GLOBAL ECONOMIC CHANGES, OPTIMIZATION OF VIRTUAL ENTERPRISES - SOFTWARE DEVELOPMENT

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Abstract: Changing market environment, global competition, rapidly fluctuating customer demands and more complex global network of supply chains require new production conceptions (Pull, Lean) and technologies. Novel supply chain paradigms (1. Lean-, 2. Agile-, 3. Leagile Supply Chain) are forms in order to increase and maintain competitiveness of companies. New organization and cooperation forms are formed. The members of an Agile Supply Chain form Virtual Enterprise (VE) network, which supports the fast and flexible fulfilment of changing customers' demands.

The goal of the study is the VE network optimization, which means the formation of optimal combination of ideal chain's members (production companies, service providers and customers). This study is original and unique, since an optimization method, objective functions (total cost and lead time) and design constraints have been elaborated. Based on the elaborated method an optimization software has been developed which can be widely used for optimization of micro- and macro regional networks.

Key words: Virtual Enterprise, optimization, total cost, total lead time, software development

Introduction

The most important logistic goal is the maximal customer satisfaction. Due to the more unique and rapidly changing customer demands, changing environment and global competition, more and more complex networks of supply chains are formed and novel supply chain paradigms (Lean-, 2. Agile- 3. Leagile-) are establishes besides the traditional chains in order to increase competitiveness of companies.

There are changes in production philosophy and organization and cooperation forms of enterprises (VE). The traditional mass ("Push") production is changed by the production of unique products ("Pull"-"make to order"). Nowadays more and more companies are adopting Lean manufacturing philosophy to reduce cost and optimize processes gaining a competitive advantage. In this study these above mentioned relevant economical processes are described, and novel supply chain paradigms and production philosophies are introduced and compared.

The members of an Agile Supply Chain usually form Virtual Enterprise network. VE is a temporary cooperation of enterprises in which the members share their skills, competencies, equipment and human resources, at the same time the risks and wastes in order to more efficient operation (Kovács and Kot, 2016).

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The goal of the study is the VE network optimization, which means the formation of optimal combination of ideal chain's members to realize the most cost- and time effective operation. This topic is unique, because the existing literature often discusses the Virtual organizations, but researchers had not deal with the optimization of VEs.

This study is original, since an optimization method, the objective functions (1. total cost, 2. total lead time) and design constraints (1. production and service capacities, 2. inventories at manufacturing companies and service providers, 3. flexibility of the supply chain) have been elaborated.

The objective of the supply chain network optimization is to manufacture and deliver final products to end-users in the most cost-effective and timely manner, the total cost and total lead time of the supply chain have to be minimized during the optimization.

Based on the elaborated method an optimization software has been developed which can be widely used for optimization of micro- and macro regional networks. By the help of the developed software an optimal micro-regional virtual network has been formed in a Hungarian micro-region in the frame of a R&D project. This VE is involving the optimal combination of enterprises of 3 counties.

Literature Review and Methodology

Changes in economy, production philosophies and supply chains of the last decade are described and evaluated in details in many literature (Bokor, 2005; Kovács and Kot, 2016).

There is a great deal of literature discussing the characteristics, management and types of supply chains (Stevens, 1989; Vonderembse, 2006; Liberko at al., 2015). Novel supply chain paradigms (Lean-, Agile- and Leagile Supply Chains) are established (Schönsleben, 2000; Naylor et al., 1999) to fulfil different customers' needs.

The Lean production philosophy is one of the most widely used paradigms in many sectors. There are lots of relevant publications in topic of Lean manufacturing (Womack and Jones, 1996; Liker and Lamb, 2000).

Flexibility and responsiveness are key characteristic of an Agile Supply Chains and Virtual Enterprises. A supply chain adapts the changes if it is flexible and agile in nature, so the flexibility is increasingly important for gaining and maintaining competitiveness. Winkler and Seebacher (2015) provide an overview of the most important scientific approaches for the measurement and evaluation of supply chain flexibility. Chan et al. (2017) reviewed the literature in topic of flexibility, concluded the definitions for strategic flexibility, resource flexibility, coordination flexibility, range flexibility, response flexibility.

