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CONSENSUS DETERMINING ALGORITHM FOR SUPPLY CHAIN MANAGEMENT SYSTEMS

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The purpose of article is to elaborate a consensus determination algorithm in supply chain management support systems, which may lead to achieving a greater flexibility and effectiveness of such systems. Using consensus methods in resolving the conflict of knowledge, in other words, determining a variant to be then presented to the user, based on the variants proposed by the system, may lead to shortening the variant determination time and to reducing the risk of selecting the worst variant. As a consequence, supply chain management might become more dynamic, which obviously influences the effectiveness of the operation of particular organizations and the entire supply chain. The originality is using consensus method to resolve knowledge conflicts in SCM systems to help decision-maker to take decision earning satisfy benefits.

Keywords: Supply Chain Management Systems, knowledge conflicts, consensus methods

1. Introduction

Nowadays a supply chain constitutes the crucial component in the operation of enterprises in the turbulent economic situation. What determines competitive advantage to an increasingly greater extent, is not only the quality and price of a product but also efficient organisation of supplies of materials, raw materials and finished goods at the lowest costs and appropriate level of customer service ensured. This leads enterprises to seeking the best strategies permitting effective supply chain management [3, 8].

It has been noticeable in the recent years that enterprises have become more interested in systems oriented towards SCM (Supply Chain Management) [10, 11]. It is indicated more and more often in the relevant literature [12, 13] that such systems ought to dynamically respond to the market needs, which contributes to increasing the value of all enterprises participating in the execution of a supply chain. However, the situation where the SCM system presents diverse variants of product flow between individual co-operators to the user occurs frequently [16]. Each of these variants can be different, that is have different values of the attributes (characteristics) describing the product flow (for example, the delivery date can be an attribute). This means that there is a conflict of knowledge between the variants generated by the SCM system. The variant selection should bring satisfying benefits to the user, that is this ought to be a variant which allows the delivery of goods in an appropriate quantity and within an appropriate time at the lowest possible costs and risk. If the user has to make the decision on which of these variants to choose alone, this process is obviously time-consuming and involves the risk of selecting the wrong variant. For instance, one might choose the variant in which, despite the timely delivery and low costs, the size of the goods batch is too big and the enterprise will have to incur the expenses of warehousing the goods. One could also select the optimum variant in terms of the size of the batch and costs but with a considerable risk of delay in delivery. Therefore, choosing a wrong or high-risk variant can cause disturbances in the performance of production or service processes in the enterprise. This will undoubtedly influence the effectiveness of its functioning and even, in an extreme case where, for instance, the customer dissatisfaction with the price, quality and timeliness of the services provided by this enterprise increases, result in its bankruptcy. Due to such problems, the conflict of knowledge should not be resolved by a human but rather by the system automatically and on a real-time basis. Various methods of resolving such conflicts can be found in the relevant literature, e.g. negotiations [4], or deductive-computing methods [2]. Negotiations enable a good resolution to the conflict of knowledge by achieving a compromise but they require an exchange of a large number of messages between the system components, as a result of which the operation of the SCM system on a real-time basis often becomes difficult or even impossible. Deductive-computing methods, for instance ones based on the game theory (game theory is a discipline of science closely related to the problems of cooperation and conflict resolving in multiagent systems, it involves construction of mathematical models of conflicts and cooperation as elements of human interaction), classical mechanics (they are employed in multiagent systems that require cooperation between a large number of agents – hundreds or even thousands of agents – such as in systems designed to reach highly distributed and dynamic goals) or a multi-criteria method (choice one of solutions on the basis of multiple criteria) permit the achievement of high computational capacity of the system but they do not ensure a correct resolution to the conflict of knowledge, because often choice one of solution is related is associated with a high level of risk.

For the purpose of eliminating the presented problems, it is possible to employ consensus methods, which allow resolving the conflict of knowledge at a time close to the real time [15] and at the same time ensure the achievement of a good compromise [9]. This is because in the case of a consensus each of the parties is taken into account, "loses" as little as possible and makes its contribution to the consensus, all parties accept the consensus, which means that the consensus represents all parties to the conflict. Consensus determination algorithms regarding various decision-making areas, such as weather forecasting, finances, or environmental monitoring, can be found in the relevant literature. However, no such consensus determination algorithms which could be used in support systems for supply chain management have been developed thus far.

