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DIFFICULT-TO-MEASURE INTEGRATION MEASUREMENT METHOD FOR DESIGNING PROCESSES IN A CHAIN-LIKE STRUCTURE OF CONFLICTED CELLS IN A SUPPLY CHAIN

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Abstract:

The paper presents an approach for integrating conflicted cells in a chain-like structure based on a measurement of the level of integration of this structure. The authors' prior experience suggests an assumption that conflicts always arise when cells are connected by a flow of materials, information, and money, although at different intensity levels. Usually, the intensity levels of said conflicts depend on the cooperation culture within a supply chain. This is a highly multidimensional problem, reflected by the literature referred to in this paper and related to this subject matter. The proposed approach treats technological processes between conflicted cells as an area of potential integration of these cells. Then, the integration becomes a problem of selecting the appropriate variant of realizing a technological process conducted in an area common for potentially conflicted cells of a company. The same approach may be used for cells belonging to separate production and distribution companies operating within a mutual supply chain. The paper proposes a method for measuring the integration level of neighboring cells, as a difficult-to-measure feature, by determining an integration loss index. Also, the paper presents a multi-criteria method based on the fuzzy set theory for selecting a preferred variant of a technological process. A presented example uses this method in a supply chain to maximize the integration level between Shipping and Recipient cells/links. It has been assumed that the preferred realization variant of the flow process will be based on the following criteria: 1) shipping cost; 2) shipping quality; 3) shipping time. Also, an algorithm is shown for applying the presented methodology, which is helpful for managers interested in increasing the integration level of a supply chain. The methodology allows for increasing the integrity of conflicted cells both in newly designed supply chains as well as in existing ones when remodeled or reorganized. Moreover, the paper indicates some problems associated with the efficient implementation of the proposed method.

Keywords: *hard-to-measure parameters, integration measurement, supply chain, technological processes design*

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1. Introduction

A natural aspiration of humans to perfection manifests, among others, in improving processes for manufacturing and distributing goods. These processes, however, are rarely performed by single units (single persons or single cells of an enterprise). The turn of the millennium showed an unprecedented scale of cooperation in producing and distributing goods, as never before in history. Naturally, the most dominant factor prompting cooperation is the possibility of gaining mutual benefits. However, since time began, an inherent part of every cooperation was the incompatibility of the goals of cooperating entities. Increasing incompatibilities led to contradictions, whereas the unsolved contradictions were developing into conflicts. The conflicts destroyed the cooperating structures, and then new structures appeared in that place, to collapse after some time. Such processes occur in the full range of enterprises - from small family businesses to global corporations. One has noticed the risk presented by contradictories of interest between parties cooperating within a single joint business (developing into conflicts) and addressed to reduce it. The most common idea for mitigating conflicts in a business structure is integrating the parties of an enterprise.

The problem of integrating supply chains acquires exceptionally high importance in emergency/extraordinary circumstances like natural disasters or during economic, social, health, or national/international security crises, including military conflicts, as experienced by millions worldwide in recent years. Good integration of supply chains is necessary for assuring efficient, reliable supplies, frequently being one of the conditions for business success, but also domestic safety or even victory in war.

In practice, the integration may take various forms on many levels and in various areas of cooperation. Rarely, however, is it formalized and still more rarely measured. For entities (whole enterprises and single cells) belonging to a cooperating structure, the integration manifests, most frequently, by answering the following question: How far do I have to forgo my benefits for the good of the whole structure?

This paper has been inspired by a project for improving a supply chain in one Polish food industry factory belonging to a worldwide multinational corporation. One of the essential conclusions resulting from the project was that individual links of the analyzed supply chain were conflicted. They were competing with each other instead of cooperating. The lack, at that time, of efficient methods and tools acceptable for the managers of the corporation motivated research studies leading to the methodology described in our paper.

So, we recognized a demand for a versatile tool for improving the integration level of a supply chain. For this purpose, a rigorous approach based on fuzzy logic has been employed for analyzing the integration level as a difficult-to-measure quantity. The approach defines a parameter as a measure of the integration level. An original algorithm has been developed for increasing the integration level in a serially integrated chain.

The most important thesis of the paper is that it is possible, when designing technological processes within a cooperating structure, to include the demands and needs of individual entities constituting the structure, thus integrating the structure without forcing the entities to forgo their benefits. This paper presents an original methodology and an algorithm to achieve the objective as mentioned above.

2. Literature review

Usually, the term "integration" is understood as 1) consolidating; 2) creating a whole from parts; 3) including a selected element into a whole; 4) welding and coordinating constituents of a collectivity. In a more scientific meaning, particularly when related to the systems theory, it may be said that system integration is a coupling of several sub-systems into a single joint system, in a way that provides higher efficiency than a set of uncoupled constituent sub-systems.

Important review papers present studies and methods for integrating supply chains include: (Danese et al., 2020), (Hosseini et al., 2019), (Kache and Seuring 2014), (Machado et al., 2019).

It is interesting to compare the subject literature in terms of methods applied therein. In a few recent years, one can notice papers, as (Basole and Nowak, 2018), (Danese et al., 2013), (Fattahi et al., 2017), (Peng et al., 2020), (Pham and Pham2021), (Shah et al., 2020), (Woo et al., 2013), (Zhou et al., 2012) proving hypotheses related to defining some quality features of a supply chain. These hypotheses, mostly, are formulated linguistically and proved using the methodology presented, e.g., in (Rencher, 2003). Papers (Basnet, 2013), (Chen and Lu, 2020) and (Shou et al., 2021) use other sociological tools for integration measurement. In (Bruque-Cámara et al., 2016) analyzed the combined effect of community cloud computing and physical-informational supply chain integration on firms.

In (Li and Chen, 2018) presents an approach that defines a retailer's procedures toward manufacturers and is based on the games theory. In (Li and Chen, 2020) employs a similar investigation approach for establishing an integration strategy in a three-tier supply chain with two suppliers, one manufacturer, and two retailers.

Also, there exist integration methods based on fuzzy logic. For example, (Cigolini and Rossi, 2008) uses classical linguistic judgment and triangular modifiers for evaluating and quantifying respondents' opinions; (Bautista-Santos et al., 2016) proposes a similar fuzzy-based expert model and recommendations, developed after applying the model in actual chains, for companies cooperating in three cooperation levels. For the same levels, (Bhagwat and Sharma, 2009) presents a similar AHP method-based model for evaluating survey data.

Another noticeable direction, described recently, is including the problem of integration into the education process (Pekkanen et al., 2020) and the area of responsibility of experts working in chain structures (Alfalla-Luque et al., 2015), (Heydari and Rafiei, 2020). Also, cultural impact on integration is studied (Durach and Wiengarten, 2020), (Jacobs et al., 2016), (Van Staden et al., 2020), (Wei et al., 2020).

