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Novel supply chain concepts and optimization of virtual enterprises to reduce cost, increase productivity and boost competitiveness

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Abstract. Global competition and increasingly complex networks of supply chains require new production philosophies, novel supply chain paradigms (Lean, Agile and Hybrid ones) and new organization and cooperation forms of companies in order to reduce cost, increase productivity and boost competitiveness. Therefore, members of an Agile supply chain form a virtual enterprise (VE) network, which stands for temporary cooperation of VE members (final assemblers, suppliers, service providers) in which the members share their skills, human and equipment resources as well as waste for more efficient operation. The goal of this study is VE optimization, which means forming optimum combinations of potential chain members. This innovative and original approach involves developing an optimization method and defining objective functions (total cost, total lead time) and design constraints (production and service capacities, inventories and members flexibility) for optimum formation of VEs. The focus of VE optimization is to manufacture and deliver final products to customers in the most time- and cost-effective manner, with the total cost and total lead time of the supply chain being minimized during the optimization. Unique optimization software has been developed based on this method. It can can be widely used for optimizing micro- and macro regional virtual networks.

Key words: virtual enterprise, optimization, cost, lead time, software development.

1. Introduction

In the changing economic environment of global competition, which entails continuous change of customer demands, enterprises have to focus on cost reduction, productivity and profitability.

In the production process, resources (raw materials, labor, machines, equipment, energy and other facilities) are always limited. It is thus very important at manufacturing companies to produce cost -effective final products in a short lead time. This can be effected by combining minimized cost with higher effectiveness. New production philosophies are therefore required.

Expensive mass production ("Push" – "make to stock") is being replaced by the more cost-effective production of unique products ("Pull" – "make to order"). More complex networks of supply chains are being formed and novel supply chain (SC) paradigms (Lean, Agile and Hybrid ones) have emerged as an alternative to traditional supply chains in order to increase competitiveness and reduce production as well as operation costs of companies. Different supply chains have to fulfill different customer needs.

New organization and cooperation forms of companies are established in order to increase productivity and competitiveness, reduce production as well as operation costs and optimize processes. Agile supply chain is relevant here because the members of the chain cooperate within the framework of a virtual enterprise (VE). The essence of this concept is the flexible and fast response to customer and market demands. Agile supply chain is applied with innovative, more custom-designed and higher variety products that are smaller in volume. A VE stands for temporary cooperation of enterprises in which the members (final assemblers, component suppliers, raw material suppliers, service providers) share their skills, equipment, human resources and risks in order to reduce costs and increase competitiveness and profit [1].

This research study is very important and relevant because cost and lead time reduction and improvement of productivity are very important goals of all companies and supply chains.

The goal of the research was virtual enterprise optimization, which means forming an optimum combination of potential VE members to achieve the most effective operation in terms of cost and/or lead time. The goal was to develop an optimization method and optimization software. The aim of the method and the software is to manufacture and deliver final products to customers in the most time- and cost-effective way.

2. Literature review

Changes in the economy, production philosophies and supply chains are described in many works [1–3]. Definitions, characteristics of supply chains and supply chain planning also appear frequently in the literature [4–7]. Existing literature often discusses *inter alia* the following most important objectives for supply chain optimization: cost [8, 9], profit [10], lead time [11] and customer service level [12].

Novel supply chain paradigms (Lean, Agile and Hybrid supply chains) are established [13, 14] to fulfil different customer needs.

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Enterprises forming Lean supply chains apply the Lean production philosophy. There are many relevant publications on the topic of Lean production philosophy [15, 16].

Flexibility and responsiveness are key characteristics of an Agile supply chain [14, 17–19]. Flexibility is becoming increasingly important for boosting competitiveness. References [20–22] reviewed the literature on the topic of measurement and evaluation of supply chain flexibility.

A virtual enterprise (VE) is a typical cooperation form for Agile supply chain members. There are several definitions for VEs [13, 23, 24]. Virtual enterprise is a short-term form of cooperation among legally independent enterprises of long-term duration, in which the members (final assemblers, suppliers and service providers) share their skills, resources and risks in order to reduce costs and increase profit.

Although the existing literature discusses the general characteristics of virtual enterprises [24–29], there is a gap in the literature in the field of optimizing virtual networks. Thus, this research topic is absolutely unique.

And optimization method, with consideration of objective functions and design constraints, has been elaborated. Based on the method elaborated, optimization software has been developed. It is also described in this study.

3. Changes in production philosophy and novel trends in supply chains formation

The main goal of the production and service sectors is maximum customer satisfaction. These unique and fluctuating customer demands (variety and volume of final products) require strictly novel production concepts in many industrial sectors [1].

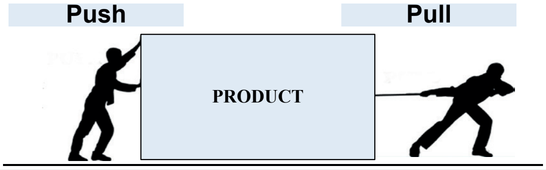
The final products required are becoming more and more complex, which entails new, more flexible production technologies and logistics processes.