There are several definitions for virtual organizations. A VE (Schönsleben, 2000) is a short-term form of cooperation among legally independent enterprises for long-term duration. Characteristics and analysis of virtual organizations appear frequently in the literature (Camarinha-Matos, 2001).

The main characteristics of the Virtual Enterprises are summarised by Gunasekaran et al. (2008): the main goal of VE is to exploit fast-changing market opportunities and sharing of risks, costs and competencies. Camarinha-Matos (2001) and Esposito and Evangelista (2014) concluded the properties and requirements and operation of VEs.

There is gap in literature concerning the optimization of virtual enterprises, this is the reason that this research is absolutely original and unique.

In the last years I have completed several R&D projects for production companies and service providers, so I have seen the significant importance of strategic cooperation and partnership of companies. This empirical experience initiated the idea of this research. Optimization method, including objective functions and design constraints has been elaborated. Based on the elaborated optimization method an optimization software has been developed.

Global Economic Changes

The most important logistic goal is the maximal customer satisfaction. It means that the acceptable delivery time has decreased and the customer's demand for quality has increased. Rapidly changing customers' demands control the whole production and service sectors. Due to the more unique and changing customer demands, novel supply chain paradigms (1. Lean-, 2. Agile-, 3. Leagile-) are introduces in order to increase and maintain competitiveness of companies. Different supply chains fulfil different customers' needs. Supply chain networks include production companies (final assemblers and suppliers), service providers and customers.

Types and Characteristics of Novel Supply Chains

Lean Supply Chain
The application of Lean manufacturing philosophy in order to optimize costs and quality, eliminate non-value-adding activities is gaining a competitive advantage (Womack et al., 1990; Liker and Lamb, 2000). This results in the realization of production smaller in volume, but more economical and flexible. This concept can be applied in case of well predictable market demand and low product variety, products with a relatively long product life cycle (more than 1-2 years). Members of the chain work in a traditional networked organizational form.

Agile Supply Chain
These chains have to be flexible in order to better respond to rapidly changing customer demands and market environment. This concept is generally applied in case of innovative and new products (volatile market demand), with relatively short product life cycle (maximum 1 year). This results in the realization of production of more custom designed final products, smaller in volume. Members of the chain work in the framework of a Virtual Enterprise.

Leagile Supply Chain

A Leagile Supply Chain is a mix of Lean Supply Chain and Agile Supply Chain. This supply chain utilizes the advantages of the Lean and Agile concepts. This paradigm can be applied in case of innovative and absolutely unique final products which are custom designed. Most of the companies of the chain apply the Lean philosophy and work in the framework of a Virtual Enterprise to utilize the flexibility of the whole organisation.

Agarwal et al. (2006) summarised the comparison of attributes among Lean, Agile and Leagile Supply Chains. Table 1 illustrates their comparison.

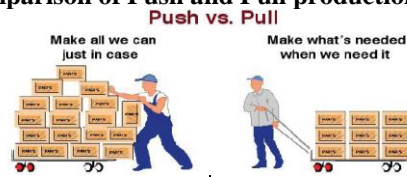**Table 1. Comparison of Lean, Agile and Leagile Supply Chains**

Distinguishing attributes	Lean supply chain	Agile supply chain	Leagile supply chain
Market demand	Predictable	Volatile	Volatile and unpredictable
Product variety	Low	High	Medium
Product life cycle	Long	Short	Short
Customer drivers	Cost	Lead-time and availability	Service level
Profit margin	Low	High	Moderate
Dominant costs	Physical costs	Marketability costs	Both
Stock out penalties	Long term contractual	Immediate and volatile	No place for stock out
Purchasing policy	Buy goods	Assign capacity	Vendor managed inventory
Information enrichment	Highly desirable	Obligatory	Essential
Forecast mechanism	Algorithmic	Consultative	Both/either
Typical products	Commodities	Fashion goods	Product as per customer demand
Lead time compression	Essential	Essential	Desirable
Eliminate muda	Essential	Desirable	Arbitrary
Rapid reconfiguration	Desirable	Essential	Essential
Robustness	Arbitrary	Essential	Desirable
Quality	Market qualifier	Market qualifier	Market qualifier
Cost	Market winner	Market qualifier	Market winner
Lead-time	Market qualifier	Market qualifier	Market qualifier
Service level	Market qualifier	Market winner	Market winner

