1.

3. Structure of the management operator

The stream-systemic process management operator located following the concept stage (cf. Figure 1) is further understood as the $\widehat{O}_{DS}$ management operator. Its structure is shown in Figure 2.

The above suggests that the activity of the $\widehat{O}_{DS}$ operator does not include the stages of hierarchical management and concept. It is strictly associated with the delivery of product manufacturing technology and quality control thereof.

The limitations are the result of difficulties in metrisable description of processes of concept creation and decisiveness of hierarchical management that are part of operation of large corporations

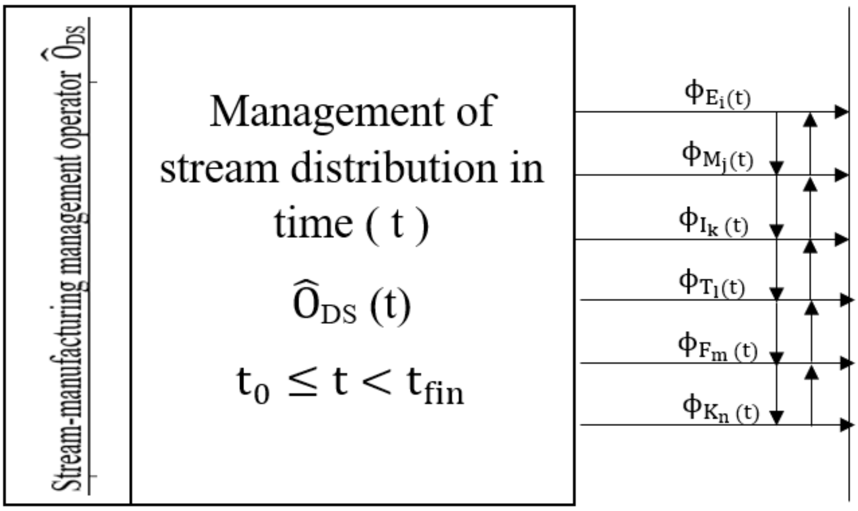

Figure 2. Structure of the $\widehat{O}_{DS}$ stream-manufacturing management operator. Source: own study.

High quality of the final product, fastest adjustments to the dynamically changing environment, and other factors that allow for the use of opportunities may be achieved upon the model of managing technology and quality control being metrisable.

The metrisability of such a model primarily means strict distribution of stream expenses in time, defined by the $\widehat{O}_K$ concept operator. Simultaneous, defined in time as $\mathbf{t_0 \leq t < t_{fin}}$, and strictly controlled stream expense, as well as the interconnections between streams make for an innovative, rational platform of modern manufacturing process management. The description of management function in time is a difficult task, thus some simplifications are necessary.

The further part of this article shows suggestions for the characteristics of processes of stream distribution and their connection with the manufacturing process.

4. $\widehat{O}_{DS}$ management operator function

Figure 2 shows the idea of system stream distribution. All the interconnections between streams are visible, i.e. intended flows of all the combinations of system elements in defined time.

We will introduce non-dimensional connections as the fundamental functions that describe the controlled stream expenses in time; these take into account the ratios of the actually expended amounts of stream elements to the same values that were defined by the norm of product concept.

These will be the following non-dimensional values that define the activirt of system streams in time $t_0 \leq t < t_{fin}$:

1. Non-dimensional momentary energy expense stream

$$r_e(t) = \frac{\int_{t_0}^{t} \phi_{E_i}^{rz}(t)\cdot dt}{\int_{t_0}^{t} \phi_{E_i}^{n}(t)\cdot dt} \tag{2}$$

2. Non-dimensional momentary material expense stream

$$r_m(t) = \frac{\int_{t_0}^{t} \phi_{M_j}^{rz}(t)\cdot dt}{\int_{t_0}^{t} \phi_{M_j}^{n}(t)\cdot dt} \tag{3}$$

3. Non-dimensional momentary ordered information expense stream

$$r_{ui}(t) = \frac{\int_{t_0}^{t} \phi_{I_k}^{rz}(t)\cdot dt}{\int_{t_0}^{t} \phi_{I_k}^{n}(t)\cdot dt} \tag{4}$$