Cell integration was reported in chains having particular features, as seaports (Han, 2018), (Panayides and Song, 2008), (Yuen and Van Thai, 2017); food supply chains (Eksoz et al., 2019); engineering projects (Eriksson, 2015); Construction Supply Chain (Golpîra, 2020). In (Yuen et al., 2017) presents studies, in the context of integration, of characteristic features for a supply chain. The extrapolation of these features to a chain of services has been considered useless due to somewhat different mechanisms ruling the chain of services. Some papers suggest a definition of an integrated chain – for example (Lee, 2005), (Van Hoek, 1998). According to (Boon-Itt and Paul, 2005), the term integration of a supply chain has different meanings depending on the point of view and subjective impressions. In the same paper, integration equals cooperation within a supply chain. In (Vitasek, 2003) proposed a definition of the integrated logistics wherein a whole supply chain is perceived, in a broad, systemic way, as a single process: from obtaining raw materials until distributing final products. All the functions that constitute the supply chain are to be co-managed as a whole instead of managing individual functions separately. Also, Vertical Integration was defined as multiple production steps for processing the raw materials into final products to be delivered to final consumers, thus increasing the value thereof.

Paper (Seuring, 2004) presents considerations on the integration based on an analysis of other papers, and presents tabulated comparison of terms: integrated chain management and supply chain management.

In (Fattahi et al., 2017) proposes a model based on a multi-stage stochastic program (MSSP) that integrates the location, distribution, and demand fulfillment decisions in a supply chain concurrently.

One of the areas of integration is the selection of means appropriate for implementing a technological process, performed in (Ambroziak and Tkaczyk, 2015), (Jachimowski et al., 2017), (Jacyna et al., 2017), (Kłodawski et al., 2017).

Paper (Lee, 2005) describes the integration problem symptomatically - as a subject matter that is easier to recognize than define and determine. Nevertheless, the article presents an approach to assessing supply chain integration using a social network analysis method originating from social sciences and based on graph theory. The paper gives no formal definitions. However, the author concludes that the integration level of two chain links becomes higher if the contacts between them are more frequent and qualitatively better, having better coordination of joint actions and better troubleshooting skills.

Referring to the literature, one can notice that particular examples of technological processes are usually described and analyzed in terms of their influence on the integration (coordination) level of a given chain. On the contrary, the approach presented in this paper allows for investigating, simultaneously, various processes and analyzing their influence on the integration of a supply chain and, therefore, makes it possible to improve the chain's integration by selecting the appropriate variants of these processes. Also, as met in the literature, the problem of integration is narrowed to strictly defined structures. In contrast, this paper presents a novel, more versatile approach that allows measuring and increasing the integration level in any chain-like structure.

3. Structure and representation of a serially integrated chain

Uncorrelated variables were found and eliminated from the factor analysis. The principal component analysis extraction was used. The Bartlett test of sphericity was used to determine the statistical significance of correlations between variables. The central limit theorem implies that each variable is normally distributed if the sample size is large enough. The Kaiser-Meyer-Olkin measure of sampling adequacy value indicates how well the factors are predicted. A value of 0.8 or greater is deemed meritorious. Values between 0.7 and 0.8 are considered middling, values between 0.6 and 0.7 are considered mediocre, values between 0.5 and 0.6 are considered miserable, and values below 0.5 are considered unacceptable. If the sampling adequacy measure is less than 0.5, the variables with the lowest sampling adequacy are eliminated sequentially.

The degree to which a factor structure explains a variable's variance is known as its communality.

In Fig. 1, Λ_{IN} denotes an input stream of materials, information, or finances; Λ_{OUT} is an output stream of materials, information, or finances; F is a vector of external disturbance relative to L; G is a vector of internal limitations within L.

This paper postulates that technological processes between individual elements of a chain create an area of integration/disintegration for this chain. It has been assumed that:

- a technological process is a set of operations having a defined goal and involving knowledge, skills, and resources for achieving this goal;
- a realization variant of a technological process is a way for achieving the goal of the technological process using knowledge, skills, and resources peculiar to this variant;
- a technological process is defined by a goal and at least one realization variant.

Let S is a set of means used for achieving the goal of a process under consideration. Let V^* is the total number of realization variants of this process, and v is a consecutive realization variant of the process ($v = 1, 2, \ldots, V^*$). Then, v-th realization variant V_v of the process is described by an ordered pair of $\langle S_v, U_v \rangle$, where:

S_v is a set of means used in the v-th realization variant of the process,

$S_v \subseteq S$, U_v is a set of operations realized by the means belonging to set S_v. In other words:

$$V_v = \{(S_v, U_v) : v = 1, 2, \ldots, V^*\} \tag{1}$$

An operation consists of actions characterized by a particular sequence. The actions are elementary fragments of the process.

This paper adopts the following postulate (pointed in (Ratkiewicz, 2019)): *A chain becomes integrated to a higher level if any link constituting it considers the needs of other links when defining its stream of materials (information, finances, et cetera)* Λ_{OUT}.

A chain is serially integrated if the above postulate occurs between *neighboring links* (i.e., links connected by flows of materials and information). Fig. 2 shows exemplary areas of serial integration. Technological processes executed in neighboring links create the integrating factor.

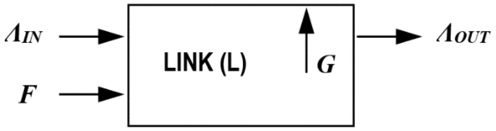

Fig. 1. Illustration of a chain link L

One can present a serial integration of a chain in a formalized manner as follows:

A chain under consideration consists of Q links. It is assumed that any q-th, ($q = 1, 2, ..., Q$) link L of the chain is defined by the following vector:

$$\mathrm{L}_q = \langle \Lambda_{INq}, F_q, G_q, \Lambda_{OUTq} \rangle \tag{2}$$

where the vector components are interpreted as:

Λ_{INq} – a set of qualitative and quantitative features defining the stream of materials, information, or finances at the input to the q-th link L ($q = 1, 2, ..., Q$);

F_q – a set of external disturbances at the input to the q-th link L ($q = 1, 2, ..., Q$);

G_q – a set of internal limitations in the q-th link L ($q = 1, 2, ..., Q$);

Λ_{OUTq} – a set of qualitative and quantitative features defining the stream of materials, information, or finances at the output from the q-th link L ($q = 1, 2, ..., Q$);