Hence, the present paper aims at developing a consensus determination algorithm in supply chain management support systems, which may lead to achieving a greater flexibility and effectiveness of such systems. Article is a continuation of research presented in [16, 17]. The first part of article presents a short characteristics of consensus methods. Next, the distance functions between variants are presented. The algorithm of consensus determining was elaborated in the final part of article.

2. Consensus methods

The relevant literature [9] defines consensus as an agreement and originates from the choice theory. Consensus is determined based on the existing solutions to a given problem, is very close to them, but does not have to be one of these solutions. Hence, the supply chain management variant presented to the used does not need to be a variant determined by the SCM system. It can be a totally new variant formed on the basis of the existing variants (that is ones determined by the SCM system). Owing to that all variants generated by the SCM system can be taken into consideration. It needs to be noticed that since supply chain management is a continuous process, the selection from among the variants generated by the system is also made in a permanent manner. The time allocated for making this choice is very short because the system may generate new variants of solutions after a moment and a new choice needs to be made. So if the SCM system generates a few or ten-odd solution variants, one new variant can be determined automatically based on these variants and next presented to the user. Owing to that all variants generated by the SCM system can be taken into account. Such a behaviour permits, among others, shortening the target variant determination time. The user does not have to analyse individual variants and contemplate their selection as the system will perform these actions automatically (of course user always have a possibility to analyse individual variants manually). It needs to be emphasised that due to the continuity of the supply chain management process, it is often impossible for the user to analyse the variants. This is because the time between the successive choices is so short that one is unable to make a decision without aid from the system. Employing consensus methods also allows reducing the risk of selecting the worst variant since all variants are taken into consideration in the case of a consensus. It should be noticed that this risk is extremely high because selecting a wrong variant may result, for instance, in untimely deliveries or their high cost intensity, which can lead to disturbances in the goods production or service provision processes and, in consequence, to reduced economic effectiveness of an enterprise or even its bankruptcy. Applying consensus methods, in turn, may result in a more flexible, effective and less risky execution of the supply chain management process.

The research conducted by the authors of the paper [16] show that the SCM system modules related to suppliers, producers, wholesalers, retailers and individual customers – based on the information obtained from transactional and analytical systems – due to various criteria or information analysis methods (such as the lowest price, the shortest lead time, non-linear programming, genetic algorithms, multi-criteria methods) generate diverse solution variants for individual supply chain components [14]. These variants differ in terms of attributes and values of these attributes. Hence, a conflict between these variants emerges in the system. Therefore, the user needs to choose a variant to be implemented at a given time. Such a choice in not easy because one is never sure which of the variants may bring results that will be satisfying to the user. This is why such a choice involves a high risk, and at the same time the user is incapable of analysing the considered variants due to time limits arising from the fact that decisions need to be made very quickly for supply chain management to be effective. Hence, conflicts of knowledge occur when the parties to the conflict assign different values to the same objects in the world and the same characteristics [16]. If the SCM system generates different solution variants (for example due to the employment of diverse support methods for supply chain management), the conflict of knowledge may refer to a characteristic such as "quantity" (in the generated variants the quantity of the goods to be shipped can differ), "cost" (in the generated variants delivery costs can differ), or "time" (in the generated variants delivery can be performed at different hours).

Resolving this type of conflicts is extremely important because only then is there a possibility to determine the right variant for the user, one being a compromise between the variants generated by the SCM system. Owing to that, each time the system generates different variant versions, the user obtains satisfying solutions characterised by a low risk level, which means that they will be released form the necessity to make a choice, which, as was stated above, is frequently impossible due to time limits. As a consequence, this may contribute to timeliness, appropriate volume of the supply batches and low cost level. If the system ignores this aspect, the user might have problems with proper supply chain management. Selecting a wrong or high-risk variant can result in problems with maintaining production continuity, increased warehousing costs, or lack of financial liquidity and, as a result, decreased economic effectiveness of the enterprise. Therefore, the use of consensus methods will permit resolving conflicts of knowledge and, as a consequence, streamline supply chain management.