4. Non-dimensional momentary activity in time expense stream

$$r_{\text{T}}(t) = \frac{\int_{t_0}^{t} \phi_{T_l}^{rz}(t)\cdot dt}{\int_{t_0}^{t} \phi_{T_l}^{n}(t)\cdot dt} \tag{5}$$

5. Non-dimensional momentary finance expense stream

$$r_f(t) = \frac{\int_{t_0}^{t} \phi_{F_m}^{rz}(t)\cdot dt}{\int_{t_0}^{t} \phi_{F_m}^{n}(t)\cdot dt} \tag{6}$$

6. Non-dimensional momentary correction expense stream

$$r_k(t) = \frac{\int_{t_0}^{t} \phi_{K_n}^{rz}(t)\cdot dt}{\int_{t_0}^{t} \phi_{K_n}^{n}(t)\cdot dt} \tag{7}$$

The defined non-dimensional momentary expenses of streams in time can be experimentally measured during the course of the process. Their proper measurement values ought to be close to unity, while improper values diverge from unity. The latter means inconsistency of the actual activities with the defined recipe for the process

The **rz** indices in Formulas 2-7 are actual flows, while the **n** indices stand for normative flows.

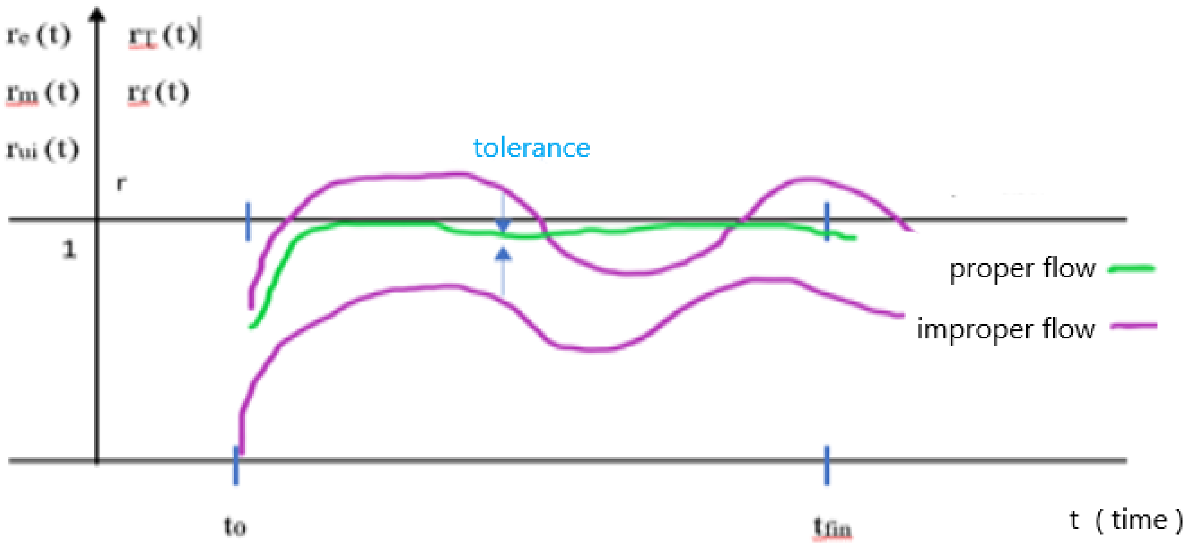

Figure 3. Proper and improper flows of the management function. Source: own study.

Figure 3 provides an example illustration of proper and improper flows of the management operator function in time. The actual and normative values need to be provided during the process, as specific numbers illustrating elements of streams consumed at small time intervals.

5. Constructive connections of the $\widehat{O}_{DS}$ management operator

In order to show the interrelations between the functions of management operators, we will additionally introduce the notion of the weight of the functions within the manufacturing process.

The sum of all the measures of the weighs equals 100%, or 1. The individual weights of management functions are assigned the symbols of: α_e, α_m, α_{ui}, α_{T}, α_f, and α_k and are translated to the non-dimensional stream functions. We can assume that the role of each stream in the manufacturing process is equal, however, a possibility of defining unequal roles exists.

Let us formulate a scalar connection between the stream functions and their weights. The global management operator Z(t) function is:

$$Z_g(t) = r_e^z(t)\frac{\alpha_e}{360} + r_m^z(t)\frac{\alpha_m}{360} + r_{ui}^z(t)\frac{\alpha_m}{360} + r_T^z(t)\frac{\alpha_T}{360} + r_f^z(t)\frac{\alpha_f}{360} + r_k^z(t)\frac{\alpha_k}{360}$$

The geometric interpretation of the Z_g (t) function is shown in Figure 4.