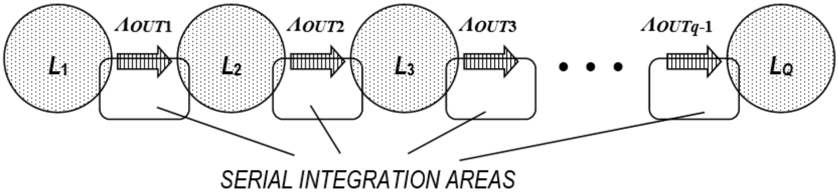

Fig. 2. Illustration of a serially integrated chain. Based on (Ratkiewicz, 2019)

It has been assumed that:

- the flow stream always relates to a transfer of materials, information, or finances;
- a feature may be of a quantitative or qualitative nature;
- T_{OUTq} denotes the total number of features describing the flow stream at the output from the q-th link L ($q = 1, 2, ..., Q$),
- $c_{OUTq,t}$ denotes a value of t-th feature characterizing the flow stream from the q-th link L, ($t = 1, 2, ..., T_{OUTq}$),
- $w_{OUTq,t}$ denotes a weight value defined from the point of view of the q-th link L for t-th feature characterizing the flow stream at the output from L_q.
- T_{INq+1} denotes the total number of features defined for the flow stream at the input to the (q+1)-th link L ($q = 1, 2, ..., Q; q + 1 \leq Q$),
- $c_{INq+1,t}$ denotes a value of t-th feature characterizing the flow stream at the input to the (q+1)-th link L ($t = 1, 2, ..., T_{INq+1}$; $q = 1, 2, ..., Q; q + 1 \leq Q$),
- $w_{INq+1,t}$ denotes a weight value defined from the point of view of the (q+1)-th link L, for of t-th feature characterizing the flow stream at the input to the (q+1)-th link L ($t = 1, 2, ..., T_{INq+1}$; $q = 1, 2, ..., Q; q + 1 \leq Q$),ink L ($q = 1, 2, ..., Q$);

One can write a vector of features defining the flow stream at the output from the q-th link L as follows:

$$\Lambda_{OUTq} = \langle L_{OUTq}, C_{OUTq}, W_{OUTq} \rangle \tag{3}$$

where:

L_{OUTq} – is a set of features characterizing the flow stream at the output from the q-th link L; the cardinality of this set is P_{OUTq};

$C_{OUTq} = \langle c_{OUTq,t} \rangle$ – a vector of values of features ($t = 1, 2, ..., T_{OUTq}$) characterizing the flow stream at the output from the q-th link L; the dimension of this vector is T_{OUTq};

$W_{OUTq} = \langle w_{OUTq,t} \rangle$ – vector of values of weights defined from the point of view of q-th link L for the features of the set L_{OUTq}; the dimension of vector W_{OUTq} is T_{OUTq}.

Vector of features defining the flow stream at the input to the (q+1)-th link L has the following form:

$$\Lambda_{INq+1} = \langle L_{INq+1}, C_{INq+1}, W_{INq+1}, \rangle \tag{4}$$

where:

L_{INq+1} – a set of features characterizing the flow stream at the input to the (q+1)-th link L ($q = 1, 2,..., Q; q + 1 \leq Q$); the cardinality of this set is T_{INq+1};

$C_{INq+1} = \langle c_{INq+1,t} \rangle$ – vector of values of features ($t = 1, 2, ..., T_{INq+1}$) characterizing the flow stream at the input to the (q+1)-th link L ($q = 1, 2, ..., Q; q + 1 \leq Q$); the dimension of this vector is T_{INq+1};

$W_{INq+1} = \langle w_{INq+1,t} \rangle$ – vector of values of weights defined from the point of view of the (q+1)-th link L ($q = 1, 2, ..., Q; q + 1 \leq Q$), for the features from the set L_{INq+1}; the dimension of vector W_{INq+1} is T_{INq+1}.

4. Evaluation measures of serial integration of a chain

As follows from Fig. 2, the cells constituting areas of serial integration must, in those areas, exhibit consistency of features of the flow of materials and/or information and/or finances that are to be evaluated. more formally, one may write it as follows: a necessary condition for chain integration in terms of flow is that:

$$\forall q, q + 1; q + 1 \leq Q \qquad L_{OUTq} \equiv L_{INq+1} \tag{5}$$

According to (5), the sets of features defined for the flow stream of materials at the output from the q-th link L are identical to the sets of features defined for the flow stream of materials at the input to the (q+1)-th link L. For both links, the material flow stream between the q-th and the q+1-th link L is defined by the same qualitative and quantitative features.

The following denotations are introduced:

$c^*_{OUTq,t}$ – a normalized value of the t-th feature (p = 1, 2, …, T_{OUTq}), characterizing the flow stream at the output from the q-th link L,

$c^*_{INq+1,t}$ – a normalized value of the t-th feature (p = 1, 2, …, T_{INq+1}), characterizing the flow stream at the input to the (q+1)-th link L , (q = 1, 2, ..., Q; q +1 ≤ Q).

The normalization denotes a transformation of the value of every feature to a form that makes it possible to compare the values of different features, for example, according to (Sendek-Matysiak and Pyza, 2018). In (Wasiak et al., 2016) such a transformation is called “standardization”.

An integration loss index A is introduced to define a measure of the integration in a chain. For two neighboring links numbered as q, q+1, the integration loss index may be written as follows:

$$A_{q,q+1} = \sum_{t=1}^{T_{OUTq}} \left| \left(c^*_{OUTq,t} \cdot w_{OUTq,t}\right) - \left(c^*_{INq+1,t} \cdot w_{INq+1,t}\right) \right| \tag{6}$$

whereas for the whole chain, it reads:

$$A = \sum_{q=1}^{Q-1} \sum_{t=1}^{T_{OUTq}} \left| \left(c^*_{OUTq,t} \cdot w_{OUTq,t}\right) - \left(c^*_{INq+1,t} \cdot w_{INq+1,t}\right) \right| \tag{7}$$

The smaller the integration loss index A is, the better the integration of the chain.

In a state of complete serial integration of chain links, every link, when defining its streams, fully satisfies the needs of a neighboring link L, i.e.:

$$\begin{gathered} \forall q, q+1; q+1 \leq Q \\ \Lambda_{OUTq} \equiv \Lambda_{INq+1} \quad \Rightarrow \quad A = 0 \end{gathered} \tag{8}$$

Said complete serial integration can be obtained, in a relatively most effortless manner, within a single enterprise, in which different divisions function as links L. The evaluation of the effectiveness of an individual division is inferior to the effectiveness of the whole enterprise.

An example of a partial activity leading to the integration of a supply chain (and, specifically, to impose a common form of the stream Λ_{OUT} for all the links L) is introducing a unified form of a unit load based on the so-called EUR pallet.