3.1. Push and pull production philosophies. Traditional mass production ("push" – make to stock) is being replaced by unique production ("pull" – make to order).

Push-based production is based not on real customer demand but only on customer forecasts, which results in high levels of inventories. Meanwhile, pull-based production is based on real customer demand, i.e. the production process starts only once a well-defined customer demand appears [1, 29]. Table 1 shows the main characteristics of push and pull production philosophies.

The possibilities and advantages of the pull production philosophy are described by the following key performance indicators (KPI): 1. higher productivity; 2. shorter production lead time; 3. higher utilization of human resources and equipment; 4. production is scheduled based on the customer's demands; 5. smaller space needed for production; 6. only small amounts of stock are created in the production process; 7. flexible reaction to changing customer demands, etc.

Table 1.
Characteristics of push and pull production philosophies [30]



● lower productivity, ● low utilization of resources (machine, human, etc.), ● long production lead times, ● higher amount of inventories, ● extra inventory costs, ● extra floor space is needed, ● imbalances in the operations are hidden – bottlenecks are hidden, ● lot of wastes in the processes, ● little motivation for improvement.	● higher productivity and more cost effective production, ● high utilization of resources, ● production lead times are short, ● inventories and inventory holding costs are minimized, ● imbalances in operation (bottlenecks) are apparent, ● wastes can be eliminated easily, ● constant motivation for improvement.

3.2. Novel supply chain concepts. Supply chain members are production companies, service providers and customers. The rapidly changing market environment and global competition resulted in more complex networks of supply chains emerging. Cooperation between chain members became more dynamic.

The key to the chains' success is maximum customer satisfaction, which can be achieved by fast reaction to the changes in fluctuating customer and market demands.

To retain competitiveness of the supply chains and their members, novel supply chain concepts are formed besides the traditional chains [14, 17]. Novel supply chains have to fulfill different customer needs (Table 2).

Table 2
Characteristics of Lean-, Agile- and Hybrid supply chains

	Lean supply chain	Agile supply chain	Hybrid supply chain
Main goal of the concept:	– to minimize costs and waste, – to eliminate non-value-adding activities, – to improve the processes continuously.	– flexible and fast response to customer demands and market environment.	– to utilize Lean techniques during production throughout the chain, – to apply elements of Agile supply chains to form advantageous strategic cooperation.
Characteristics of manufactured products:	– traditional, basic products, – low product variety, higher in volume, – relatively long product life cycle (more than 1–2 years).	– innovative, unique products (IT, electronic and sport sectors), – higher product variety, smaller in volume, – short product life cycle (maximum of 1 year).	– innovative, more unique products, – high-end, more custom-designed product portfolio, smaller in volume, – shorter product life cycle.

	Lean supply chain	Agile supply chain	Hybrid supply chain
Organizational form of chain members:	– traditional networked organizational form.	– within the framework of a virtual enterprise.	– within the framework of a virtual enterprise.

4. Characteristics and benefits of virtual enterprises

A virtual enterprise is a typical cooperation form of Agile supply chain members, which provides fast fullfilment of rapidly changing customer demands.

4.1. Characteristics of virtual enterprises. Agility refers to the relation between the finished-product producing company and the customers' market, i.e. to how fast can the manufacturing companies respond to the customers' demands (in the variety and volume of finished products). Flexibility and responsiveness are main characteristic of Agile supply chains and virtual enterprises.

There are several definitions for virtual enterprises. In my opinion, the most detailed definition is the following: VE is a temporary cooperation of enterprises in which the members (final assemblers, component suppliers, raw material suppliers, service providers) share their skills, equipment, human resources and risks in order to reduce costs and increase competitiveness and profit.

The main characteristics of virtual enterprises are the following:

- VE is a short-term cooperation of legally independent enterprises.
- The VE network is typified by flexible and dynamic relationships.
- The main goal of a VE is to share the costs, skills, human and equipment resources and risks of the members to grasp advantageous market opportunities.
- Results of VE cooperation include the reduction of costs along with increasing productivity and competitiveness.
- Collaboration of VE members requires the application of information communication technologies (ICT).

Members of supply chain networks and of a virtual enterprise (Fig. 1): 1. production companies [final assemblers (FA); primary, secondary or raw material suppliers (S)]; 2. service providers (SP) [logistics, IT, financial, etc., SPs] and 3. customers (C) [consumers, end-users] [5].

4.2. Benefits of virtual enterprises. The competitiveness of VE members originates from the maximum utilization of resources (human, equipment, facility, etc.) and synergy between the members.

Benefits of virtual enterprises resulting from cooperation between members are the following:

- Members share the skills, resources, costs and risks. → Maximum utilization of human and equipment resources. → Reduction of manufacturing and operation costs.

