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DISTANCE FUNCTION BETWEEN STRUCTURE OF VARIANTS IN CONSENSUS DETERMINING PROCESS IN SUPPLY CHAIN MANAGEMENT SYSTEMS

Abstract: Consensus methods allow to resolve the knowledge conflicts, among other things, in supply chain management systems. The purpose of the article is to elaborate the distance function between the variants generated by the system SCM. This is one of the stages of the consensus determining process. The first part of the article presents a characteristic of knowledge conflicts, consensus methods and a definition of the structure of the variant. Next, the formal definition of distance function was elaborated. This definition is necessary in order to elaborate the algorithms of consensus determining.

Keywords: supply chain management systems, knowledge conflicts, consensus methods, distance functions.

1. Introduction

Supply chain management has become a decisive element in the functioning of any organization and an important source of competitive advantage. A well-defined product with good marketing backup, best functionality and attractive price is no longer a guarantee of success [Siurdyban, Møller 2012]. Low retail margins, consolidation and market globalization pose a serious challenge to many companies, also on the Polish market. At present, competitive advantage is often based on the effective organization of product supply, cost reduction and proper customer service [Rutkowski 2010]. The most important benefit of supply chain management is a significant reduction of stock, both for the supplier and the customer. In the traditional approach, supplies are shipped in large batches, with volume being determined by economic order quantity principles. In addition, the discounts offered by suppliers are typically based on shipment volume, which has the effect of a further increase in individual order volumes. Consequently, both suppliers and customers face the problem of an elevated stock level. This results in an imbalance of manufacturing resources load on the supplier side, and a cash flow imbalance on the customer side [Matuszak 2002]. The supply chain should ideally be based on the JIT model (justin-time), i.e. on the synchronization of production plans, accompanied by frequent and relatively low-volume supplies. This model brings considerable benefits, such as reduction of stock levels, stabilization of productive capacity load and a reduction of resource demand, resulting in greater flexibility and operational cost cutbacks. Supply chain management offers companies greater control by improving their ability to promptly react to dynamic changes in demand. It also helps optimize the cost and standard of service, and allows for the optimal use of the available resources and information [Matuszak 2002].

This trend has been reflected in the recent interest of companies in IT solutions to facilitate the integration of supply chain management (SCM) processes. The SCM systems are mainly focused on the close coordination of activities between business partners. However, as pointed out in professional literature, the IT systems should offer the capability of a dynamic reaction to market needs. In other words, they should operate in real time, thus increasing the value for all the actors involved in the supply chain [Billewicz, Billewicz 2007]. Meeting this requirement is a difficult task, due to the great complexity of computing the algorithms used in SCM systems. Furthermore, SCM systems are typically based on data generated by ERP (Enterprise Resource Planning) systems – this creates a demand for integration between flexible analytical applications and inflexible data-collection systems [Adamczewski 2009]. In effect, the SCM system provides the user with a range of solutions for improved product flow between the supply chain actors, but the task of selecting the most suitable solution is left to the user's discretion. This requires additional analysis on the user's part, which is a time-consuming process, and one burdened with considerable risk. This dilemma is often referred to as the knowledge conflict. For an SCM system to offer a dynamic and efficient management of the supply chain, such conflicts need to be resolved.

Professional literature provides a range of methods to address the knowledge conflict, but none of them are without flaws. For example, methods based on negotiation offer good conciliation of conflicting interests, but at the cost of increased communication between individual modules, which naturally affects the speed of operation. On the other hand, methods belonging to the realm of deduction and computing (such as solutions based on game theory, classical mechanics, operational research methods of behavioral and social sciences or choice methods) do not encumber the system, but cannot be trusted to offer good conciliation.

It seems that addressing the knowledge conflict is best approached from the perspective of consensus methods. Their conciliation capacity is comparable with that of negotiation methods, but at largely reduced CPU load and limited communication between system modules. The above features make them capable of operating close to real time.

Consensus methods allow for the automatic determination of a single best variant, which is then presented to the user. Consequently, they improve the flexibility of the IT systems used in supply chain management.