Production Philosophies and Cooperation Forms of Supply Chain' Members

The key of success of supply chains is to understand the customers' requirements, and to fulfil it with the highest quality and fast, at the same time the better respond to rapidly changing market environment. Supply chains are globalized, more and more complex networks of supply chains are formed, cooperation between members became more dynamic. Due to the above mentioned tendencies, there are changes in production philosophy and production processes. The traditional mass production ('Push' - 'make to stock') is changed by the production of unique products ('Pull' - 'make to order').

Push based production planning is based of forecasted data (not actual customer demand), it results high amount of stock. On the contrary, in case of Pull based production, the production starts only when an actual customer demand appears. Based on the fundamental differences between the two approaches it can be concluded that Pull production results the following advantages (Table 2).

Table 2. Comparison of Push and Pull production philosophies

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

Lean philosophy

More and more companies of the Lean supply chains are adopting Lean manufacturing philosophy. The Lean production philosophy utilizes the benefits of Pull production philosophy, and it is widely used in many sectors, both at production and service enterprises, e.g. in automotive industry, electronic industry, offices and banks as well. The essence of the Lean production system is to improve quality of the products and processes, reduce wastes and optimize the cost of production processes in order to gain and maintain competitiveness (Kovács, 2012).

Based on the Lean approach all of activities can be categorized into three groups:

− value added activities (e.g. manufacturing, assembly, etc.),
− required but non-value added activities (e.g. machine set-up, testing, etc.),
− wastes are any element that does not add value, or that the customer is not willing to pay for (e.g. over-production, inventories, etc.).

Goals of the Lean philosophy are the following:

− eliminate wastes, seven types of wastes (McLachlin, 1997) can be identified in processes (Fig. 1),
− reduce the required but non-value added activities.

The result of the Lean approach is illustrated in Figure 2. In case of Lean manufacturing the ratio of the value adding and non-value adding activities will be improved in processes.
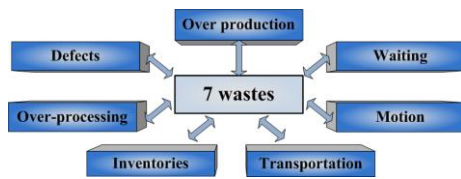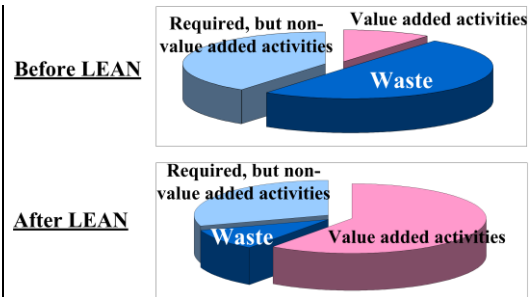
Figure 1. Seven types of wastes

Figure 2. Ratio of the value adding and non-value adding activities before- and after Lean process improvement

Cooperation form of chain's members: members work in a traditional networked organizational form, on the contrary, in case of Agile Supply Chain the members of the chain work in the framework of a Virtual Enterprise.

There are lot of Lean tools and methods for process improvement /e.g. Pull system, JIT, Kanban, Value Stream Mapping, Jidoka, One-piece flow, 5S, Takt-time analysis, Heijunka, etc. /. (Womack and Jones, 1996; Liker and Lamb, 2000) Lean tools and methods are easy to use due to their simplicity, the most of them are require very little time effort.

Application of Lean philosophy results the improvement of the following KPIs (Key Performance Indicators): higher productivity, shorter lead times, shorter set up times, smaller stocks, increased quality, higher utilization of resources, etc.

Virtual Enterprise

The members of an Agile Supply Chain usually form a dynamic cooperation in the framework of VE, which provides the fast fulfilment of the rapidly changing customers' demands. VEs are used in an increasing number of industries, e.g. automotive industry, fashion industry, food industry, etc.