Determining consensus consist of three major stages (Fig. 1). In the first stage it is necessary to carefully examine the structure of the set of all the variants generated by the system SCM, or specify characteristics that represent these variants and the domains of its values (this aspect was presented at [16]). Structures of variants are knowledge structures of SCM. In the second stage it is necessary to define the distance functions among particular variants (it was presented at [17]) and to define set of variants (a profile), on the basis of which consensus will be determine. The third stage is an elaborate of consensus determining algorithms - the determining of such a variant, that the distance between this variant (consensus), and the individual variants generated by SCM is minimal (according different criterions). So, the consensus is not the average.

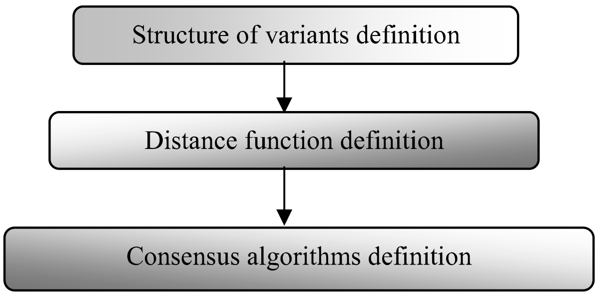

Figure 1. The stages of consensus determining.
Source: own preparation on the basis of [16]

In order to elaborate the algorithms of consensus dethermining it can be use a structure defined at the paper [16] in the following way (the first stage of consensus determining):

Definition 1
Let:
Set of products $T = \{t_1, t_2, \ldots, t_N\}$
Set of places $M = \{m_1, m_2, \ldots, m_L\}$

The structure of variant is called the following sequence:

$$W = \left\{ \left\langle t_1, m_{p1}, m_{q1}, dt_{m_{p1}}, dt_{m_{q1}}, i_1, k_1 \right\rangle, \left\langle t_2, m_{r2}, m_{s2}, dt_{m_{r2}}, dt_{m_{s2}}, i_2, k_2 \right\rangle, ..., \left\langle t_N, m_{xN}, m_{yN}, dt_{m_{xN}}, dt_{m_{yN}}, i_N, k_N \right\rangle \right\}$$

where:

$p, q, r, s, x, y = \{1..L\}$,

$dt_{m_{p1}}, dt_{m_{r1}}, ..., dt_{m_{xN}}$ - date and time of sending of product $t_1, t_2, ..., t_n$ from the place $m_p, m_r, ..., m_x$,

$dt_{m_{q1}}, dt_{m_{s1}}, ..., dt_{m_{yN}}$ - date and time of receiving of product $t_1, t_2, ..., t_n$ at the place $m_q, m_s, ..., m_y$,

$i_1, i_2, ..., i_N$ - the amount of transported products $t_1, t_2, ..., t_n$ (the size of the batch),

$k_1, k_2, ..., k_N$ - the cost of transport $t_1, t_2, ..., t_n$.

This definition allows the representation of individual variants of solutions in the form of uniform structure. It is complex, multi-value structure consist of different types of data.

3. Distance functions

The paper [17] suggest the distance function between structures of variants. It is the second stage of consensus determining. It must be noted that calculation of a distance between two variant structures may be based on calculation and summation of distances between individual elements of those structures.

For the purpose of defining time distance between two dates, let us assume that chronon, that is the smallest unit of time [1, 5] equals one minute (this degree of accuracy seems sufficient, since transportation of goods in practical application cannot be accomplished with down-to-one-second accuracy). Naturally, this assumption does not preclude one from adopting other time units as chronons. Therefore, definition of this function is as follow:

<u>Definition 2</u>

Distance ϑ between two dates $dt1$ and $dt2$ in the structure of variants is called the function:

$$\vartheta(dt1, dt2) = |dt1 - dt2|.$$

The example is distance between dates: 10-11-2012 15:00 and 11-11-2012 16:30, which equal 1 day, 1 hour and 30 minutes that is 24 * 60 + 90 =1530 minutes.