Arriving at a consensus is a task involving three basic stages. The first stage is a precise analysis of the structure set of all the solution variants generated by the SCM system, i.e. the determination of their key features and value domains. Variant structures represent the knowledge structure of the SCM system. In the second stage, a function is determined for computing the distance between individual variants. In the third stage, consensus algorithms are designed. These involve the determination of a variant (consensus) characterized by the minimal distance to other variants generated by the SCM system (based on various selection criteria).

Sobieska-Karpińska, Hernes [2012b] have already postulated the use of consensus methods for solving the knowledge conflict. However, the authors focused mainly on the initial stage, namely the definition of the variant structure. For the efficient construction of consensus algorithms, an equally strong emphasis should be placed on researching the second stage of the process.

This article is an attempt at defining the function of distance between the structures of individual variants of product flow.

2. Determining the consensus in supply chain management systems

The concept of using consensus methods in supply chain management systems [Sobieska-Karpińska, Hernes 2012a] is based on the assumption that individual modules of the SCM system referencing suppliers, producers, wholesalers, retailers and individual customers, based on information from transaction systems (such as Enterprise Resource Planning) and analytical systems (such as Manufacturing Execution System, Customer Relationship Management), generate different sets of solution variants for individual elements of the supply chain due to differences in the criteria or analytical methods employed (such as lowest price, shortest lead time, non-linear programming, genetic algorithms). The resulting variants differ in terms of attributes and attribute values, thus generating a knowledge conflict between the variants.

Knowledge conflicts, therefore, emerge when the same objects of the physical world and the same features are attributed different values by conflicting entities. Assuming that the SCM system generates different sets of solution variants (e.g. due to different methods of supply chain management support), then the conflict of knowledge will apply to such features as “volume” (since variants within the generated set may differ in terms of volume to be shipped) or “time” (variants may differ in terms of lead time).

It is important to address this type of conflicts, since solving them is the only way to ensure the correct solution variants generated by the system. If a system lacks this ability, the user may face problems in the proper management of the supply chain. The use of consensus methods allows for the resolution of knowledge conflicts, and, consequently, improves the process of supply chain management.

In general terms, consensus can be defined as agreement [Nguyen 2002]. If an SCM system generates several variants, then, by employing consensus methods, a new variant may be calculated and presented to the user. The resulting variant does not necessarily belong to the set of variants generated by the SCM system [Sobieska-Karpińska, Hernes 2011]. Since the consensus approach takes into account all the variants generated by SCM software, it may expedite the time needed for the determination of the target solution (by freeing the user from the tasks involved in analysis and variant selection) as well as limit the risk of selecting the worst variant (since consensus calculation takes into account all variants). Consequently, the supply chain management process is more rapid and effective.

For elaborating the consensus determining algorithms at paper [Sobieska-Karpińska, Hernes 2012b] the structure of variants is defined as follows:

Definition 1

The structure of variants is encapsulated in the following sequence:

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

where:

$p, q, r, s, x, y = \{1..L\}$, where L denotes a number of supply chain participants.

$dt_{m_{p1}}, dt_{m_{r1}}, \ldots, dt_{m_{xN}}$ – date and time of leaving the places $m_p, m_r, \ldots, m_x$ by products $t_1, t_2, \ldots, t_N$,

$dt_{m_{q1}}, dt_{m_{s1}}, \ldots, dt_{m_{yN}}$ – date and time ofthe products $t_1, t_2, \ldots, t_N$ arriving to places $m_q, m_s, \ldots, m_y$,

$i_1, i_2, \ldots, i_N$ – number of transport products $t_1, t_2, \ldots, t_N$,

$k_1, k_2, \ldots, k_N$ – cost of transport products $t_1, t_2, \ldots, t_N$.