Agility refers to the connection between the final assembly company and the customers' market that how fast can the chain respond to the customers' demands and the new challenges of the market. Flexibility is a key characteristic of an Agile Supply Chain.

There are several definitions for virtual organizations. In my opinion the most detailed definition is given by Esposito and Evangelista (2014). They prepared a very detailed and systematic evaluation of the most frequently cited characteristics of Virtual Enterprises. They summarized the following characteristics:

− the main goal of a VE is to exploit fast-changing market opportunities,
− members of the VE share the skills, core competencies, costs, risks and resources,

- the VE is characterized by a flexible and dynamic network,
- the network is typified by relationships involving legally independent enterprises,
- the partnership is typically temporary,
- coordination and communication are based on information communication technologies (ICT).

Supply chain networks include: 1. production companies (final assemblers, primary or secondary suppliers, or raw material suppliers); 2. service providers (logistics service providers, information service providers, Research & Development service providers, financial service providers, etc.) and 3. customers (consumers, end users, etc.).

Essence of establishing a VE is to share the skills, core competencies, costs, risks and resources of enterprises in order to faster respond to business opportunities increasing and maintaining competitiveness of the chain and its members.

Figure 3. shows network of supply chains and a VE as a temporary alliance of legally independent enterprises.
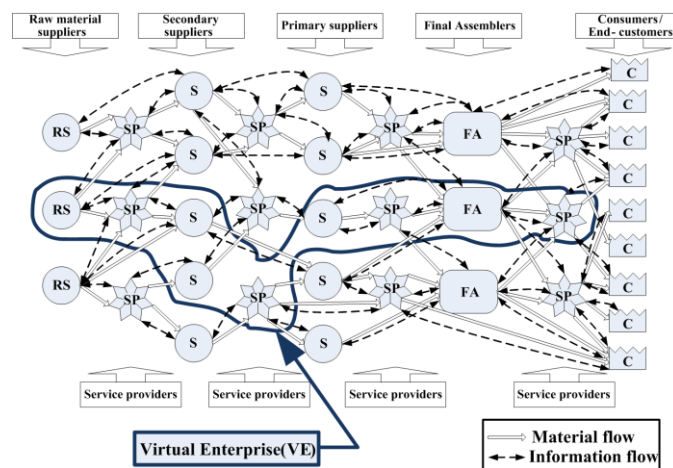
Figure 3. Network of supply chains and a temporary Virtual Enterprise

Due to this cooperation, enterprises do not have to invest in new production or service technologies or human resource, so the operation cost can be reduced at the whole chain and at individual enterprises. Consequently cost reduction, higher utilization of production and service capacities and human resources will be realized. The chain's members can get new business opportunities that would be unreachable without this collaboration.

Intensive use of information communication technologies (ICT) and knowledge management (KM) are essential conditions for optimal operation of a VE.

Optimization of a Virtual Enterprise network

The goal of the VE network optimization is forming the optimal combination of ideal chain's members (production companies, service providers and customers). The goal of the research is the optimization of supply chain network, which means to manufacture and deliver final products to end-users in the most cost-effective and timely manner, the total cost and total lead time of the supply chain have to be minimized during the optimization.

During the optimization the objective functions (1. total cost, 2. total lead time) and design constraints (1. production and service capacities, 2. inventories at manufacturing companies and service providers, 3. flexibility of the supply chain) are defined. Total cost and total lead time have to be minimized during the optimization, taking into consideration the above mentioned 3 design constraints. Consequently the total cost function (eq. 7), total lead time function (eq. 12) and 3 design constraints (eq. 13-17) are defined.

During the optimization the input data are the following: product types and quantities ordered by customers, final assemblers, possible primary suppliers, secondary suppliers, service providers, manufacturing capacities of production companies, service capacities at service providers are described. Transport distances between the possible chain's members, cost and time of different activities required for manufacturing of final products.

Indices used in the following mathematical formulation are: i- products; j- possible suppliers (primary, secondary, or other suppliers); k- final assemblers; l- customers; m- required service providers; t- time intervals.

Total cost objective function

Total cost is the sum of raw material and component cost, production cost, transportation cost, inventory cost, cost of service providers and operation cost of the VE.

