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PROTOTYPING OF ACCEPTABLE VARIANTS OF MANUFACTURING NETWORKS

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Abstract: *In this paper a proposal for the formation of manufacturing network variants is presented. Special attention is focused on logistical and resources constraints. The proposed concept is dedicated to small and medium enterprises (SMEs) which have problems in building cooperation connected with joint manufacturing, based on determined elements of the production process of new products. The main goal of this discussion is to plan for the acceptable variants of networks which are able to undertake new production execution on time and with acceptable cost, according to logistical constraints (production capacity, transportation, storage capacity, etc).*

Key words: *logistics, production networks, production orders planning, scheduling.*

1 INTRODUCTION

Nowadays, participation in networks is very important for any organization that strives to achieve a differentiated competitive advantage. Collaboration is a process in which enterprises share information, resources and responsibilities to plan together, implement, and evaluate activities to achieve a common goal. Thus, enterprises, especially small or medium sized, are changing their modus operandi by partnering with other enterprises in complex value chains to eliminate waste and reduce costs [8].

Collaborative networks manifest in a large variety of forms. Moving from the classical supply chain, characterized by relatively stable networks with well-defined roles and requiring only minimal coordination and information exchange, more dynamic structures are emerging in industry [15], [3]. Some of these organizational forms are goal-oriented, i.e. focused on a single project or business opportunity, such as in the case of virtual manufacturing networks [1], [2]. The concept of virtual manufacturing networks is understood as a temporary network of enterprises that join skills and resources, supported by computer networks, to respond to business opportunities. Unfortunately, the agility, flexibility and dynamism required for these organizations is limited by the difficult process of establishing them. Due to the multi-faceted perspectives of production network prototyping there is no single modeling formalism or theory that can properly cover all needed modeling aspects [4], [7]. Very often it is necessary to mix different modeling formalisms in order to get an effective methodology. Modelling of manufacturing networks is essentially a multi-criteria decision-making problem. For instance, the partners are selected according to: punctuality, partnership synergy, reliability, cost, economical situation, trust, quality, etc. Furthermore, perfect data on such factors is hardly ever available, therefore in this situation modeling of networks is very difficult. Thus, some researchers have suggested methods based on multi-attribute value theory or analytic hierarchy process (AHP) [12], fuzzy programming method, [9], genetic algorithms [14], which can help evaluate the certainty of decisions under imperfect data.

Another method which has recently been developed is the method of Robust Portfolio Modeling (RPM) [6]. This method is especially suitable for solving multi-criteria portfolio-selection problems and can be used in solving linear problems.

Recently, problems of modelling of collaborative networks have been considered within the ECOLEAD project (European Collaborative Networked Organizations Leadership Initiative). The ECOLEAD project has led to an effective contribution to the establishment of comprehensive reference models for collaborative networks, and thus offers a basis for researchers interested in the field [1]. One of the main problems considered was the selection of partners for a dynamic collaborative network. In this project the problem of partner selection was considered as a work-allocation problem, which is approached by multi-objective mixed integer linear programming [2].

In solving problems in modeling networks, optimization and simulation methods are often chosen, which are very time-consuming and work consuming [10], [13]. The setting of acceptable solutions in "on-line" mode is not allowed. Thus, one should conduct research to create and implement methods and computer systems which can quickly set acceptable variants of a planned collaborative manufacturing network with consideration to capabilities and logistic constraints. Thus, in this paper, a concept of methodology of collaborative manufacturing network prototyping based on the procedure of assessment of sufficient conditions and using a Hasse diagram is suggested.

2 COLLABORATIVE PRODUCTION NETWORKS

Last time, some researchers with practical perspective focused on the idea of a VO breeding environment (VBE) for dynamic formation of Virtual Organizations (VO) [1], [2]. This concept has emerged as the necessary context for the effective creation of dynamic virtual networks, especially in the manufacturing sector in works [5], [10]. In the considered case, VO Breeding Environment (VBE) is understood as an association of organizations, adhering to the base of long term cooperation agreement and adoption of common operating principles and infrastructures, with the main goal of increasing their preparedness towards rapid configuration of temporary alliances for collaboration in potential virtual organizations (e.g. virtual manufacturing networks - VMN) [2].