If it is assumed that:

$$T = \{product1, product2\},\ M = \{enterpr1, enterpr2, enterpr3\},$$

then an example of the structure of variants can be the following sequence:

$$W = \left\{ \left\langle \begin{matrix} product1, enterpr1, enterpr2, 2012 \\ -12-01\ 12.00, 2012-12-01\ 17.00, 35, 276.00 \end{matrix} \right\rangle, \right.$$

$$\left. \left\langle product2, enterpr3, enterpr2, 2012-12-01\ 7.00, 2012-12-01\ 14.00, 7, 130.00 \right\rangle \right\}.$$

In this example, product1 in quantities of 35 must leave the enterprise1on the December 1st, 2012 at 12.00 and arrive at enterprise2 on the same day at 17.00, the cost of a transport is 276.00, instead product2 in quantities of 7 must leave enterprise3 on December 1st, 2012 at 7.00 and arrive at enterprise2 on the same day at 14.00, the cost of transport is 130.00.

This definition enables presenting particular variants of solution as a uniform structure. It is a complex, multi-attribute structure. Different types of data appear in this structure. If the variants structures generated by SCM are different or values of the attributes of these structures are different, then at the system a knowledge conflicts appears. To resolve this conflict, and so obtain the correct determination of the consensus algorithms, it is necessary to go to the second phase of consensus determining, that is the definition of the distance function between the structures of the variants.

3. Distance function between structures of variants

Defining the functions of distance between variants is an important step in consensus calculation, since those functions are used for the construction of consensus calculation algorithms. It must be noted that the calculation of a distance between two variant structures may be based on the calculation and summation of distances between individual elements of these structures. Analysis of individual elements of a variant structure shows that knowledge conflicts apply mainly to attributes $dt_{m_p}, dt_{m_r}, ..., dt_{m_x}$, $dt_{m_q}, dt_{m_s}, ..., dt_{m_y}$, $i_1, i_2, ..., i_N$, $k_1, k_2, ..., k_N$. It is assumed that the attributes of *product* and *place* are not directly involved in conflict, due to the functional dependencies between variant structure attributes. The time and date of departure and arrival, as well as product quantity, are related to the place of departure and to the target destination. This type of correlations should be taken into account in the third stage of the consensus calculation process, i.e. during the design of consensus algorithms.

Furthermore, to calculate the function of distance between two dates, one may employ a time model postulated, for example, in [Allen 1983; Dyreson et al. 1995]. The model is based on the assumption of the linear property of time; thus, time distance can be represented as a section on the real numbers axis (by adopting the condition of the finite quality of the universe). Such a section is referred to as time-line. Any point on the time-line represents a moment in time with a time distance of zero. To facilitate the implementation of this model, the time-line may be divided into a finite number of equal units, referred to as chronons. A chronon represents the shortest time unit. In a practical application, one can define a chronon in terms of natural time units, such as seconds, minutes and hours. The above time model incorporates two forms of time: time proper and the transaction time. Time proper refers to the actual time of event occurrence and, as such, is independent of the IT system, whereas transaction time represents the time of recording the event by the database system. The postulated time model is a non-deterministic model, since it assumes that time does not need to be represented with down-to-one-chronon accuracy; it may as well be described in terms of a timeframe window (consisting of more than one chronon). However, as in the case of dates of variant structures, time proper equals transaction time (since variants are entered in the database at the moment of their generation) and, as such, can be determined with down-to-one-chronon accuracy.

For the purpose of defining the time distance between two dates, let us assume that a chronon equals one minute (this degree of accuracy seems sufficient, since the transportation of goods in a 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.

Definition 2

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 the 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 the number of the product and the cost of transport, one can use the function used in many papers [eg. Daniłowicz, Nguyen 2002] specifying the distance between real numbers:

Definition 3

The distance between numbers *x, y* belonging to the string composed with *m* real numbers is the following function:

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

The following example illustrates this definition:

Let *m*=3 and the string of numbers is the 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 $= \frac{1}{3}|4-8| = 1\frac{1}{3}$.

Having defined the distance between different parts of the variant structure, it is possible to define the distance between two structures of variants.