− *Production cost*

The production cost (including additional activities joining to manufacturing activity, e.g. machine setup, material supply, loading unit formation, …) is the sum of production costs at suppliers and production cost at final assembly company:

$$C_p = cp_{ij} \cdot Q_{ijt} + cp_{ik} \cdot Q_{ikt} \ , \tag{2}$$

where: cp_{ij} - production cost per unit of raw materials and components of product I at supplier j; cp_{ik} - production cost per unit of product i at final assembly k; Q_{ijt} - production quantity volume of components of product i at supplier j in each t time period; Q_{ikt} - production volume of product i at final assembly k in each t time period.

- *Cost of raw materials and components*

The total material cost is the sum of material costs at suppliers and at final assembler:

$$C_m = cm_{ij} \cdot Q_{ijt} + cm_{ik} \cdot Q_{ikt} \ , \tag{1}$$

where: cm_{ij} and cm_{ik} - material cost per unit; Q_{ijt} and Q_{ikt} - production quantities.

- *Transportation cost*

The transportation cost is the sum of transportation of each product on each relation of the network, between suppliers and final assembly and between final assembly and customers:

$$C_t = ct_{ijk} \cdot Q_{ijkt} + ct_{ikl} \cdot Q_{iklt} \ , \tag{3}$$

where: ct_{ijk} and ct_{ikl} - transportation cost per unit; Q_{ijkt} and Q_{iklt} - flow of goods.

- *Inventory cost*

The inventory cost is including the holding and storage costs of stocks at suppliers, at assembler, at customers and at service providers (especially at warehousing service providers):

$$C_i = ci_{ij} \cdot I_{ijt} + ci_{ik} \cdot I_{ikt} + ci_{il} \cdot I_{ilt} \ , \tag{4}$$

where: 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*

Activities of service providers are including the processes required for financing, warehousing, packaging, labelling, etc. of product *i*.

$$C_s = \sum_m Csp_{imt} \ , \tag{5}$$

where: Csp_{imt} - cost of activities of service providers required for manufacturing of product *i*.

- *Operational cost of the Virtual Enterprise*

Operational cost of the VE (C_o) is including e.g. the management cost of the network, cost of the information and communication technology, etc. The amount of this cost component is depending on the size of the network (n_c) and profile of chain's members (p).

$$C_o = C_o(n_c, p) \ . \tag{6}$$

Total cost objective function is the summation of all cost components given by Eqs. (1-6).

$$\boxed{f_1 = C_p + C_m + C_t + C_i + C_s + C_o} \ . \tag{7}$$

Total lead time objective function

Total lead time is the sum of production lead times at manufacturing companies, lead times of services completed by service providers, lead times of warehousing and transport times.

− *Production lead time*

The production lead time (including additional activities joining to manufacturing activity, e.g. machine setup, material supply, loading unit formation, etc.) is the sum of lead times at suppliers and final assembly company:

$$T_p = tp_{ij} \cdot Q_{ijt} + tp_{ik} \cdot Q_{ikt} \ , \tag{8}$$

where: tp_{ij} and tp_{ik} - unit production lead time at supplier and final assembler;

Q_{ijt} and Q_{ikt} - production quantity volume at suppliers and final assembler.

− *Service lead time*

Activities of service providers are including the processes required for financing, warehousing, packaging, labelling, etc. of product i.

$$T_s = \sum_m Tsp_{imt} \ , \tag{9}$$

where: Tsp_{imt} - time consumption of activities of service providers required for manufacturing of product i.

− *Warehousing time*

Total warehousing time is the sum of the storage times at suppliers, at assembler, at customers and at service providers (especially at warehousing service providers):

$$T_w = tw_{ij} + tw_{ik} + tw_{il} + tw_{im} \ . \tag{10}$$

− *Transport time*

The transportation cost is the sum of transportation of each product on each relation of the network, between suppliers and final assembly and between final assembly and customers:

$$T_t = tt_{ijk} + tt_{ikl} \ . \tag{11}$$

Total cost objective function is the summation of all cost components given by Eqs. (8-11).

$$\boxed{f_2 = T_p + T_s + T_w + T_t} \ . \tag{12}$$

Constraints

− *Production- and service capacity constraint*

The production volume (Q_{ijt}) have to be limited by minimum and maximum volume at suppliers:

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

where: A_{ijt} - 1 if the raw materials and components of product i are produced at supplier j, otherwise 0.