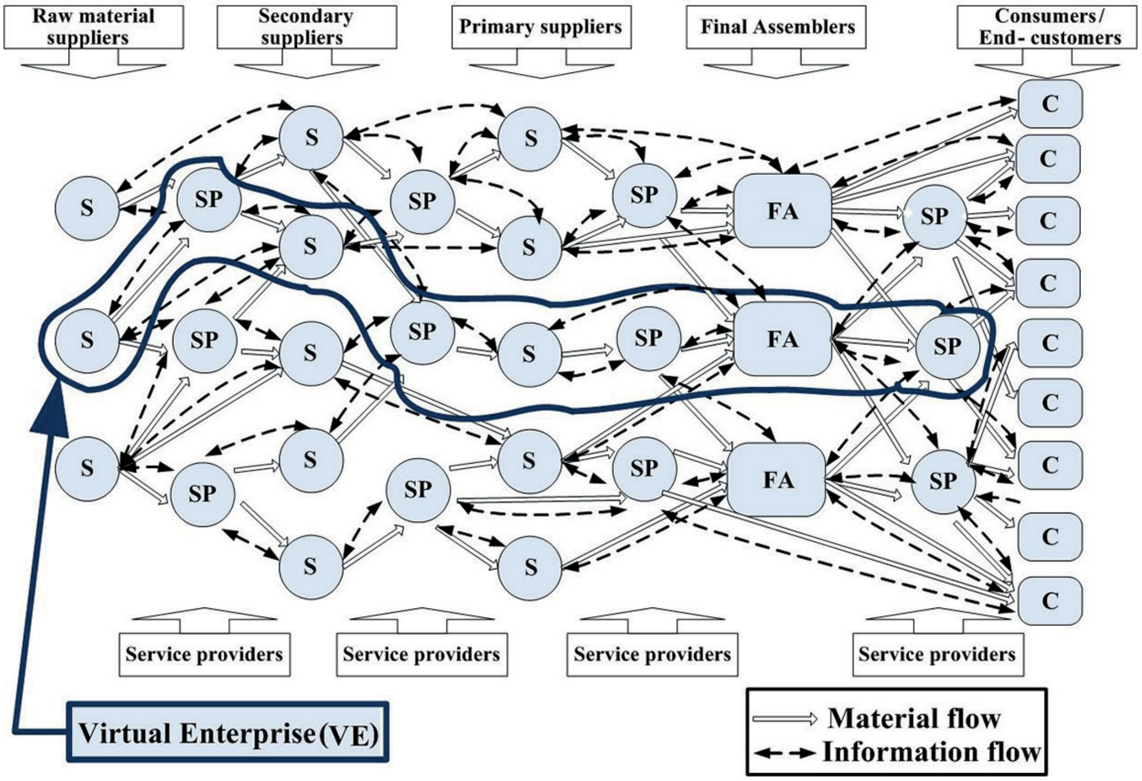


Fig. 1. Network of supply chains and a temporary virtual enterprise. Source: own

- Shorter lead time: the customer receives the ordered product in the shortest time possible.
- Members need not invest in their own, new technologies or workforce for manufacturing. → Possibility of applying resources and new technologies of other chain members. → Reduction of manufacturing and operation costs.
- Members can get new business opportunities that would be unreachable without this collaboration.
- Flexible production and service processes matching more unique and rapidly changing customer demands. → Unique products/services. In the case of several industries, the variation of finished products/services that can be chosen by the customers is huge.
- Higher income, higher profit for the companies. → Increasing tax revenue for the government.
- Maintaining and creating new jobs. → Reduction of unemployment.
- Maximum satisfaction of more unique and changing customer demands, higher quality and variety of finished products and services.

5. Method for optimization of virtual enterprise networks

I have come up with an optimization method for VEs, which translates into manufacturing and delivering finished products to customers in the most time- and cost-effective way. Objective functions and design constraints were also defined during this optimization.

Indices used in the mathematical formulations presented below are: i – products; j – potential suppliers (raw material, primary, secondary, etc. suppliers); k – final assemblers; l – customers; m – service providers; t – time intervals. FA: final assembler; S: supplier; SP: service provider; C: customer.

5.1. Objective function.

5.1.1. Total cost objective function. Total cost objective function is the summation of raw material and component cost, production cost, transportation cost, inventory cost, cost of service providers and operation cost of the VE (obtained from (2–7)).

$$\boldsymbol{f_1 = C_{Pi} + C_{Mi} + C_{Ti} + C_{Ii} + C_{Si} + C_{Oi}} \tag{1}$$

Production cost (including additional activities accompanying production activity) is the sum of production costs at Ss and at FAs:

$$C_{Pi} = \sum_j \sum_t cp_{ij} \cdot Q_{ijt} + \sum_k \sum_t cp_{ik} \cdot Q_{ikt} \tag{2}$$

cp_{ij} – production cost per unit of raw materials and components of finished product i at Ss; cp_{ik} – production cost per unit at FAs; Q_{ijt} – production volume of components of product i at Ss in each t time period; Q_{ikt} – production volume of product i at FAs in each t time period.

Cost of raw materials and components is the sum of material costs at Ss and at FAs:

$$C_{Mi} = \sum_j \sum_t cm_{ij} \cdot Q_{ijt} + \sum_k \sum_t cm_{ik} \cdot Q_{ikt} \tag{3}$$

cm_{ij} and cm_{ik} – material cost per unit; Q_{ijt} and Q_{ikt} – production volumes.