Definition 4

The distance between two structures of variants:

$$W^{(1)} = \left\{ \begin{array}{l} \left\langle t_1^{(1)}, m_{p1}^{(1)}, m_{q1}^{(1)}, dt_{m_{p1}}^{(1)}, dt_{m_{q1}}^{(1)}, i_1^{(1)}, k_1^{(1)} \right\rangle, \ldots, \\ \left\langle t_N^{(1)}, m_{xN}^{(1)}, m_{yN}^{(1)}, dt_{m_{xN}}^{(1)}, dt_{m_{yN}}^{(1)}, i_N^{(1)}, k_N^{(1)} \right\rangle \end{array} \right\},$$

$$W^{(2)} = \left\{ \begin{array}{l} \left\langle t_1^{(2)}, m_{p1}^{(2)}, m_{q1}^{(2)}, dt_{m_{p1}}^{(2)}, dt_{m_{q1}}^{(2)}, i_1^{(2)}, k_1^{(2)} \right\rangle, \ldots, \\ \left\langle t_N^{(2)}, m_{x1}^{(2)}, m_{y1}^{(2)}, dt_{m_{x1}}^{(2)}, dt_{m_{y1}}^{(2)}, i_N^{(2)}, k_N^{(2)} \right\rangle \end{array} \right\},$$

is the following function:

$$\Psi(W^{(1)}, W^{(2)}) =$$

$$= \sum_{j=1}^{N} \left(\vartheta(dt_{m_{pj}}^{(1)}, dt_{m_{pj}}^{(2)}) + \vartheta(dt_{m_{qj}}^{(1)}, dt_{m_{qj}}^{(2)}) + \chi(i_j^{(1)}, i_j^{(2)}) + \chi(k_j^{(1)}, k_j^{(2)}) \right).$$

The so elaborated 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 other structures (for example the variants generated by system), it should proceed in the following way:

- calculate the distance between the considered structure and each of the other individual structures,
- calculate the sum of these distances.

The example of such calculation is the following:

The following structures are given:

$$W^{(1)} = \left\{ \left\langle \begin{array}{l} product1, enterpr1, enterpr2, 2012-12 \\ -01\,12.00, 2012-12-01\,17.00, 35, 276.00 \end{array} \right\rangle \right\},$$

$$W^{(2)} = \left\{ \left\langle \begin{array}{l} product1, enterpr1, enterpr2, 2012-12 \\ -01\,11.00, 2012-12-01\,15.00, 30, 250.00 \end{array} \right\rangle \right\},$$

$$W^{(3)} = \left\{ \left\langle \begin{array}{l} product1, enterpr1, enterpr2, 2012-12 \\ -01\,10.00, 2012-12-01\,13.00, 20, 150.00 \end{array} \right\rangle \right\},$$

$$W^{(4)} = \left\{ \left\langle \begin{array}{l} product1, enterpr1, enterpr2, 2012-12 \\ -01\,11.00, 2012-12-01\,14.00, 25, 200.00 \end{array} \right\rangle \right\},$$

$$W^{(5)} = \left\{ \left\langle \begin{array}{l} product1, enterpr1, enterpr2, 2012-12 \\ -01\,12.00, 2012-12-01\,16.00, 30, 226.00 \end{array} \right\rangle \right\}.$$

The distance between structure $W^{(1)}$ and the other structures is calculated as follows (to calculate the distance between dates only an hour is taken into consideration, because the day in each structure is the same):

$$\Psi(W^{(1)},W^{(2)}) = 60(\text{minutes}) + 120(\text{minutes}) + \frac{1}{2}|35-30| + \frac{1}{2}|276-250| = 195,5$$

$$\Psi(W^{(1)},W^{(3)}) = 120(\text{minutes}) + 240(\text{minutes}) + \frac{1}{2}|35-20| + \frac{1}{2}|276-150| = 430,5$$

$$\Psi(W^{(1)},W^{(4)}) = 60(\text{minutes}) + 180(\text{minutes}) + \frac{1}{2}|35-25| + \frac{1}{2}|276-200| = 283$$

$$\Psi(W^{(1)},W^{(5)}) = 0(\text{minutes}) + 60(\text{minutes}) + \frac{1}{2}|35-25| + \frac{1}{2}|276-226| = 90$$

The distance between $W^{(1)}$ and the other structures equals:

195,5+430,5+283+90= 999.