In considering the distance between number of the product and the costs of transport, it can be use the function used in many papers [e.g. 6, 7, 9] specifying the distance between real numbers:

Definition 3
The distance between numbers *x, y* belonging to the string composed with *m* real numbers is called follow function:

$$\chi(x,y)=\frac{1}{m}|x-y|.$$

The following example illustrates this definition.
Let's $m = 3$ and string of numbers is following: {2, 4, 8}. The distance between numbers 2 and 4 equals $=\frac{1}{3}|2-4|=\frac{2}{3}$, the distance between numbers 2 and 8 equals $=\frac{1}{3}|2-8|=2$, whereas the distance between numbers 4 and 8 equals $=\frac{1}{3}|4-8|=1\frac{1}{3}$.

At the article [17] the distance between two variants is defined as follow:

Definition 4
The distance Ψ between two structures of variants:

$$W^{(1)}=\Big\{\Big\langle t_1{}^{(1)},m_{p1}{}^{(1)},m_{q1}{}^{(1)},dt_{m_{p1}}{}^{(1)},dt_{m_{q1}}{}^{(1)},i_1{}^{(1)},k_1{}^{(1)}\Big\rangle,\ldots,$$
$$\Big\langle t_N{}^{(1)},m_{xN}{}^{(1)},m_{yN}{}^{(1)},dt_{m_{xN}}{}^{(1)},dt_{m_{yN}}{}^{(1)},i_N{}^{(1)},k_N{}^{(1)}\Big\rangle\Big\}$$
$$W^{(2)}=\Big\{\Big\langle t_1{}^{(2)},m_{p1}{}^{(2)},m_{q1}{}^{(2)},dt_{m_{p1}}{}^{(2)},dt_{m_{q1}}{}^{(2)},i_1{}^{(2)},k_1{}^{(2)}\Big\rangle,\ldots,$$
$$\Big\langle t_N{}^{(2)},m_{x1}{}^{(2)},m_{y1}{}^{(2)},dt_{m_{x1}}{}^{(2)},dt_{m_{y1}}{}^{(2)},i_N{}^{(2)},k_N{}^{(2)}\Big\rangle\Big\}$$

is called following function:

$$\Psi(W^{(1)},W^{(2)})=\sum_{j=1}^{N}\vartheta(dt_{m_{pj}}{}^{(1)},dt_{m_{pj}}{}^{(2)})+\vartheta(dt_{m_{qj}}{}^{(1)},dt_{m_{qj}}{}^{(2)})+\chi(i_j{}^{(1)},i_j{}^{(2)})+\chi(k_1{}^{(1)},k_1{}^{(2)})$$

Presented definition enables to calculate the distance between the two structures of variants. However, in order to calculate the distance between one structure (for example consensus), and more other structures (for example the variants generated by system), it should be proceed in the following way:
- calculate the distance between considered structure and each of the other individual structures,
- calculate the sum of these distances.

The algorithm of consensus determining (the third stage of consensus determining), using presented distance function, is elaborated in the next part of article.

4. Consensus determining algorithm

The postulated method of distance calculation may be employed in design of consensus algorithms. The consensus is determining on the basis of set of variants generated by system, called the profile, defined as follow:

Definition 5

The profile $A = \{W^{(1)}, W^{(2)}, \ldots, W^{(R)}\}$ is called set M variants, such that:

$$W^{(1)} = \Big\{\Big\langle t_1^{(1)}, m_{p1}^{(1)}, m_{q1}^{(1)}, dt_{m_{p1}}^{(1)}, dt_{m_{q1}}^{(1)}, i_1^{(1)}, k_1^{(1)}\Big\rangle, \ldots, \Big\langle t_N^{(1)}, m_{xN}^{(1)}, m_{yN}^{(1)}, dt_{m_{xN}}^{(1)}, dt_{m_{yN}}^{(1)}, i_N^{(1)}, k_N^{(1)}\Big\rangle\Big\}$$

$$W^{(2)} = \Big\{\Big\langle t_1^{(2)}, m_{p1}^{(2)}, m_{q1}^{(2)}, dt_{m_{p1}}^{(2)}, dt_{m_{q1}}^{(2)}, i_1^{(2)}, k_1^{(2)}\Big\rangle, \ldots, \Big\langle t_N^{(2)}, m_{x1}^{(2)}, m_{y1}^{(2)}, dt_{m_{x1}}^{(2)}, dt_{m_{y1}}^{(2)}, i_N^{(2)}, k_N^{(2)}\Big\rangle\Big\}$$

$$\vdots$$

$$W^{(R)} = \Big\{\Big\langle t_1^{(R)}, m_{p1}^{(R)}, m_{q1}^{(R)}, dt_{m_{p1}}^{(R)}, dt_{m_{q1}}^{(R)}, i_1^{(R)}, k_1^{(R)}\Big\rangle, \ldots, \Big\{\Big\langle t_N^{(R)}, m_{x1}^{(R)}, m_{y1}^{(R)}, dt_{m_{x1}}^{(R)}, dt_{m_{y1}}^{(R)}, i_N^{(R)}, k_N^{(R)}\Big\rangle$$