In this paper a VBE idea can be identified with the modus operandi of a cluster of enterprises. The concept of a cluster is often characterized by the geographical closeness, the same industrial branch (e.g. metal branch), and working relationships, which are also motivating factors in building trust between partners. The clusters can support the exploitation of local competencies and resources by an agile and fast configuration of a set of partners for each business opportunity (e.g. new production order). Therefore, in times of competition and market turbulence, clusters may offer the opportunity to share experiences and costs in the learning process of introducing new information and communications technology for instance, within an industry cluster, and to reduce the risk of losses and failure. [1].

In the considered case, the virtual manufacturing network (VMN) is understood as a temporary subset of production enterprises and related supporting institutions of the cluster, which together are able to execute new production orders (production project) on time with the assumed costs, supported by a computer network (Internet) (Fig. 1.).

In order to support the rapid formation of collaborative networks, as a basic rule, it is necessary that potential partners are ready and prepared to participate in such collaboration. This readiness includes common interoperable infrastructure, common operating rules and common cooperation agreement, among others. Any collaboration also requires the base level of trust [2]. On the other hand, these enterprises are characterized by following limitations: production capacity (nature of operations, time of availability, cost of using production resources), transportation routes, means of transport (quantity, capacity, time and cost of drive) and capacity of warehouses. Thus, forming the new virtual manufacturing network within the cluster is not easy.

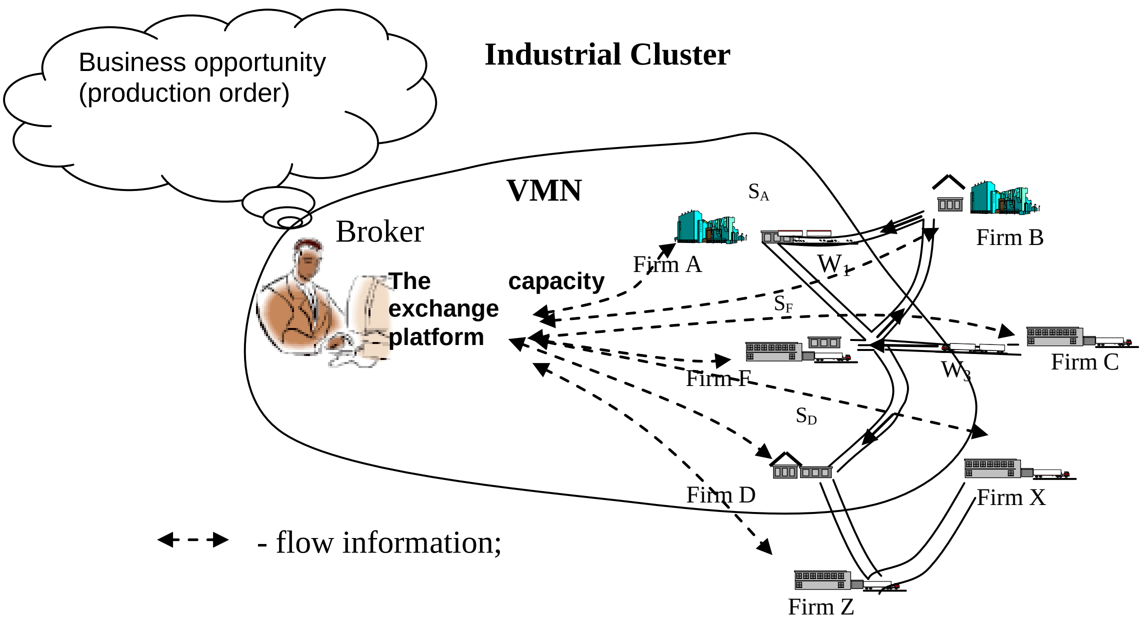

Fig.1 *Selection of virtual manufacturing network (VMN) from industrial cluster*

A very important component of the model presented is one of the members of the cluster acting as a broker. The main goal activity of the broker is to identify business opportunities and connect cooperating companies, which would be able to execute a production order with known limitations. The broker has to organize a temporary network of enterprises which guarantees that production order execution is on time and with as low as possible realization costs.