Transportation cost is the sum of transportation costs between Ss and FAs and between FAs and Cs:

$$C_{Ti} = \sum_j \sum_k \sum_t ct_{ijk} \cdot Q_{ijkt} + \sum_k \sum_l \sum_t ct_{ikl} \cdot Q_{iklt} \tag{4}$$

ct_{ijk} and ct_{ikl} – transportation cost per unit; Q_{ijkt} and Q_{iklt} – volumes of goods.

Inventory cost includes storage costs of stocks at Ss, at FAs, at Cs and at SPs:

$$C_{Ii} = \sum_j \sum_t ci_{ij} \cdot I_{ijt} + \sum_k \sum_t ci_{ik} \cdot I_{ikt} + \sum_l \sum_t ci_{il} \cdot I_{ilt} \tag{5}$$

ci_{ij}, ci_{ik} and ci_{il} – inventory cost per unit; I_{ijt}, I_{ikt} and I_{ilt} – inventories of goods.

Cost of service activities at service providers (e.g. financing, documentation, packaging, labelling, etc.):

$$C_{Si} = \sum_m \sum_t Csp_{imt} \tag{6}$$

Csp_{imt} – cost of activities of service providers needed for manufacture of product i.

Operational cost of a virtual enterprise (e.g. management cost, cost of ICT, etc.) depends on the size of the network (n_c) and chain member profiles (p):

$$C_{Oi} = C_{Oi}(n_c, p). \tag{7}$$

5.1.2. Total lead time objective function. Total lead time objective function is the summation of production lead times at manufacturing companies, lead times of services at service providers, lead times of warehousing and transport times (obtained from (9–12)).

$$\boldsymbol{f_2 = T_{Pi} + T_{Si} + T_{Wi} + T_{Ti}} \tag{8}$$

Production lead time is the sum of lead times at Ss and FAs:

$$T_{Pi} = \sum_j \sum_t tp_{ij} \cdot Q_{ijt} + \sum_k \sum_t tp_{ik} \cdot Q_{ikt} \tag{9}$$

tp_{ij} and tp_{ik} – unit production lead times; Q_{ijt} and Q_{ijt} – production volume at Ss and FAs.

Service lead time is the sum of time consumption of service provider activities required for manufacturing (financing, packaging, etc.):

$$T_{Si} = \sum_m \sum_t Tsp_{imt}. \tag{10}$$

Warehousing time is the sum of storage times at *Ss*, at *FAs*, at *Cs* and at *SPs*:

$$T_{Wi} = \sum_j tw_{ij} + \sum_k tw_{ik} + \sum_l tw_{il} + \sum_m tw_{im}. \tag{11}$$

Transport time is the sum of transportation times of goods, between *Ss* and *FAs* and between *FAs* and *Cs*:

$$T_{Ti} = \sum_j \sum_k tt_{ijk} + \sum_k \sum_l tt_{ikl}. \tag{12}$$

5.2. Constraints.

5.2.1. Production and service capacity constraint. Production volumes have to be limited by minimum and maximum volume at suppliers and at final assemblers:

$$Q_{ijt}^{\min} \le Q_{ijt} \le Q_{ijt}^{\max}, \tag{13}$$

$$Q_{ikt}^{\min} \le Q_{ikt} \le Q_{ikt}^{\max}. \tag{14}$$

Service capacities have to be limited by minimum and maximum volume at service providers:

$$Q_{imt}^{\min} \le Q_{imt} \le Q_{imt}^{\max}. \tag{15}$$

5.2.2. Inventory constraint. Depending on the inventory strategy of the supply chain, the volume of inventories at the manufactures' and service providers' have to be limited:

$$\begin{gathered} I_{ijt}^{\min} \le I_{ijt} \le I_{ijt}^{\max};\ I_{ikt}^{\min} \le I_{ikt} \le I_{ikt}^{\max}; \\ I_{imt}^{\min} \le I_{imt} \le I_{imt}^{\max}. \end{gathered} \tag{16}$$

5.2.3. Flexibility constraint. Responsiveness and flexibility of supply chain members have become key to being competitive and profitable.

The VE is characterized by a dynamically forming and flexible network, so the following flexibility constraints can be defined for its members:

- flexibility of the manufacturing system at the manufacturing companies (producing goods that are readily adaptable to changes, both in type and volume),
- flexibility of the IT infrastructure at supply chain members (operation of the VE is based on the application of ICT for managing information flow),
- financial liquidity of the supply chain members (high flexibility and starting a new project requires investment),
- flexibility due to the organizational structure of the supply chain members (fastness of decision-making depends on the type and size of the enterprise's organizational structure).

These constraints can all be described by values to be found in the (1–5) interval.

5.3. Optimization method. Single-objective optimization is performed by means of the systematic search method. During multi-objective optimization, on the other hand, the normalized weighting method is used:

$$f(x) = \sum_{\alpha=1}^{2} w_\alpha f_\alpha(x) / f_\alpha^0 \tag{17}$$

$f_\alpha(x)$ – cost- and time-objective functions; w_α – weight of the cost- and time objective functions; $w_\alpha \ge 0$; $\sum_{\alpha=1}^{2} w_\alpha = 1$.