5. A multi-criteria method for selecting a preferred project variant of a process based on fuzzy set theory

In this paper, the term "feature" equals the term "criterion."

Moreover, the following terms are introduced:

$\mu(x_{tn})$ – a value of the membership function of the t- th quantitative or qualitative feature (t = 1, 2, ..., T, T – the total number of the considered features (criteria)) in the middle of the n–th interval, n = 1, 2, ..., N_t; N_t – the total number of the intervals of the argument of the t–th feature;

e – a number of the decision stage related to selecting a realization variant of a process between links.

$p_v(x_{tn})$ – a probability of assuming, by the t–th feature, a value from the n–th interval, in the v–th realization variant of the process; v = 1, 2, ..., V^*_e, where V^*_e is the total number of realization variants of the process at the e-th decision stage;

w^q_t –the weight of the t-th feature defined from the point of view of the q–th chain link. The values of w^q_t are to be defined for two neighboring links.

In order to illustrate some of the above denotations, Fig. 3 shows an exemplary structure being a part of a supply chain. The diagram illustrates possible realization variants of individual technological processes, maximizing the integration level of the chain structure shown in Fig. 3. This structure comprises a Supplier, a Distribution Warehouse (decomposed into shadowed links in Fig. 3), and a Recipient.

The approach presented in this paper (process engineering) is based on defining, at every decision stage (Fig. 3), realization variants of technological processes and then selecting the variant that is preferable to realize.

The method under consideration comprises, for every decision stage e, the following nine steps:

1. Defining weights w^q_t for every t from the point of view of q, q+1.
2. Defining the membership function $\mu(x_{jn})$, i.e., a level of membership of the argument x into the goal of a criterion for every criterion. The membership function may be interpreted as a preference function. Its shape should be defined from the point of view of that neighboring link which has a bigger weight for the considered criterion. Optionally (or in the case of equal weights for both links), the shape of $\mu(x_{jn})$ may be defined by an Expert who assists in selecting the preferred variant of the technological process.

3. Defining $p_v(x_{tn})$ for every v, t, n. From a practical point of view, the shape of $p_v(x_{tn})$ should have a different graphical representation (for example, a histogram) than the shape of $\mu(x_{jn})$. The probability density $p_v(x_{tn})$ should be defined in accordance with the art, for example, as suggested in (Hajek, 1998). In practice, it is reasonable to give this action over to the Expert acting in step 2 of the method.
4. Reading the values of $\mu(x_{tn})$ and $p_v(x_{tn})$ for every t, n.
5. Calculating, for every v, t, n, values of $\mu(x_{tn})\cdot p_v(x_{tn})$.
6. Calculating, for every v, t, values of $\sum_{n=1}^{N_t} \mu(x_{tn}) \cdot p_v(x_{tn})$
7. Calculating, for every v, q, values of $\sum_{t=1}^{T} w_t^q \cdot \sum_{n=1}^{N_t} \mu(x_{tn}) \cdot p_v(x_{tn})$
8. Calculating, for every v, values of:

$$\left|\sum_{t=1}^{T} w_t^q \cdot \sum_{n=1}^{N_t} \mu(x_{tn}) \cdot p_v(x_{tn}) - \sum_{t=1}^{T} w_t^{q+1} \cdot \sum_{n=1}^{N_t} \mu(x_{tn}) \cdot p_v(x_{tn})\right| \tag{9}$$

9. Selecting, for the realization, that v-th variant, for which expression (9) has its minimum value.

With a higher number of realization variants of any technological process and a higher number of links, a simpler implementation of the above method may be based on a mathematical model. Then, an additional binary type variable, av, has to be introduced: $a_v = 1$, if a technological process is realized according to the v–th realization variant; $a_v = 0$, otherwise. Then, after completing steps 1 – 3, and 6, one must solve the following task of mathematical optimization. The objective function:

$$\min \left| \sum_{v=1}^{V_e^*} \sum_{t=1}^{T} \sum_{n=1}^{N_t} \mu(x_{tn}) \cdot p_v(x_{tn}) \cdot w_t^q \cdot a_v - \sum_{v=1}^{V_e^*} \sum_{t=1}^{T} \sum_{n=1}^{N_t} \mu(x_{tn}) \cdot p_v(x_{tn}) \cdot w_t^{q+1} \cdot a_v \right| \tag{10}$$

subject to:

$$\sum_{v=1}^{V_e^*} a_v = 1 \qquad \text{for all } e \tag{11}$$

$$\sum_{n=1}^{N_t} p_v(x_{tn}) = 1 \qquad \text{for all } v, t \tag{12}$$

$$\sum_{t=1}^{T} w_t^q = 1 \qquad \text{for all } q \tag{13}$$

a_v - is binary; $p_v, \mu, w_t^q \geq 0$.

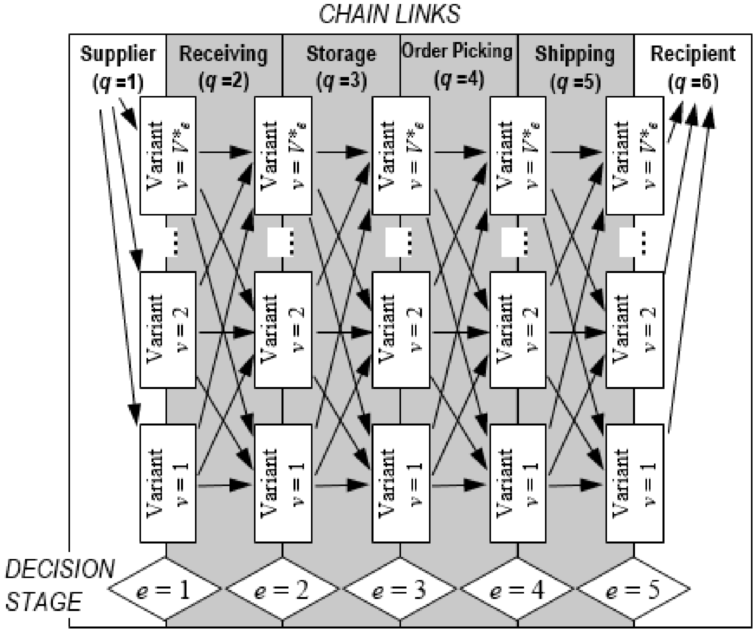

Fig. 3. Illustration of a part of a supply chain with some of the adopted denotations

The above mathematical model comprises decision variables a_v. The limitation (11) has the following interpretation: exactly one variant of the process will be selected for the realization at every decision stage. The limitation (12) imposes that the sum of the probability densities is 1. The limitation (13) denotes that the sum of the weights defined for any chain link is 1.