The production volume (Q_{ikt}) have to be limited by minimum and maximum volume at final assembler:

$$Q_{ik}^{\min} \cdot A_{ikt} \leq Q_{ikt} \leq Q_{ik}^{\max} \cdot A_{ikt} \ , \qquad (14)$$

where: A_{ikt} - 1 if product i are produced at final assembly k, otherwise 0.

The service activity capacity (C_{imt}) have to be limited by minimum and maximum volume at service providers:

$$Q_{im}^{\min} \cdot A_{imt} \leq C_{imt} \leq Q_{im}^{\max} \cdot A_{imt} \ , \qquad (15)$$

where: A_{imt} - 1 if the given service activity at service provider m required for the production of product i, otherwise 0.

− *Inventory constraint*

Stock is one of the biggest wastes in the supply chain according to Lean philosophy, but this inventory provides the flexibility of the chain's member and the whole chain. Depending on the inventory strategy of the supply chain, the volume of inventories at manufactures and service providers have to be limited:

$$I_{ij}^{\min} \leq I_{ijt} \leq I_{ij}^{\max} ; \ I_{ik}^{\min} \leq I_{ikt} \leq I_{ik}^{\max} ; \ I_{im}^{\min} \leq I_{imt} \leq I_{im}^{\max} \ . \qquad (16)$$

− *Flexibility constraint*

Customers' needs drive markets nowadays in many sectors where responsiveness and flexibility have become key to compete and be profitable. A supply chain adapts the changes if it is flexible and agile in nature. Supply chain flexibility is increasingly important for increasing and maintaining competitiveness.

The VE is characterised by a dynamically forming and flexible network, so from a practical point of view the following flexibility constraints are defined for the chain members in the developed software:

− flexibility of the manufacturing system at the manufacturing companies (flexibility for building multiple models of different volumes within the same plant),

− flexibility of the IT infrastructure at members (operation of the VE is based on the intensive use of information communication technologies, enterprises need to adopt ICT tools for managing information flow),   (17)

− liquidity of the chain members (flexibility and beginning of a new project requires investment),

− flexibility due to the organizational structure of the chain members (fastness of decision making is depending on the size and type of the organizational structure of the enterprise).

These types of constraints are not easy to define, but these can be given by a value in a given interval (1-5).

Optimization method

Recently the optimization in case of <u>single objective</u> (cost or time) optimization has been performed by systematic search method.

During <u>multi-objective</u> optimization the normalized weighting method is used to show the weight of the cost- and time objective functions. The normalized objectives method solves the problem of the pure weighting method e.g. at the pure weighting method, the weighting coefficients do not reflect proportionally the relative importance of the objective, because of the great difference on the nominal value of the objective functions. At the normalized weighting method we reflect closely the importance of objectives.

$$f(x) = \sum_{\alpha=1}^{\lambda} w_\alpha f_\alpha(x) / f_\alpha^0 \qquad (18)$$

where: $f_\alpha(x)$ are the cost- and time objective functions, w_α is the weight of the cost- and time objective functions, $w_\alpha \geq 0$ and $\sum_{\alpha=1}^{\lambda} w_\alpha = 1$. The condition $f_\alpha^0 \neq 0$ is assumed.

These methods are absolutely relevant in the case of a small network, but for a huge network a more robust optimization algorithm will be applied in the future.

Software development for optimal design of Virtual Enterprises

Based on the elaborated theoretical model and method, software was developed for optimal forming of networks by the contribution of Márk Mihalik, an engineering student. The software was written in Java programming language. Java is a general-purpose computer programming language that is concurrent, object-oriented, and class-based. Java is a platform free programming language.