6. Software development for optimum design of virtual enterprises

Based on the elaborated theoretical method, software was developed for optimum forming of VEs with the contribution of Mark Mihalik, an engineering student. The software was written in Java programming language. The operation of the software is presented by means of a case study.

6.1. Case study – problem statement. The goal is the formation of an optimum virtual enterprise which consists of one final assembler (FA), suppliers and 4 forwarding service providers. One optimum primary supplier has to select from among four potential primary suppliers (S_{11}, S_{12}, S_{13}, S_{14}) and one optimum secondary supplier has to select from among five potential secondary suppliers (S_{21}, S_{22}, S_{23}, S_{24}, S_{25}) (Fig. 2).

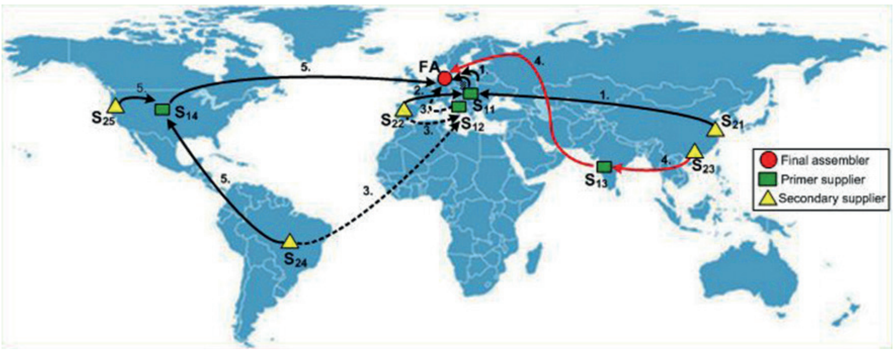


Fig. 2. Potential supply chain combinations. Source: own

Relations of the final assembler and potential suppliers can be defined by means of a relation matrix while the distances between the final assembler and potential suppliers can be presented in a distance matrix.

Relation matrix:

$$\underline{\underline{R}} = \begin{array}{cc} & \begin{array}{cccc}1 & \ldots & \ldots & n\end{array} \\ \begin{array}{c}1\\ \vdots \\ \\ \vdots \\ n\end{array} & \left[\begin{array}{cccc} & & & \\ & & & \\ & 1/0 & & \\ & & & \\ & & & \end{array}\right]\end{array} \tag{18}$$

- n: identifiers of final assembler, potential primary and secondary suppliers,
- value of elements of $\underline{\underline{R}}$ is 0 (there is no relation between members) or 1 (there is a relation).

Distance matrix:

$$\underline{\underline{L}} = \begin{array}{cc} & \begin{array}{cccc}1 & \ldots & \ldots & n\end{array} \\ \begin{array}{c}1\\ \vdots \\ \\ \vdots \\ n\end{array} & \left[\begin{array}{cccc} & & & \\ & & & \\ & & & \\ & & & \\ & & & \end{array}\right]\end{array} \tag{19}$$

- value of elements of the $\underline{\underline{L}}$ matrix is the distance between potential chain members [km].