It should be noted that the presented method is an expansion and an aggregation of the measures of the supply chain integration of (6) and (7). It may be illustrated by comparing the expressions (6) and (9). Neglecting, for simplicity, the indexes, one may notice that both comprise the weight w of a feature, whereas the product $p \cdot \mu$ in (9) corresponds to the value c^* of a feature in (6) and (7)

6. An example of selecting a realization variant of the flow of materials in relation Shipping – Recipient

This example relates to the area indicated in Fig. 3 between the links of Shipping ($q = 5$) and Recipient ($q = 6$). One of the most frequent questions that arise in this area today is: Should the pallet load units (plu), picked in the Distribution Warehouse, and after applying a transportation lock (heat shrink film), be loaded onto a car as a whole (Variant 1), or, on the contrary, they should be unpacked and then every single packaging of the goods (a unit load) should be packed onto a car separately (Variant 2). Fig. 4 shows a diagram of the flow of materials defined for the two variants and drawn using symbols used in the mapping of transport technology processes. It has been assumed that the selection of the preferred realization variant of the flow process of materials will be based on the following criteria: 1) shipping cost; 2) shipping quality; 3) shipping time. Table 1 presents the results of defining weights for individual criteria (i.e., step 1 of the selection method).

Table 1. Defining weights of individual criteria w^q_t from the point of view of Shipping and Recipient.

Chain link	**Value** q, q+1	**Criteria**			**Total**
		$t = 1$: **cost**	$t = 2$: **quality**	$t = 3$: **time**	
Shipping S	5	0.5	0.25	0.25	1
Recipient R	6	0.2	0.5	0.3	1

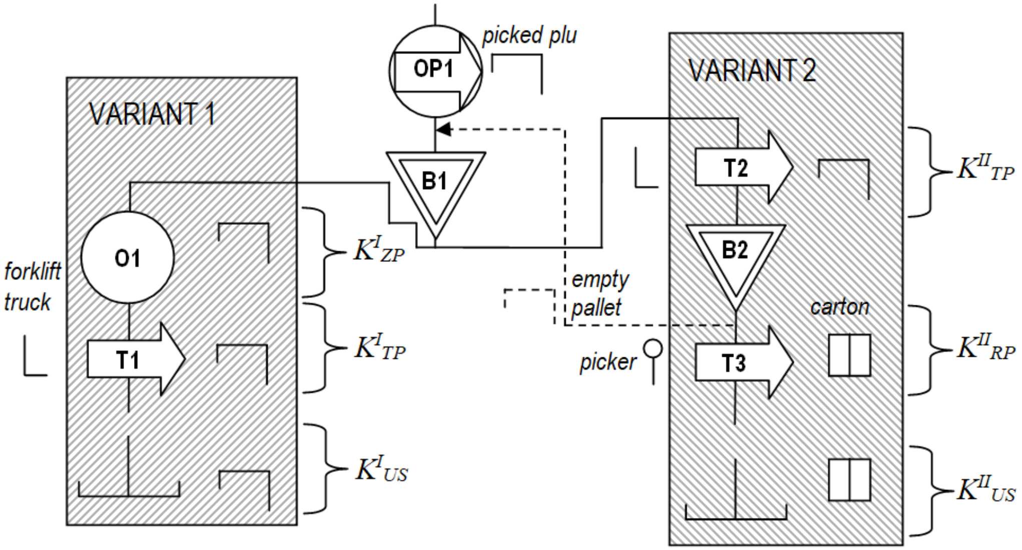

Fig. 4. Diagram of two variants of the flow of materials at the output from the Distribution Warehouse. Based on (Ratkiewicz and Lewczuk, 2018)

6.1. Shipping cost

As results from Table 1, the shipping cost is essential from the Shipping link point of view and significantly less important from the Recipient point of view. Analyzing the variants of shipment shown in Fig. 4, one may notice that in the first variant, one saves the costs of unpacking a plu. In contrast, losses appear from increased transport costs (poorer usage of the cubature and load of the transport). In the second variant, the situation is the opposite. So, the costs of both variants should be formalized and compared in identical conditions. One may write the costs as follows (Ratkiewicz and Lewczuk, 2018):

- for Variant 1:

$$K^{I} = K^{I}_{ZP} + K^{I}_{TP} + K^{I}_{US} \tag{14}$$

- for Variant 2

$$K^{II} = K^{II}_{TP} + K^{II}_{RP} + K^{II}_{US} \tag{15}$$

where:
K^{I} – costs of the shipping Variant 1; K^{I}_{ZP} – the cost of the transportation lock for a plu for the shipping Variant 1; K^{I}_{TP} – the cost of delivering a plu onto the car box body for the shipping Variant 1; K^{I}_{US} – the cost of using cars in the shipping Variant 1; K^{II} – the cost of the shipping Variant 2; K^{II}_{TP} – the cost of delivering a plu onto the car box body for the shipping Variant 2; K^{II}_{RP} – the cost of unpacking a plu and loading the load into the car box body for the shipping Variant 2; K^{II}_{US} – the cost of using cars in the shipping Variant 2.

Fig. 4 shows the localization of the costs mentioned above. Following (Ratkiewicz and Lewczuk, 2018), a term of a shipment base cost is introduced, including all expenses related to the shipment of a single picked pallet load unit (pplu), excluding the expenses related to the transport of the load to the Recipient. Let $K^{I}_{BW} = K^{I} / \Lambda_{OUT5}$ [€/pplu] is the shipment base cost in Variant 1, and $K^{II}_{BW} = K^{II} / \Lambda_{OUT5}$ [€/pplu] is the shipment base cost in Variant 2. The values of K^{I} and K^{II} are calculated according to (Ratkiewicz and Lewczuk, 2018). Then, one assumes that the average shipping cargo is 33 pplus, i.e., $\Lambda_{OUT5} = 33$. Similarly to (Ratkiewicz and Lewczuk, 2018) four cases have been considered with different parameters reflecting various actual cases. Case 1 assumes high car transport costs and low warehouse labor costs. Case 2 assumes low car transport costs and high warehouse labor costs. In Case 3 – transport costs and storing costs are similar to Case 2, and it assumes a higher coefficient of the car box body usage. Case 4 assumes the cost parameters similar to Case 3 and extremely high fragmentation of the shipment (600 stock items). Table 2 presents the base costs for the 4 cases mentioned above.

Table 2. Shipment base costs

Base cost	Case 1	Case 2	Case 3	Case 4
K^{I}_{BW} [€/pplu]	59.68	54.45	36.87	36.87
K^{II}_{BW} [€/pplu]	41.08	37.94	33.55	36.96

Figs. 5a, 5b show an exemplary membership function $\mu(x_{tn})$ and a probability density $p_v(x_{tn})$ (defined arbitrarily based on Table 2) (steps 2, 3 of the method) for both variants.