<u>Case study – problem statement</u>

In this case study (Figure 4) the supply chain consists of one final assembler (FA), four possible primary suppliers (S_{11}, S_{12}, S_{13}, S_{14}) and five possible secondary suppliers (S_{21}, S_{22}, S_{23}, S_{24}, S_{25}).
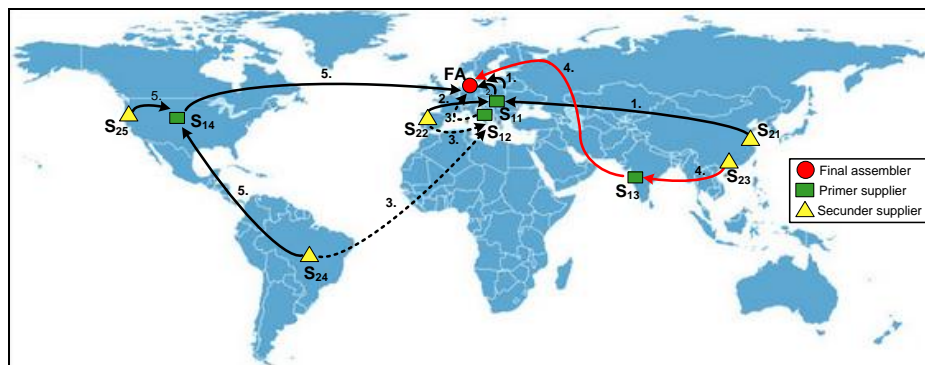

Figure 4. Possible supply chain combinations

Relations of possible suppliers and the final assembler can be defined by a relation matrix ($\underline{\underline{R}}$), the distances of different members can be given by a distance matrix ($\underline{\underline{L}}$).

Relation matrix:

$$\underline{\underline{R}} = \begin{array}{c} \\ 1 \\ \vdots \\ \\ \vdots \\ n \end{array} \begin{bmatrix} & & 1/0 & & \end{bmatrix} \begin{array}{c} 1 \; \ldots \quad \ldots \; n \end{array}$$

- *n:* identifiers of final assembler, possible primary- and secondary suppliers,
- value of *n* is 0 (there is not relation) or 1 (there is relation between members). (19)

Distance matrix:

$$\underline{\underline{L}} = \begin{array}{c} \\ 1 \\ \vdots \\ \\ \vdots \\ n \end{array} \begin{bmatrix} & & & & \end{bmatrix} \begin{array}{c} 1 \; \ldots \quad \ldots \; n \end{array}$$

- value of elements of $\underline{\underline{L}}$ matrix is the distance between the supply chain members [km]. (20)

It is assumed in the calculation that the unit production cost (cp_i) is 2.85 Eur/pieces in Asia and 5 Eur/pieces in Europe and in America. We also assume that the material cost (cm_i) is 5 Eur/pieces all over the world. The specific transport cost (ct_i) between Europe and Asia and Europe and America is 0.00012 Eur/Km (possibility of water transport), inside Europe is 0.00024 Eur/Km (road transport).

The objective function in the optimization is the total cost (eq. 7) and total lead time (eq. 12). In this case study the inventory cost and costs of services are not taken into consideration.

Optimization software

Figure 5 shows the main screens and the main menus of the developed software.

Figure 5. Main screen of the program

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

2.) In the menu "**Data for potential members of the supply chain**" (Figure 6) we can define the cost components, time components, capacities and constraints relating to the final assembler, suppliers and forwarding service providers.

Figure 6. Parameter setting relating to supply chain members

3.) In the menu "**Relations for members of the supply chain**" the relation matrix of the supply chain members (eq. 19), distance matrix of members (eq. 20) and transport mode000s used for good's flow can be given (Figure 7).

Figure 7. Parameter setting relating to relation of supply chain members

Objective function/s (cost or/and time) used during the optimization can be selected in the menu "Results of the optimization" (Figure 8). Flexibility constraints applied in the optimization can also be set in this menu.

Optimization in case of single objective optimization is performed by systematic search. During multi-objective optimization the normalized weighting method is used. The weight (importance) of the cost- and time objective functions can be set.

The result of the cost optimization in case of the case study can be seen in this screen. The possible combinations of members that fulfil the constraints can be listed in the screen.

The optimal supply chain formation in our case study is **FA – S$_{13}$ – S$_{23}$** (depicted by red line on Figure 4), when the total cost of one piece of a final product is minimal, only 27,4 [Euro/piece].