In order to determine consensus of defined profile it is necessary to elaborate theorem, on the basis of which specified will then be consensus algorithm.

Theorem 1

Let $pr(dt_{xy}), pr(i_y), pr(k_y)$ denote respectively ascending order of values $dt_{xy}{}^L, pr_y{}^L, k_y{}^L$ $(L = 1, \ldots, R)$,

$l^1_{dt_{xy}}$ denote $(R+1)/2$ element $pr(dt_{xy})$,

$l^2_{dt_{xy}}$ denote $(R+2)/2$ element $pr(dt_{xy})$,

$l^1_{i_y}$ denote $(R+1)/2$ element $pr(i_y)$,

$l^2_{i_y}$ denote $(R+2)/2$ element $pr(i_y)$,

$l^1_{k_y}$ denote $(R+1)/2$ element $pr(k_y)$,

$l^2_{k_y}$ denote $(R+2)/2$ element $pr(k_y)$ and

$$CON = \left\{ \left\langle CON(t_1), CON({}_{p1}), CON(m_{q1}), CON(dt_{m_{p1}}), CON(dt_{m_{q1}}), CON(i_1), CON(k_1) \right\rangle ,..., \left\langle CON(t_N), CON(m_{xN}), CON(m_{yN}), CON(dt_{m_{xN}}), CON(dt_{m_{yN}}), CON(i_N), CON(k_N) \right\rangle \right\}$$

will be the consensus according given profile.

then for each dt_{xy}

$$l^1_{dt_{xy}} \le dt_{xy}{}^L \le l^2_{dt_{xy}} \Rightarrow dt_{xy}{}^L \in CON(dt_{xy}),$$

$$(l^1_{dt_{xy}} > dt_{xy}{}^L) \vee (dt_{xy}{}^L l^2_{dt_{xy}}) \Rightarrow dt_{xy}{}^L \notin CON(dt_{xy}),$$

and

for each i_y^L

$$l^1_{i_y} \le i_y{}^L \le l^2_{i_y} \Rightarrow i_y{}^L \in CON(i_y),$$

$$(l^1_{i_y} > i_y{}^L) \vee (i_y{}^L l^2_{i_y}) \Rightarrow i_y{}^L \notin CON(i_y)$$

and

for each k_y^L

$$l^1_{k_y} \le k_y{}^L \le l^2_{k_y} \Rightarrow k_y{}^L \in CON(k_y),$$

$$(l^1_{k_y} > k_y{}^L) \vee (k_y{}^L l^2_{k_y}) \Rightarrow k_y{}^L \notin CON(k_y).$$

Proof 1

The ascending order can be presented as points on the axis of Reals and then the shortest distance to all points of a given range is a point lying in the middle of this range.

On the basis of theorem 1 it can be elaborate algorithm which determine consensus of profile of variants. Algorithm function in this way, that ascending order of values dt_{xy} is determining with all the variants and so it is with the values i_y and k_y. Then be calculated between which values in these systems must be the value which is a consensus. In the next step, set the value of consensus of products and places in this way, that with profile it is selected values of these attributes of this variant, in which the distance between a cost of this variant, and cost of variant determining by consensus, is minimal. The algorithm terminates when all elements of variant are verified and consensus is determining. The formal definition is as follows:

Algorithm 1

Data: Profile $W= \{W^{(1)}, W^{(2)}, ... W^{(R)}\}$ consist of R variants.
Result: Consensus

$$CON = \left\{\left\langle CON(t_1), CON(_{p1}), CON(m_{q1}), CON(dt_{m_{p1}}), CON(dt_{m_{q1}}), CON(i_1), CON(k_1)\right\rangle, ...,\right.$$
$$\left.\left\langle CON(t_N), CON(m_{xN}), CON(m_{yN}), CON(dt_{m_{xN}}), CON(dt_{m_{yN}}), CON(i_N), CON(k_N)\right\rangle\right\}$$

according W.