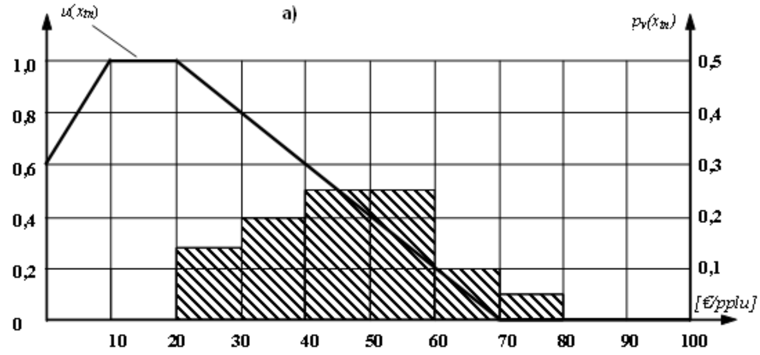

Fig. 5a. An exemplary membership function $\mu(x_{tn})$ and an exemplary probability density $p_v(x_{tn})$ for the shipping cost criterion for Variant 1

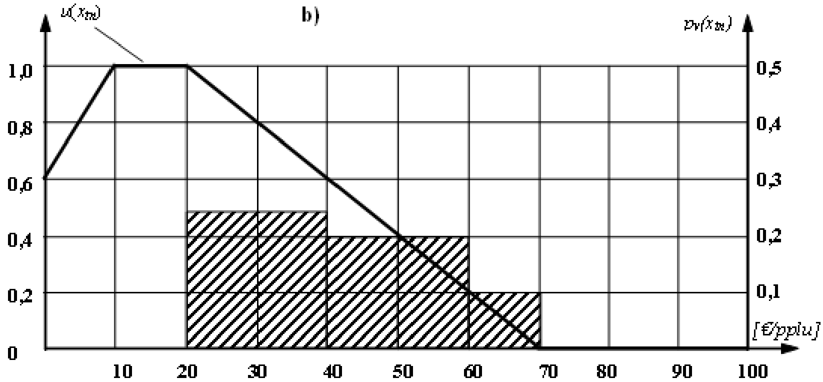

Fig. 5b. Exemplary membership function $\mu(x_{tn})$ and exemplary probability density $p_v(x_{tn})$ for the shipping cost criterion for Variant 2

6.2. Shipping quality

As results from Table 1, this criterion is essential from the Recipient link point of view, less critical from the Shipping link point of view. In this paper, the problem of the shipping quality is limited to the problem of damaging the load. Table 3 shows the percentage of the load damaged during shipment. The data comes from sales networks and distribution companies operating in Poland and practicing both considered shipping variants.

Figs. 6a, 6b show an exemplary membership function $\mu(x_{tn})$ and a probability density $p_v(x_{tn})$ defined arbitrarily based on Table 3 (steps 2, 3 of the method) for both variants.

Table 3. Percentage of damaged load in both shipping variants. Based on (Ratkiewicz, 2019)

Company	**Variant 1 (palletized shipment) [%]**	**Variant 2 (depalletized shipment) [%]**
A	4,22	3,6
B	1,46	2,21
C	2,3	1,8
D	2,2	2,4
Average	2,55	2,50

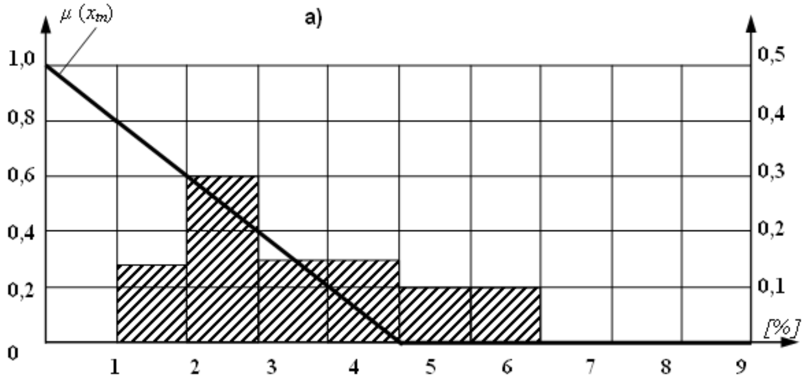

Fig. 6a. An exemplary membership function $\mu(x_{tn})$ and an exemplary probability density $p_v(x_{tn})$ for the shipping quality criterion for Variant 1

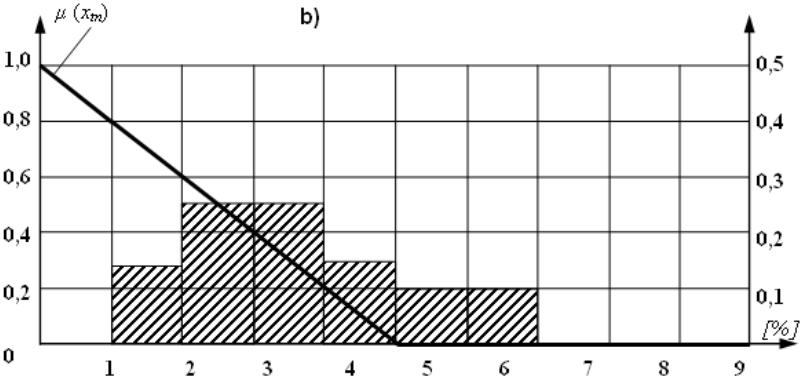

Fig. 6b. An exemplary membership function $\mu(x_{tn})$ and an exemplary probability density $p_v(x_{tn})$ for the shipping quality criterion for Variant 2

6.3. Shipping time

As results from Table 1, the shipping time is essential for both the Recipient and the Shipping links. One may expect that a time difference in shipment promotes Variant 1 due to a shorter loading time. We assume that the difference in the shipping time is due to the actions denoted O1, T1 (Variant 1) and T2, B2, T3 (Variant 2) (Fig. 4). These actions may be named loading actions. The time of executing the shipping loading actions for Variant 1, R^I_N is:

$$R^I_N = max(R^I_{LZP}\ ,\ R^I_{UZP}) + R^I_{TP} \tag{16}$$

The time of executing the loading actions for Variant 2 R^{II}_N is:

$$R^{II}_N = R^{II}_{TP} + R^{II}_{RP} \tag{17}$$

Table 4 shows the times of executing the loading actions for both variants of the shipment and four cases. It suggests that Variant 1 is significantly better considering the criterion of the shipping time.