Figure 8. Results of optimization

Summary

The topic of the study very actual, because the most important economical processes, production philosophies (Push → Pull, Lean), novel supply chain conceptions (1. Lean-, 2. Agile-, 3. Leagile Supply Chain) were described and evaluated.

Due to the continuously changing environment and global competition new organization and cooperation forms were formed. Virtual Enterprise (VE) as a usual dynamic cooperation form of Agile Supply Chain was introduced, furthermore characteristics and advantages of VE were detailed.

The goal of the study was the VE network optimization, which means the formation of optimal combination of ideal chain's members.

The objective of the supply chain network optimization is to manufacture and deliver final products to end-users in the most cost-effective and timely manner, the total cost and total lead time of the supply chain have to be minimized during the optimization.

This study is original and unique, since an optimization method, consequently the objective functions (1. total cost, 2. total lead time) and design constraints (1. production and service capacities, 2. inventories at manufacturing companies and service providers, 3. flexibility of the supply chain) have been elaborated.

Based on the elaborated method an optimization software has been developed which can be widely used for single- and multi-objective optimization of micro- and macro regional networks. The single objective (cost or lead time) optimization was performed by systematic search method, during the multi-objective (cost and lead time) optimization the normalized weighting method was used.

By the help of the developed software an optimal micro-regional virtual network has been formed in a Hungarian micro-region in the frame of a R&D project. This VE is involving the optimal combination of enterprises of 3 counties.

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GLOBALNE ZMIANY GOSPODARCZE, OPTYMALIZACJA WIRTUALNYCH PRZEDSIĘBIORSTW - ROZWÓJ OPROGRAMOWANIA

Streszczenie: Zmiana otoczenia rynkowego, globalna konkurencja, gwałtowne wahania zapotrzebowania klientów i bardziej złożona globalna sieć łańcuchów dostaw wymagają nowych koncepcji produkcji (Pull, Lean) i technologii. Paradygmaty łańcucha dostaw (1. Lean-, 2. Agile-, 3. Leagile Supply Chain) są formami powstałymi w celu zwiększenia

i utrzymania konkurencyjności firm. Powstają nowe formy organizacji i współpracy. Członkowie Łańcucha Agile Supply Chain tworzą sieć wirtualnego przedsiębiorstwa (Virtual Enterprise, VE), która zapewnia szybkie i elastyczne spełnianie zmieniających się wymagań klientów. Celem badania jest optymalizacja sieci VE, co oznacza tworzenie optymalnej kombinacji idealnych członków łańcucha (firm produkcyjnych, dostawców usług i klientów). Przedstawione badania są oryginalne i unikalne, ponieważ opracowano metodę optymalizacji, funkcje celu (całkowity koszt i czas realizacji) oraz ograniczenia projektowe. Na podstawie opracowanej metody opracowano oprogramowanie optymalizacyjne, które można szeroko wykorzystać do optymalizacji sieci mikro- i makroregionalnych.

Słowa kluczowe: wirtualne przedsiębiorstwo, optymalizacja, całkowity koszt, całkowity czas realizacji, rozwój oprogramowania

全球經濟變化，虛擬企業優化 - 軟件開發

摘要： 不斷變化的市場環境，全球競爭，客戶需求迅速波動，更為複雜的全球供鍊網絡需要新的生產理念（Pull，Lean）和技術。新型供應鏈範式（1.Lean-2. Agile-3.Leagile供應鏈）是增加和保持公司競爭力的形式。形成新的組織合作形式。敏捷供應鏈的成員形成虛擬企業（VE）網絡，支持快速靈活地實現不斷變化的客戶需求。研究的目標是VE網絡優化，這意味著形成理想連鎖成員（生產公司，服務提供商和客戶）的最佳組合。這項研究是原始和獨特的，因為已經闡述了優化方法，目標函數（總成本和交貨時間）和設計約束。基於詳細的方法，已經開發出可以廣泛用於微區域和宏觀區域網絡優化的優化軟件。

關鍵詞： 虛擬企業，優化，總成本，總時間，軟件開發