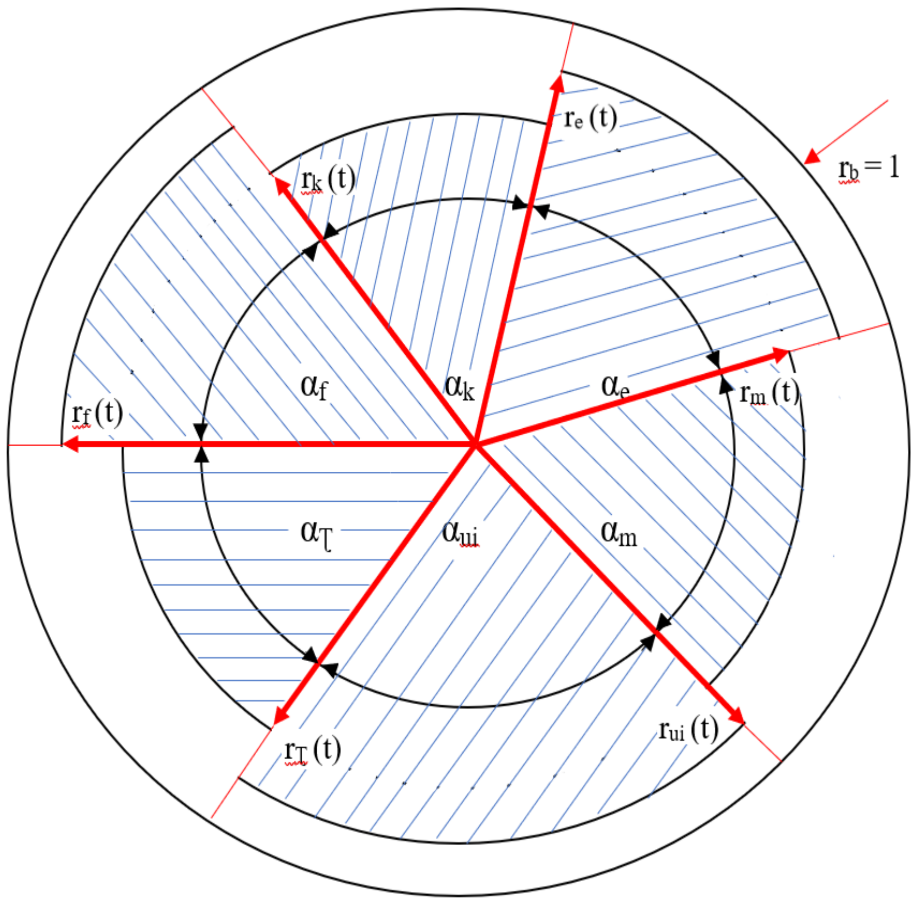

Figure 4. Area shares of non-dimensional streams within the manufacturing process. Source: own study.

The Z(t) function defines the ratio of the sum of the circle sections with the experimentally-defined radius length to the weight for the area of the circle with the radius $r_b = 1$.

The values of the Z_g (t) function are between 0 and 1 [$\mathbf{0 \le Z_g(t) \le 1}$ **].**

The global Z_g (t) function may be a constitutive, scalar characteristics of the process flow. It combines the flows of all the stream functions and their weights. The values for the Z_g (t) function can be found in the set: [0,1].

Proper flow of the process in time t signifies that the value of Z_g (t) equals 1 with some deviation $Z_g (t) \approx 1$.

Following the assumption of the presence if weights of stream functions, it is also possible to construct vector representations of the global $\vec{\mathbf{z}}_{\mathbf{g}}(\mathrm{t})$ management function. This is illustrated in Figure 4 where, within a rectangular grid (x, y) vectors of stream functions are presented: $\overrightarrow{\mathbf{r_e}}$, $\overrightarrow{\mathbf{r_m}}$, $\overrightarrow{\mathbf{r_{uı}}}$, $\overrightarrow{\mathbf{r_T}}$ $\overrightarrow{\mathbf{r_f}}$, $\overrightarrow{\mathbf{r_k}}$

The x axis shows the weights which are in the continuum of [0,1].