Figs. 7a, 7b show an exemplary membership function $\mu(x_{tn})$ and a probability density $p_v(x_{tn})$ (defined arbitrarily based on Table 4) (steps 2, 3 of the method) for the criterion of the shipping time for both variants.

Table 4. Times of executing the loading actions [h]

Variant 1 (for 300 or 600 items)	$max(R^I_{LZP}\ ,\ R^I_{UZP})$	R^I_{TP}	R^I_N
	0.86	0.89	1.75

Variant 2	R^{II}_{TP}	R^{II}_{RP}	R^{II}_N
for 300 items	0.84	3.99	4.83
for 600 items	0.84	6.69	7.53

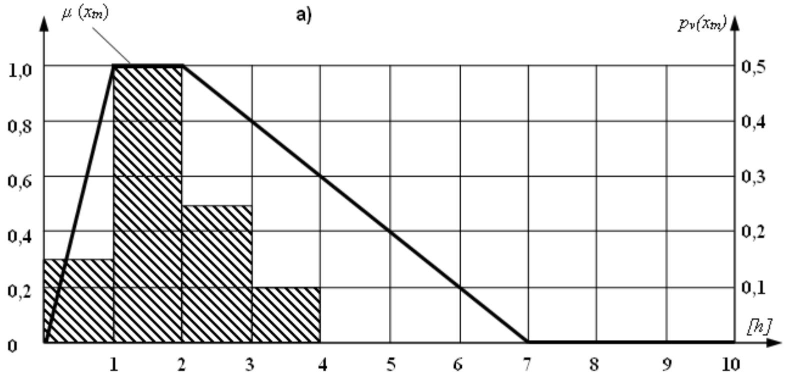

Fig. 7a. An exemplary membership function $\mu(x_{tn})$ and an exemplary probability density $p_v(x_{tn})$ for the shipping time criterion for Variant 1

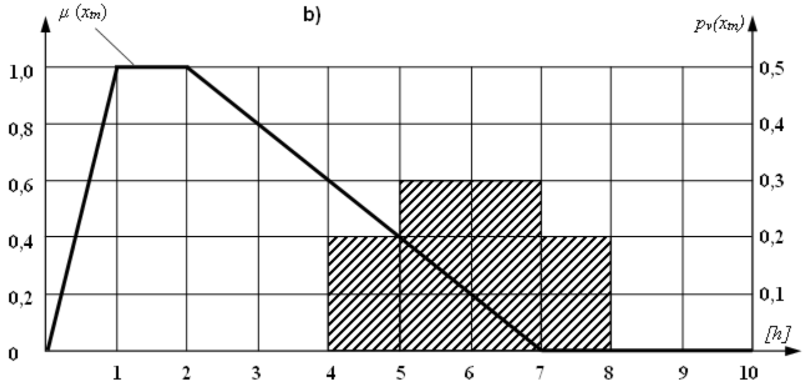

Fig. 7b. An exemplary membership function $\mu(x_{tn})$ and an exemplary probability density $p_v(x_{tn})$ for the shipping time criterion for Variant 2

6.4. Calculation results

Table 5 shows the results of steps 3, 4, 5, 6 of the selection method. Table 6 shows the results of steps 7 and 8 of the selection method.

In the 9-th step of the method, one must choose the variant for which (9) is of a smaller value. As it results from Table 6, one should choose Variant 1, i.e., the palletized shipment.

7. Application of the method

As results from the present study, one may recommend the following algorithm to logistics operations managers in distribution/production companies according to the diagram shown in Fig. 8.

The proposed approach offers a measurable and effective way to improve the serial integration of cells in any chain structure. Basing on the general diagram shown in Fig. 3, one may develop a more specific algorithm shown in Fig. 8, dedicated, for example, for managers. Moreover, the diagram shown in Fig. 3 may be expanded towards other cells that belong to the structure.

8. Conclusions

Concluding, the presented approach makes it possible to integrate cells connected via processes of different nature (production, distribution, financial, or informational). The necessary condition for using the described approach is the presence of optional variants of technological processes, this belonging to the field of process engineering. The presented method helps managers and engineers to design flows of various kinds of technological, distribution, and transportation processes in any chain-like structure.

One may employ the methodology presented in this paper as supplementation of methods/tools packets for improving manufacture and/or distribution processes (for example, according to the Lean production/Lean distribution concepts). Another possible use of the presented approach may include an obtained value of the integration loss index as an additional criterion for a multi-criteria evaluation for selecting the preferred variant of a technological process for every pair of neighboring links of a supply chain (Fig. 3).

Main difficulties in applying the proposed multi-criteria method for selecting a preferred project variant of a process may be described twofold. On the one hand, the quality of the transformation of the needs of individual cells into a membership function μ(xtn) is essential. On the other hand, it is necessary to define the probability densities pv(xtn) for the process and, simultaneously, preserve its parameters as reliably as possible. So, the robustness and the reliability of the presented methodology is a derivative of the robustness of the employed method for evaluating the membership functions and probability densities, this being a common feature of methods based on fuzzy logic. Also, the results may be disturbed by irrational/irresponsible setting the weights in the multi-criteria method for selecting a preferred variant.

Therefore, further works are needed to increase the applicability of the proposed method considering the difficulties mentioned above.

Table 5. Results of actions 3-6 of the method for selecting a variant of material flow in relation Shipping - Recipient

Criterion	Variant	Interval *n*	1	2	3	4	5	6	7	8	9	10	Total	
Criterion t = 1: cost	Variant v =1	$\mu(x_{tn})$	0,8	1	0,9	0,7	0,5	0,3	0,1	0	0	0		
		$p_v(x_{tn})$	0	0	0,15	0,2	0,25	0,25	0,1	0,05	0	0	1	
		$p_v(x_{tn})\cdot\mu(x_{tn})$	0	0	0,135	0,14	0,125	0,075	0,01	0	0	0	0,485	$= \sum_{n=1}^{N_t} \mu(x_{1n})\cdot p_1(x_{1n})$
	Variant v =2	Interval *n*	1	2	3	4	5	6	7	8	9	10	Total	
		$\mu(x_{tn})$	0,8	1	0,9	0,7	0,5	0,3	0,1	0	0	0		
		$p_v(x_{tn})$	0	0	0,25	0,25	0,2	0,2	0,1	0	0	0	1	
		$p_v(x_{tn})\cdot\mu(x_{tn})$	0	0	0,225	0,175	0,1	0,06	0,01	0	0	0	0,57	$= \sum_{n=1}^{N_t} \mu(x_{1n})\cdot p_2(x_{1n})$