The postulated method of distance determination may be employed in the design of consensus algorithms. It must be noted that SCM systems may generate different solution variants for each of the elements of the supply chain. Proper supply chain management requires the examination of all the possible combinations of these variants. For instance, if three solution variants are generated for each of the elements of the supply chain, i.e. at the level of suppliers, producers, wholesalers, retailers and consumers – proper supply chain management requires the examination of 243 (3^5) variant combinations.

The task of analyzing all variants is typically delegated to appointed personnel or to an SCM system. In both cases, the process is time-consuming. The former requires the manual processing of vast amounts of information. The latter – due to the computational complexity of the analytical algorithms adopted in the SCM systems since they apply to NP-complete problems. In addition, the system typically generates more than two variants for each stage of the supply chain. Consequently, the number of variant combinations grows exponentially. Moreover, there is no guarantee that the solutions selected as the most appropriate during the analytical phase will prove effective in practical application. In other words, the selection is burdened with risk. In contrast, consensus methods do not require the analysis of all the possible combinations, based on the assumption that the variants generated for each element of the supply chain can be interpreted as profiles (element sets) to be used in consensus calculation.

Therefore, the use consensus methods allows for the elimination of time-consuming analysis of individual variants, be it manual or computer-aided. At the same time, it must be noted that – for consensus calculation purposes – the solution variants should be represented by unified data structures for each of the elements of the supply chain (for instance: all variants generated for producers must be expressed in identical data structure form).

4. Summary

Defining the function of distance between variant structures in SCM systems is an important stage of consensus calculation. Let us reiterate that consensus is defined as a solution characterized by the minimal distance to other variants generated by the SCM system. Thus, determining the function of distance computation is a prerequisite of consensus calculation. On the other hand, adopting consensus methods for the purpose of resolving knowledge conflicts in SCM systems allows for the effective use of several variants of the SCM process, thus saving time since the user does not need to decide on a variant. The system generates a final variant solution without user participation, thus offering close to real-time processing capabilities, since the time-consuming process of individual variant analysis by the user is eliminated. In addition, the postulated approach largely alleviates the risk of the user making a bad call in variant selection. Naturally, the risk cannot be eliminated altogether, since consensus methods do not warrant optimal solutions. However, the solution will bring tangible benefits for the user (for instance, a reduction of cost to an acceptable level), and consequently improve the effectiveness of the supply chain management process.

The distance function elaborated in the article may be used in the development of a consensus determining module (which can be employed in SCM systems), because on the basis of this function it is possible to find a variant, in which the distance between the other variant is minimal, in other words, to determine the consensus. SCM systems consisting of this module can operate in each of the enterprises which cooperate within a supply chain.

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FUNKCJA OBLICZANIA ODLEGŁOŚCI POMIĘDZY STRUKTURAMI WARIANTÓW W PROCESIE WYZNACZANIA CONSENSUSU W SYSTEMACH WSPOMAGAJĄCYCH ZARZĄDZANIE ŁAŃCUCHEM DOSTAW

Streszczenie: Metody consensusu pozwalają na rozwiązywanie konfliktów wiedzy, między innymi w systemach wspomagających zarządzanie łańcuchem dostaw. Celem niniejszego artykułu jest opracowanie funkcji obliczania odległości pomiędzy strukturami wariantów rozwiązań generowanych przez system SCM. Jest to jeden z etapów procesu wyznaczania consensusu. W pierwszej części tekstu przedstawiono charakterystykę konfliktów wiedzy, metod consensusu wraz z definicją struktury wariantu. W dalszej części opracowano zaś formalną definicję funkcji odległości, która jest niezbędna w celu opracowania algorytmów wyznaczania consensusu.

Słowa kluczowe: systemy zarządzania łańcuchem dostaw, konflikty wiedzy, metody consensusu, funkcje odległości.