The new production order is specified by the size of the planned production, given time of execution (T) and intended costs of realization (V_p) (price). The method of production order realization is described by production (technological) process $P = (Z_1, Z_2, \ldots, Z_n)$, marked as a vector. The elements of this vector are characterized by partial operations which are executed in various enterprises. Execution of this order often exceeds the potential of single enterprise, according to its production capacity and technology possessed. In this case, rapid formation of a collaborative network is necessary.

3 PROBLEM FORMULATION

In this paper the following research problem is considered: is there a virtual manufacturing network (VMN) of enterprises which can execute production order on time with the assumed costs? The main goal of the research is to propose a methodology of rapid prototyping of VMN.

The solution to this problem requires answering the following questions:

- Does the structure of production capacity of cooperating enterprises allow for the execution of a new production order in time?
- Can new production operations be executed using the existing transportation system?
- What is the total cost of production order execution?
- What is an acceptable variant of production flow between partners of VMN?

In the case considered, the following hypothesis is assumed: There is an effective computational methodology of virtual networks variants prototyping for enterprises from industry cluster which have production capability in conditions of deterministic resources and logistic constraints of the system.

4 METHODOLOGY OF PROTOTYPING OF MANUFACTURING NETWORKS

The prototyping of virtual collaborative manufacturing networks (VMNs) based on selection of such enterprises within a cluster which have production capacity and the ability to allow production orders execution. The briefly proposed manufacturing production networks prototyping concept can be presented as a three-phase procedure of prototyping of production network (Fig 2.).

In the first phase, one of the members of the cluster (acting as a broker) identifies and acquires new collaboration opportunities (business opportunities). The broker is responsible for working out a production order according to customer needs and the preparation of detailed specifications of technological processes (operations, sequence of operations, preliminary schedule of execution of operations), etc. This information concerning the production order realization is made available on the capacity exchange platform on the Internet, where candidate partners have access to it.

In the formation phase, potential partners declare the capacity of work (resources) that they can use to perform operations of the new process and costs of use of resources and time availability. In this situation, let $M = \{1,\ldots,m\}$ denote the set of candidate partners. The production order is divided into operations, denoted by $Z = \{1,\ldots, n\}$. Each operation $j \in Z$ has a work load w_j, which describes the amount of work required (hours) in order to perform that operation. The information gathered from candidates includes the following parameters:

$c_{i,j}$ - capacity of work that *i*-th candidate partner can perform on *j*-th operation;
$v_{i,j}$ - costs of *i*-th candidate partner working on *j*-th operation (€/hours).

The methodology of prototyping of acceptable networks consists of three stages. In the first stage a set of acceptable variants of network (space of acceptable solutions) which guarantee production order realization on time according to availability of production resources and sequence of operations.

The initial range of potential solutions can be set according to formula 1.

$$PDR_I = \prod_{j=1}^{n} e_j, \qquad (1)$$

where:
PDR - a number of possible variants of the network;
e_j - numbers of candidate partners which are able to execute *j*-th operation according to nature of operation (for example assembly); n – numbers of operations of considered production order Z = {1,…, n}.