The y axis shows values of stream functions.

Upon summarising all the vectors, we get:

$$\vec{\mathbf{z}}_{\mathbf{g}}(\mathbf{t}) = \overrightarrow{\mathbf{r_e}}(\mathbf{t}) + \overrightarrow{\mathbf{r_m}}(\mathbf{t}) + \overrightarrow{\mathbf{r_{uı}}}(\mathbf{t}) + \overrightarrow{\mathbf{r_T}}(\mathbf{t}) + \overrightarrow{\mathbf{r_f}}(\mathbf{t}) + \overrightarrow{\mathbf{r_k}}(\mathbf{t})$$

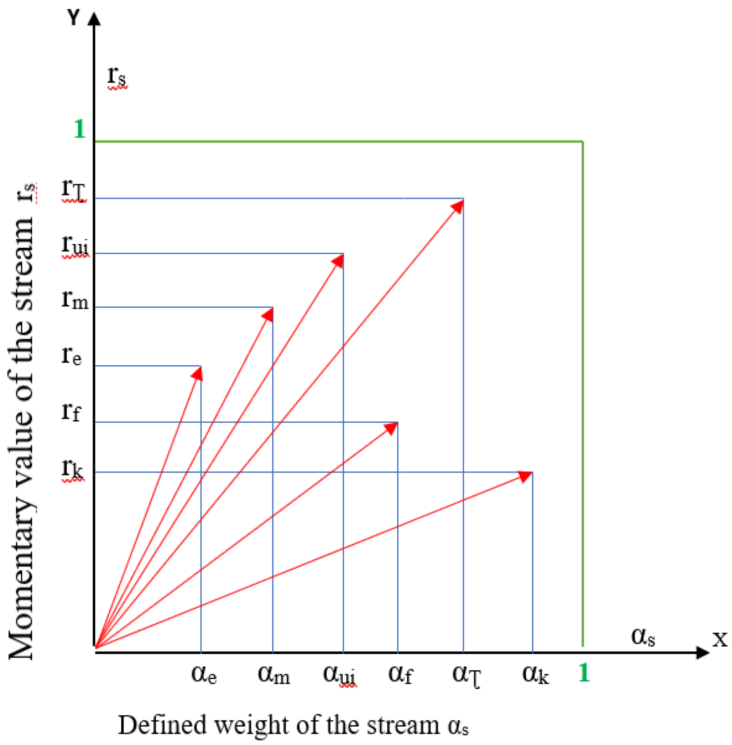

Figure 5. Vectors of non-dimensional streams in the manufacturing process: $0 \le r_s \le 1, 0 \le \alpha_s \le 1$. Source: own study.

There is also a possibility to define a singular vector $\vec{z}_g(t)$ related to the sum of the modules of the stream vectors and the maximum values of stream functions.

The vectors in Figure 5 correspond to momentary values of the states of manufacturing processes.

The global function Z_g (t) and the global vector $\vec{z}_g(t)$ are metrisable representation of manufacturing process management. Their values and flows may be defined experimentally during the manufacturing process.

The structure of these functions allows for the management and control of the manufacturing process. The flow of the scalar function $Z_g(t)$ and the global vector $\vec{z}_g(t)$ can also e used for quality control of the final product.

6. Summary

The paper presents a method for metrisability of product manufacturing process management. The mathematical description concept was based on systemic process analysis. Mathematical formulas for six functions of the manufacturing process were suggested, thus interpreting momentary expenses within the streams. A form of the management operator function was presented which takes into account the weight of individual streams. The function is interpreted as a geometric sum of areas of circle sections, each of the sections representing the weight and value of stream functions.

The paper also presents a vector representation of manufacturing process management as a sum of stream vectors.

Non-dimensional global function for manufacturing process management $Z_g(t)$ and a manufacturing process management vector $\vec{z}_g(t)$ take into account the activity of any number of streams, together with their weights (roles).

The flow values of the function $Z_g(t)$ and the vector $\vec{z}_g(t)$ in time can be defined experimentally.

The structure of the suggested management functions allows for optimization and process control. It is also strictly associated with manufacturing quality.

The presented metrizability method of manufacturing process management can also be applied to the analysis of non-metrisable product manufacturing.

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