Criterion	Variant	Interval *n*	1	2	3	4	5	6	7	8	9	10	Total	
Criterion t = 2: quality	Variant v =1	$\mu(x_{tn})$	0,9	0,7	0,5	0,3	0,1	0	0	0	0	0		
		$p_v(x_{tn})$	0	0,15	0,3	0,15	0,15	0,1	0,1	0,05	0	0	1	
		$p_v(x_{tn})\cdot\mu(x_{tn})$	0	0,105	0,15	0,045	0,015	0	0	0	0	0	0,315	$= \sum_{n=1}^{N_t} \mu(x_{2n})\cdot p_1(x_{2n})$
	Variant v =2	Interval *n*	1	2	3	4	5	6	7	8	9	10	Total	
		$\mu(x_{tn})$	0,9	0,7	0,5	0,3	0,1	0	0	0	0	0		
		$p_v(x_{tn})$	0	0,15	0,25	0,25	0,15	0,1	0,1	0	0	0	1	
		$p_v(x_{tn})\cdot\mu(x_{tn})$	0	0,105	0,125	0,075	0,015	0	0	0	0	0	0,32	$= \sum_{n=1}^{N_t} \mu(x_{2n})\cdot p_2(x_{2n})$

Criterion	Variant	Interval *n*	1	2	3	4	5	6	7	8	9	10	Total	
Criterion t = 3: time	Variant v =1	$\mu(x_{tn})$	0,5	1	0,9	0,7	0,5	0,3	0,1	0	0	0		
		$p_v(x_{tn})$	0,15	0,5	0,25	0,1	0	0	0	0	0	0	1	
		$p_v(x_{tn})\cdot\mu(x_{tn})$	0,08	0,5	0,225	1	0	0	0	0	0	0	1,8	$= \sum_{n=1}^{N_t} \mu(x_{3n})\cdot p_1(x_{3n})$
	Variant v =2	Interval *n*	1	2	3	4	5	6	7	8	9	10	Total	
		$\mu(x_{tn})$	0,5	1	0,9	0,7	0,5	0,3	0,1	0	0	0		
		$p_v(x_{tn})$	0	0	0	0	0,2	0,3	0,3	0,2	0	0	1	
		$p_v(x_{tn})\cdot\mu(x_{tn})$	0	0	0	0	0,1	0,09	0,03	0	0	0	0,22	$= \sum_{n=1}^{N_t} \mu(x_{3n})\cdot p_2(x_{3n})$

Table 6. Parameters and calculations for steps 7 and 8 for selecting a variant of material flow in the relation Shipping - Recipient

Variant v = 1 of the process				
	q = 5		q + 1 = 6	
	$\sum_{n=1}^{N_t}\mu(x_{tn})\cdot p_v(x_{tn})$	$w^5{}_t$	$\sum_{n=1}^{N_t}\mu(x_{tn})\cdot p_v(x_{tn})$	$w^6{}_t$
t = 1	0,485	0,5	0,485	0,2
t = 2	0,315	0,25	0,315	0,5
t = 3	1,8	0,25	1,8	0,3
$\sum_{t=1}^{T} w_t^q \cdot \sum_{n=1}^{N_t}\mu(x_{tn})\cdot p_v(x_{tn}) =$		0,771	$\sum_{t=1}^{T} w_t^{q+1} \cdot \sum_{n=1}^{N_t}\mu(x_{tn})\cdot p_v(x_{tn}) =$	0,79
$\left\lvert\sum_{t=1}^{T} w_t^q \cdot \sum_{n=1}^{N_t}\mu(x_{tn})\cdot p_v(x_{tn}) - \sum_{t=1}^{T} w_t^{q+1} \cdot \sum_{n=1}^{N_t}\mu(x_{tn})\cdot p_v(x_{tn})\right\rvert =$				0,023
Variant v = 2 of the process				
	q = 5		q + 1 = 6	
	$\sum_{n=1}^{N_t}\mu(x_{tn})\cdot p_v(x_{tn})$	$w^5{}_t$	$\sum_{n=1}^{N_t}\mu(x_{tn})\cdot p_v(x_{tn})$	$w^6{}_t$
t = 1	0,57	0,5	0,57	0,2
t = 2	0,32	0,25	0,32	0,5
t = 3	0,22	0,25	0,22	0,3
$\sum_{t=1}^{T} w_t^q \cdot \sum_{n=1}^{N_t}\mu(x_{tn})\cdot p_v(x_{tn}) =$		0,42	$\sum_{t=1}^{T} w_t^{q+1} \cdot \sum_{n=1}^{N_t}\mu(x_{tn})\cdot p_v(x_{tn}) =$	0,34
$\left\lvert\sum_{t=1}^{T} w_t^q \cdot \sum_{n=1}^{N_t}\mu(x_{tn})\cdot p_v(x_{tn}) - \sum_{t=1}^{T} w_t^{q+1} \cdot \sum_{n=1}^{N_t}\mu(x_{tn})\cdot p_v(x_{tn})\right\rvert =$				0,08

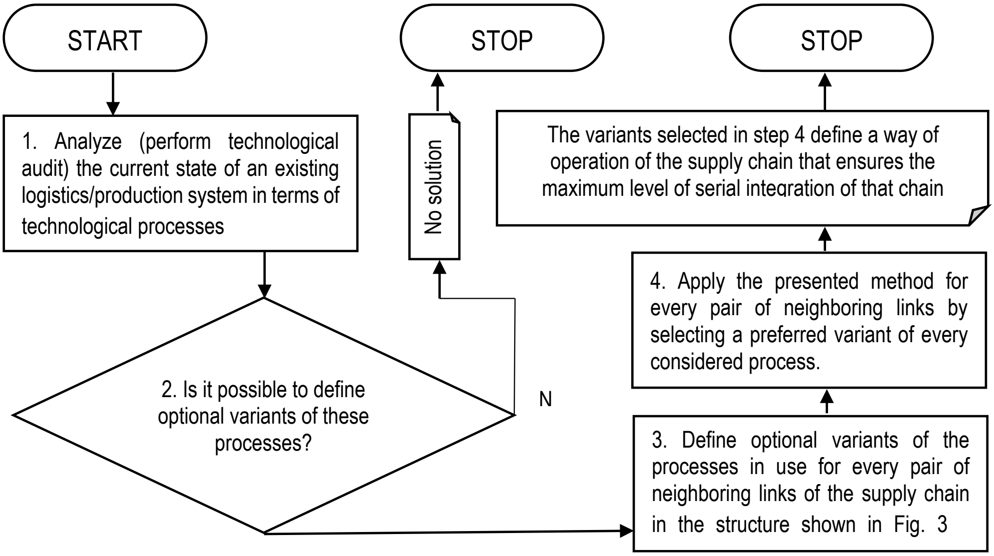

Fig. 8. An algorithm for managers

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