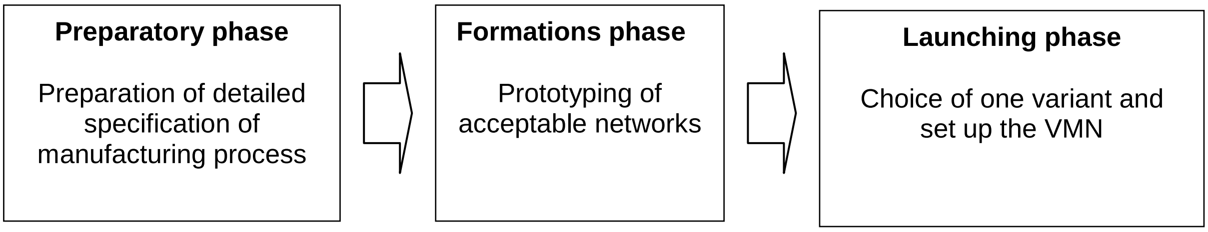

Fig. 2 *Main phases of methodology of prototyping of manufacturing networks*

A set PDR_I is limited on the basis of checking a sequence of sufficient conditions (algebraic-logical conditions). In this stage, the production capacities (machines, workstation, etc.) of each candidate partner and sequence of operations are checked. For instance, fulfilling the following sufficient condition (2) denotes availability of i-resource capability of an candidate partner which would like to participate in the network. Condition (2) checks offers of capacity of the candidate partner according to the amount of work required in order to perform that operation. In this stage enterprises which don't have enough capability in the required time or don't assure the sequence of operations are rejected. The set is limited to a set PDR_{II}.

$$\text{i)}\ \forall j \in Z, \exists i \in M, \sum_{k=1}^{T} c_{i,j} \geq w_j; \qquad (2)$$

where:
$c_{i,j}$ - capacity of work that *i*-th candidate partner can perform on *j*-th operation;
w_j, - work load, which describes the amount of work required (hours) in order to perform *j*-th operation of production order.

In the second stage, a set of variants is limited to such ones which fulfill conditions connected with logistical constraints (transportation and storage systems). Each variant is checked according to available route structure between partners, numbers and capacity of vehicles and storehouse capacity of co-operators. In the proposed approach, the transportation system realizes operations of transferring material between enterprises according to the established schedule. Vehicles with known capacity move along given routes of connected participants of the logistic network. The schedule is established on the basis of offers of forwarding enterprises which guarantee availability of vehicles with given capacity in a length of time in a given section of the route. It allows for quick and credible assessment of the possibility of transportation operation execution, without time-consuming and cost-consuming planning of transportation timetables.