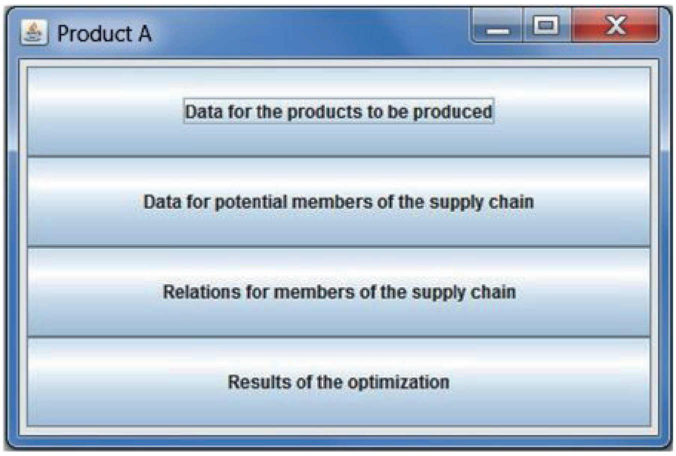
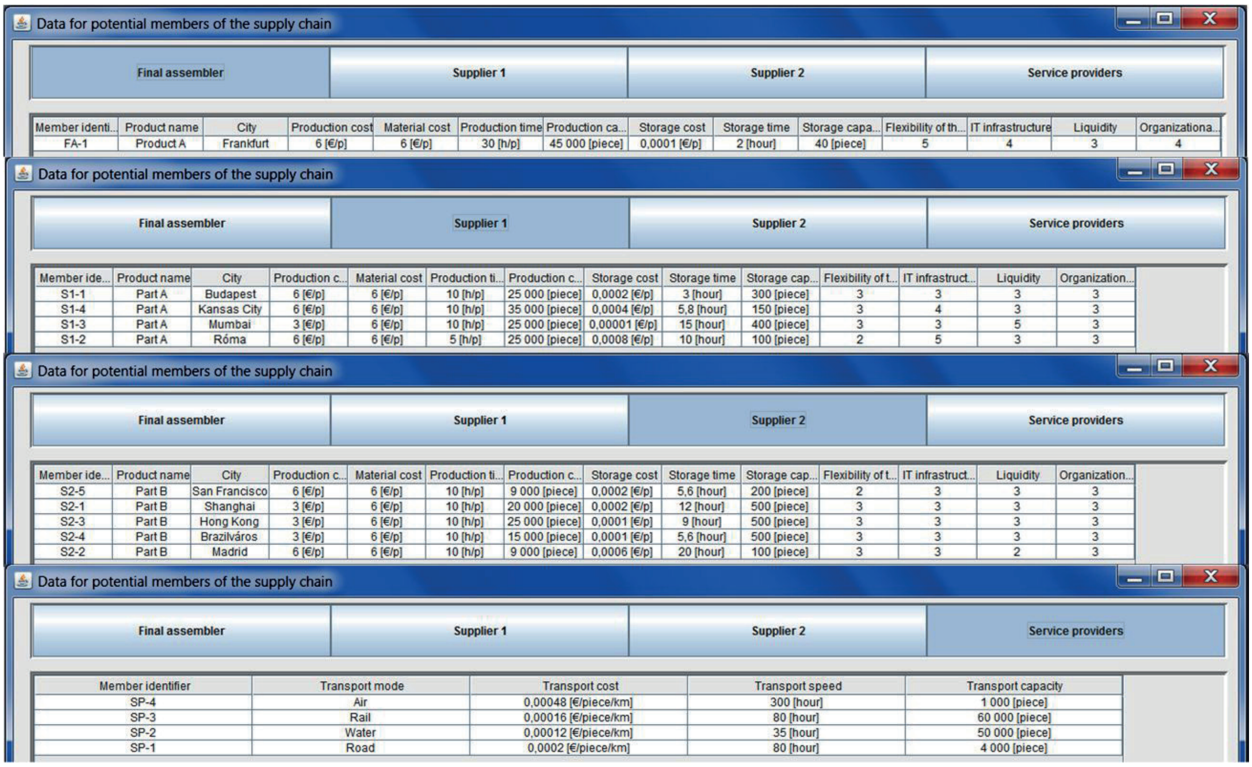


Fig. 3. Main program screen

In the case study, the material cost (cm_i) is 6 EUR/piece in Europe, in America and in Asia; the unit production cost (cp_i) is 6 EUR/piece in Europe and in America and 3 EUR/piece in Asia. The specific transport cost (ct_i) relating to the different transport modes and forwarding companies can also be seen in Fig. 4.

6.2. Running optimization software – case study. The four main menus of the software (Fig. 3) are as follows:

1. In the "Data for the products to be produced" menu, we can define the characteristics of the finished product to be produced.



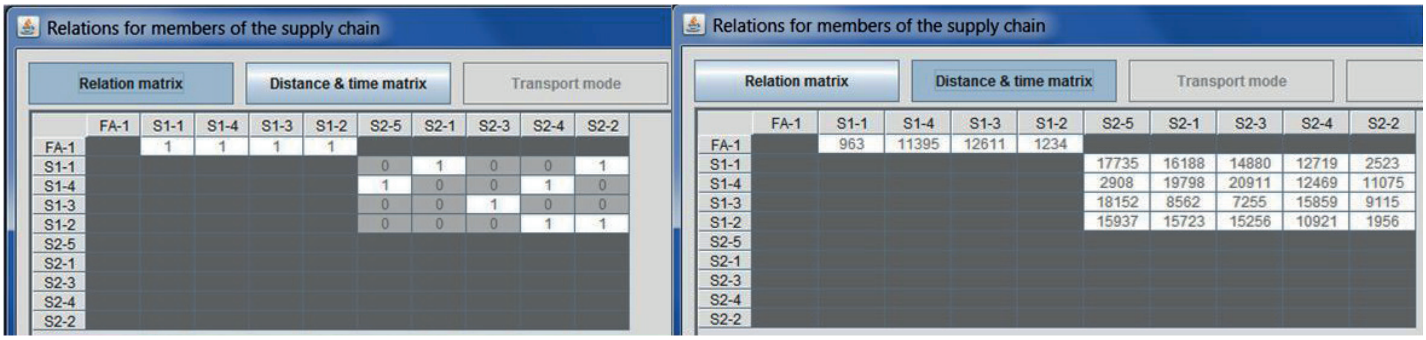
Member identi...	Product name	City	Production cost	Material cost	Production time	Production ca...	Storage cost	Storage time	Storage capa...	Flexibility of th...	IT infrastructure	Liquidity	Organizationa...
FA-1	Product A	Frankfurt	6 [€/p]	6 [€/p]	30 [h/p]	45 000 [piece]	0,0001 [€/p]	2 [hour]	40 [piece]	5	4	3	4