START
Step 1: Let $CON(x) = 0$.

Step 2: j:=dt_{xy}.
Step 3: Determining $pr(j)$.
Step 4: $l_i^1 = (R+1)/2$, $l_i^2 = (R+2)/2$.
Step 5: $l_j^1 \leq CON(j) \leq l_j^2$.
Step 6: If j=dt_{xy} then j:=i_y. Go to: Step 3.
If j:=i then j:=k_y. Go to: Step 3.
If j:=k_y then STOP. Go to: Step 7.
Step 6: Determining $CON(t_x), CON(m_{px}), CON(m_{px})$, which meets the following conditions $\min(\chi(CON(k_x), k_x)^{(2)})$.
STOP

Computational complexity is $O(N^2R)$.

Using elaborated algorithm in SCM system allow skipping the analysis of individual variants made by decision maker. At the same time, it should be noted that, in order to determining the consensus, the variants of solutions must be represented in the form of uniform data structures in the individual elements of the supply chain (for example, the structure representing the variants of solutions for the manufacturer must have the same attributes, however, the values of these attributes may vary). This assumption is necessary due to the consolidation of the data contained in the structures, for example, has not occurred, the situation, in which one variant contains a date and the cost of delivery, and does not include the lot size, instead another variant consist of a date ant the lot size, and does not include cost of delivery. The choice of such „incomplete" variants is impossible (for example, you cannot select a supplier without knowing the cost of delivery).

The elaborated algorithm can be used to create the program module of consensus determining. Such a module can be placed in the structure of the SCM system and started automatically after generated by system the different variants of solutions. After the execution of the algorithm, the solution that is the consensus is presented to the user, who shall decide on its implementation. The user is exempt from the need for continuous analysis of variants and making a selection from among the variants generated by the SCM system, time of determining destination variant is shortened, so making supply chain management becomes more flexible. In addition, the level of risk associated with the choice of a worst variant is reducing. As a result, a company may obtain a higher level of economic efficiency.

5. Conclusion

Supply chain management is related to the activities pursued by every organisation. In the past it was performed manually by people. Today, however, due to the nature of the modern economy, which is extremely turbulent, supply chain management without the use of IT systems is impossible. Support systems for such management, particularly SCM systems, permit the integration and coordination of product, information and cash flows between individual organisations being a part of a supply chain, which obviously affect the capacity of enterprises to adjust to the market demand properly. Employing SCM systems in supporting supply chain management also enables day-to-day market simulations, optimisation of delivery organisation, or definition of supply network limitations, which facilitates a prompt response to the emerging new demand on the part of customers. However, such systems operate effectively only on condition that responses to market changes are dynamic. The diversity of the criteria or methods of supply chain analysis adopted in SCM systems frequently lead to the situation where the system generates different solution variants including both incorrect and correct variants, which, for example, bear a very high risk level. In other words, there is a conflict of knowledge in this system. Choosing the best variant by the user is extremely difficult since it requires a detailed analysis of all variants, which naturally takes some time and, as a consequence, significantly reduces dynamism, thus decreasing the effectiveness of supply chain management. It is also uncertain whether the user will select the right variant even after conducting an analysis. It is often the case that – due to time limits related to the continuity of the supply chain management process – analysis is impossible and if the user relies on their experience only, the risk of choosing a wrong variant is high. Using consensus methods in resolving the conflict of knowledge, that is determining a variant to be then presented to the user, one based on the variants proposed by the system, may lead to shortening the variant determination time and to reducing the risk of selecting the worst variant. As a consequence, supply chain management might become more dynamic, which obviously influences the effectiveness of the operation of particular organisations and the entire supply chain.

Further research works should concern, among others, developing a program module determining a consensus in the SCM system and its review, developing consensus determination algorithms accounting for the differences in the structure of variant construction in individual chain areas such that, for example, it is possible to present different attributes of the variant in the case of the supplier, different in the case of the producer, and yet different in the case of the retailer. Consensus algorithms taking into consideration functional correlations between the structures of variants also need to be developed.

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