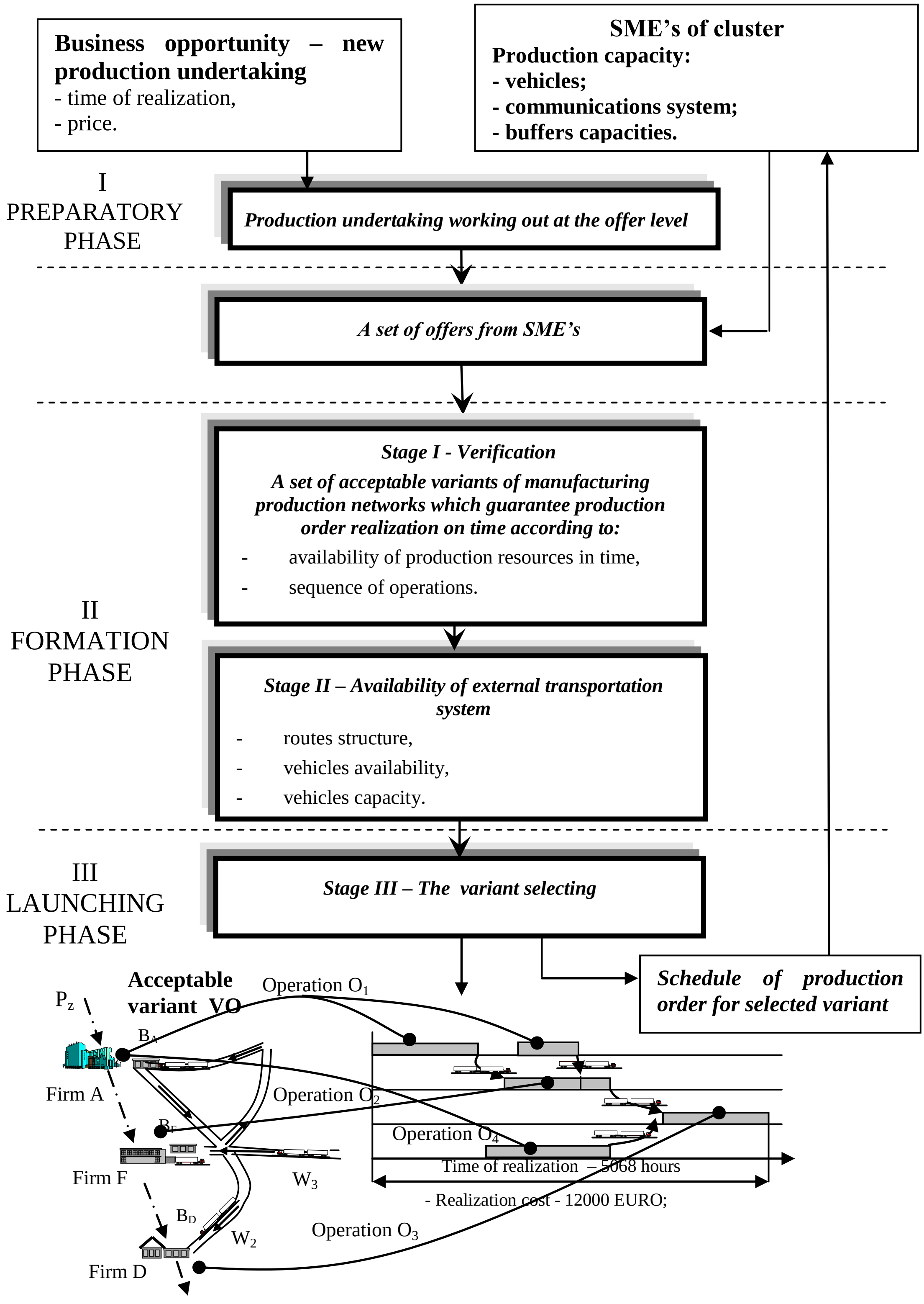

Fig. 3 *Methodology of prototyping of manufacturing networks*

In the third stage of the suggested methodology, the planned cost of production order execution is calculated. It is determined by a set of PDR_{IV} solutions, which guarantee production order execution on time. The costs of production order execution are divided into groups of costs, such as: material costs, individual operation costs of each manufacturing enterprise which participates in the network, transportation costs between partners, warehouse costs and costs of administration and management (including cost of broker service). Therefore, for each variant of PDR_{IV}, condition (3) has to be fulfilled.

$$(\sum_{j=1}^{n} v_{i,j} \cdot w_j + \sum_{j=1}^{n} v_{i,j}^{mat} + \sum_{j=1}^{n-1} v_{j,j+1}^{tran} + \sum_{j=1}^{n} v_{i,j}^{stor} + v^{adm}) \leq V_p, \tag{3}$$

where:

$v_{i,j}$ – declared costs of selected *i*-th candidate partner working on *j*-th operation (€/hours);

w_j - amount of work required (hours) in order to perform *j*-th operation;

$v_{i,j}^{mat}$ - material costs of selected *i*-th candidate partner working on *j*-th operation;

$v_{j,j+1}^{tran}$ - transportation costs between *j* and *j*+1- operation;

$v_{i,j}^{stor}$ - storehouses costs selected *i*-th candidate partner working on *j*-th operation;

v^{adm} - costs of administration and management;

V_p – intended costs of realization.

In the approach considered, all variants which guarantee production order execution on time are distinguished ($PDR_{IV} \subseteq PDR_{III} \subseteq PDR_{II} \subseteq PDR_I$). The broker has to choose one of the acceptable variants of networks and workout schedule of workflow according to logistic and resources constraints. When a set of solutions is empty, the proposed methodology rejects planned production order and gives information concerning reasons for rejection.