Member ide...	Product name	City	Production c...	Material cost	Production ti...	Production c...	Storage cost	Storage time	Storage cap...	Flexibility of t...	IT infrastruct...	Liquidity	Organization...
S1-1	Part A	Budapest	6 [€/p]	6 [€/p]	10 [h/p]	25 000 [piece]	0,0002 [€/p]	3 [hour]	300 [piece]	3	3	3	3
S1-4	Part A	Kansas City	6 [€/p]	6 [€/p]	10 [h/p]	35 000 [piece]	0,0004 [€/p]	5,8 [hour]	150 [piece]	3	4	3	3
S1-3	Part A	Mumbai	3 [€/p]	6 [€/p]	10 [h/p]	25 000 [piece]	0,00001 [€/p]	15 [hour]	400 [piece]	3	3	5	3
S1-2	Part A	Róma	6 [€/p]	6 [€/p]	5 [h/p]	25 000 [piece]	0,0008 [€/p]	10 [hour]	100 [piece]	2	5	3	3

Member ide...	Product name	City	Production c...	Material cost	Production ti...	Production c...	Storage cost	Storage time	Storage cap...	Flexibility of t...	IT infrastruct...	Liquidity	Organization...
S2-5	Part B	San Francisco	6 [€/p]	6 [€/p]	10 [h/p]	9 000 [piece]	0,0002 [€/p]	5,6 [hour]	200 [piece]	2	3	3	3
S2-1	Part B	Shanghai	3 [€/p]	6 [€/p]	10 [h/p]	20 000 [piece]	0,0002 [€/p]	12 [hour]	500 [piece]	3	3	3	3
S2-3	Part B	Hong Kong	3 [€/p]	6 [€/p]	10 [h/p]	25 000 [piece]	0,0001 [€/p]	9 [hour]	500 [piece]	3	3	3	3
S2-4	Part B	Brazilváros	3 [€/p]	6 [€/p]	10 [h/p]	15 000 [piece]	0,0001 [€/p]	5,6 [hour]	500 [piece]	3	3	3	3
S2-2	Part B	Madrid	6 [€/p]	6 [€/p]	10 [h/p]	9 000 [piece]	0,0006 [€/p]	20 [hour]	100 [piece]	3	3	2	3

Member identifier	Transport mode	Transport cost	Transport speed	Transport capacity
SP-4	Air	0,00048 [€/piece/km]	300 [hour]	1 000 [piece]
SP-3	Rail	0,00016 [€/piece/km]	80 [hour]	60 000 [piece]
SP-2	Water	0,00012 [€/piece/km]	35 [hour]	50 000 [piece]
SP-1	Road	0,0002 [€/piece/km]	80 [hour]	4 000 [piece]

Fig. 4. Parameter setting relating to supply chain members



	FA-1	S1-1	S1-4	S1-3	S1-2	S2-5	S2-1	S2-3	S2-4	S2-2
FA-1		1	1	1	1					
S1-1						0	1	0	0	1
S1-4						1	0	0	1	0
S1-3						0	0	1	0	0
S1-2						0	0	0	1	1
S2-5										
S2-1										
S2-3										
S2-4										
S2-2										

	FA-1	S1-1	S1-4	S1-3	S1-2	S2-5	S2-1	S2-3	S2-4	S2-2
FA-1		963	11395	12611	1234					
S1-1						17735	16188	14880	12719	2523
S1-4						2908	19798	20911	12469	11075
S1-3						18152	8562	7255	15859	9115
S1-2						15937	15723	15256	10921	1956
S2-5										
S2-1										
S2-3										
S2-4										
S2-2										

Fig. 5. Parameter setting relating to relation of supply chain members

2. In the “Data for potential members of the supply chain” menu, we can define the production and storage costs, production and storage times, production and storage capacities, and flexibility constraints relating to potential VE members. In this case study, these data were defined relating to the FA, potential suppliers and 4 forwarding companies (Fig. 4).
3. In the “Relations for members of the supply chain” menu, the relation matrix $\left(\underline{\underline{R}}\right)$, distance matrix $\left(\underline{\underline{L}}\right)$ and transport modes used for the movement of goods can be given. In our case, these data can be seen in Fig. 5.
4. Objective function(s) (cost or/and lead time) used during the optimization can be selected in the “Results of the optimization” menu. In this case study, the cost objective function was selected. Flexibility constraints (defined in (17)) can also be set in this menu. Values of flexibility constrains were given on the left side of Fig. 6.