In the launching phase, the broker has to choose one of the acceptable variants of networks. The information about costs and time of execution allows the manual selection of the preferred one or the use of one of the methods of multiple criteria selection. Because there are different measures (time, cost) in this approach, the use of a method of normalization of criteria is proposed. This approach is used in the Hasse method diagram [16] which allows the choice of the "rewarding" variant from set PDR_{IV}. Normalization of criteria consists of the elimination of measures and transformation of all criteria in range [0;1]. In this case it is necessary to convert every considered i-criteria according to formula (4). Then, every variant can be compared with each other according to formula (5).

$$\bar{K}_i(x) = \frac{K_i^{max} - K_i(x)}{K_i^{max} - K_i^{min}}, \tag{4}$$

Where:

$$K_i^{max} = \max_{x \in PDR_{IV}} K_i(x),$$

$$K_i^{min} = \min_{x \in PDR_{IV}} K_i(x), \quad K_i^{max} \neq K_i^{min}, i = \overline{1, N}.$$

$$\text{Variant } y \text{ "is better" than } x \Leftrightarrow \sum_{i=1}^{N} \overline{K_i}(y) > \sum_{i=1}^{N} \overline{K_i}(x), \quad (x, y) \in PDR_{IV} \tag{5}$$

For instance, PDR_{IV}={A, B, C, D, E, F} denotes the set of acceptable variants of networks. Every variant is characterized by two measures: cost and time of realization. The proposed approach of selection of "the best variant" from set PDR_{IV} in table 1 is presented. The best variant is chosen according to formula 5.

***Tab. 1** Normalization of criteria*

Variants	**Criteria**		**Normalization of criteria**		
			$K_1^{min}=500$ $K_1^{max}=700$	$K_2^{min}=20000$ $K_2^{max}=35000$	$\sum$
	K_1 [hour]	K_2 [€]	$\overline{K_1}$	$\overline{K_2}$	$\overline{K_1}+\overline{K_2}$
A	700	20000	0	1	1
B	600	25000	0,5	0,66	1,16
C	600	27000	0,5	0,53	1,03
D	600	26000	0,5	0,6	1,10
E	700	27500	0	0,5	0,5
F	500	35000	1	0	1

In the case considered, solutions are ordered from the best variant until the worst one: B, D, C, F, A, E. A Hasse Diagram for the considered case is presented in Fig. 4.

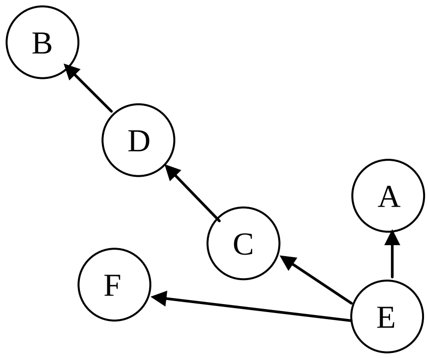

***Fig. 4** Hasse diagram for acceptable variants in relation to each other*

For such selected variant (Fig. 5) the broker can set up a new manufacturing network and can prepare contacts between selected enterprises. Afterwards, the broker can establish the schedule according to the declared capacities of all partners (Fig. 6). The synchronization of all production operations with transport and storage is of the utmost importance. This guarantees appropriate workflow during execution of new production order. The schedule has be known to every participant of manufacturing networks.

Legend:
Firm A, F, D – enterprises which realize process P;
S_A, S_F, S_D – storehouses;
— ·►production process P.

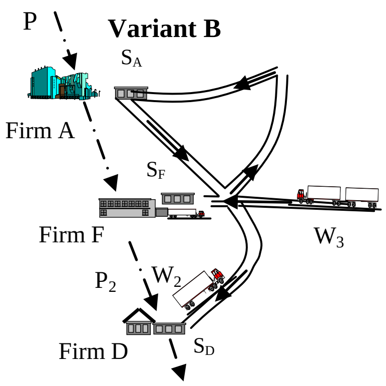

***Fig. 5** Selected variant of manufacturing network*

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