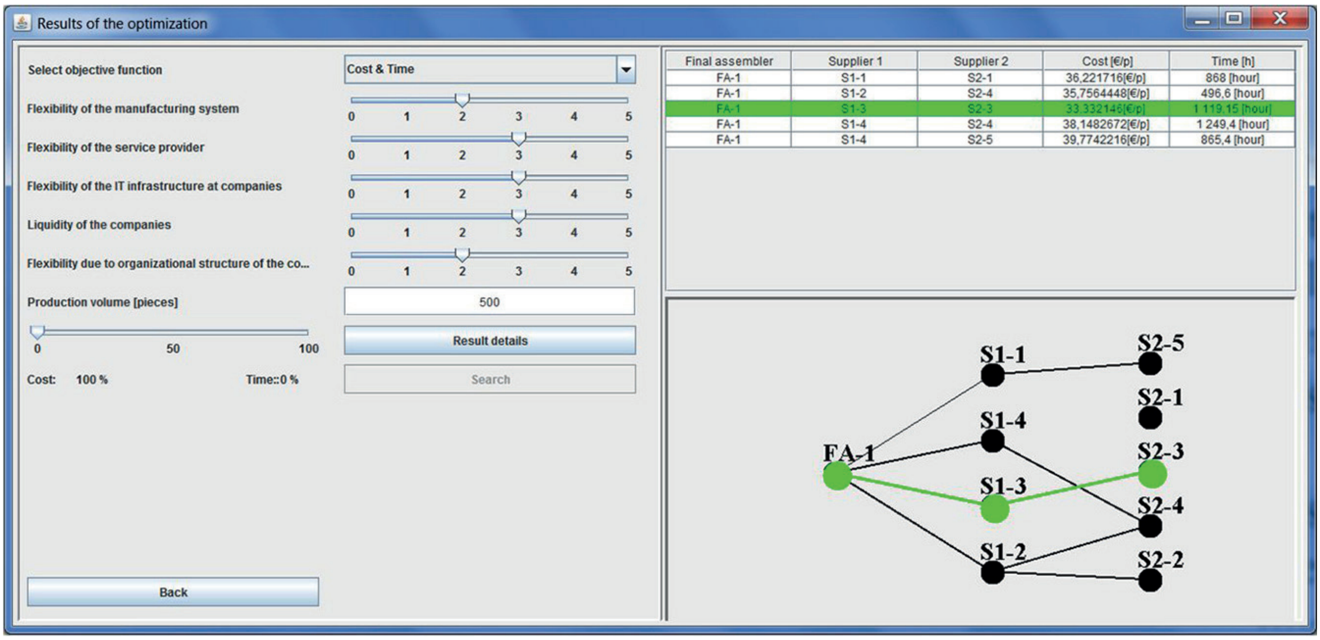
6.3. Result– optimum virtual enterprise. Network optimization in the case of single-cost objective optimization is performed by means of a systematic search in the case study. The result of cost optimization can be seen on the screen (Fig. 6). The possible virtual enterprises that fulfill the constraints are listed and shown graphically on the right side of the screen.

The optimum virtual enterprise formation in the case study is FA – S_{13} – S_{23} (depicted by the green line in Fig. 6), when the total cost of one piece of a final product is at its minimum, i.e. only 33.3 [EUR/piece].

7. Conclusions

The growing market globalization, increasing global competition and more complex product characteristics all result in the application of new technologies, methods and production philosophies. Therefore push philosophy is being replaced by the more cost-effective pull production philosophy.

More complex and dynamic networks of supply chains require novel supply chain paradigms (Lean, Agile and Hybrid ones). New organization and cooperation forms of companies are being established in order to increase profit and competi-



Select objective function: Cost & Time
Flexibility of the manufacturing system: 2
Flexibility of the service provider: 3
Flexibility of the IT infrastructure at companies: 3
Liquidity of the companies: 3
Flexibility due to organizational structure of the co...: 2
Production volume [pieces]: 500
Cost: 100 % Time::0 %

Final assembler	Supplier 1	Supplier 2	Cost [€/p]	Time [h]
FA-1	S1-1	S2-1	36,221716[€/p]	868 [hour]
FA-1	S1-2	S2-4	35,7564448[€/p]	496,6 [hour]
FA-1	S1-3	S2-3	33,332146[€/p]	1 119,15 [hour]
FA-1	S1-4	S2-4	38,1482672[€/p]	1 249,4 [hour]
FA-1	S1-4	S2-5	39,7742216[€/p]	865,4 [hour]

Fig. 6. Results of optimization

tiveness as well as reduce cost. Therefore, members of Agile supply chains form virtual enterprise networks.

The goal of the study was the optimization of virtual enterprises, which means forming optimum combinations of potential chain members (final assemblers, component suppliers, raw material suppliers, service providers). The topic of the research is important and innovative because a virtual enterprise is an advantageous cooperation form for companies, where the members share their skills, resources (human, equipment, facility), risks and waste in order to reduce production and operation costs while increasing productivity and competitiveness. While the literature often discusses virtual enterprises as such, there is a gap concerning their optimization; therefore, the results of my research are unique.

I have developed an optimization method along with the objective functions (1. total cost, and 2. total lead time) and design constraints (1. production and service capacities of members, 2. inventories at members, and 3. flexibility of members) for virtual enterprise optimization. The optimum combination of potential members of a virtual enterprise can be formed by the application of the method to achieve the most effective operation in terms of cost and/or lead time. The result of the optimization method is to manufacture and deliver finished products to customers in the most time- and cost-effective way, minimizing the total cost and total lead time of the supply chain.

Based on the method elaborated, software has been developed which can be widely used for single and multi-objective optimization of micro- and macro regional networks.

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