Methodology of Optimising Complex Logistics Supply Networks

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Abstract: This article is aimed at introducing the technical-economic analysis of the efficiency of complex logistics networks and the methodology of their optimization by the means of experiences of practical examples.

Keywords: supply networks, supply chain, optimization, genetic algorithm, distribution system

1. Introduction

The analysis and optimization of the efficiency of supply and distribution networks operating in value production chains is a complex technical-economic problem, in which the realisation of the optimum calculation criterion and target-function system is quite a difficult task. Beside this, the discovery of the optimal solution complying with the criteria is also not a trivial question. Decisions aiming at an occurrent modification of the network structure are long-term in the lives of corporations and basically determine future costs related to the operation of the network [4], [8], [10]. Researches have been performed for a relatively long time with the aim to experiment such methods and policies by the means of which decision support can be realised in specific situations like this. Our article examines a procedure recently developed by us that we have already successfully applied, several times, in the case of restructuring the network structure of multinational corporations in Hungary.

2. Analysis methods of operational efficiency of an existing network

We find it essential to review those basic purposes that motivate such complex examinations in corporate practice based on our experience:

- Is the number of depots sufficient (too many or too few)?

- Is the spatial dimension of our warehouses appropriate? If not, where should we build new warehouse(s)?
- Is it ideal to operate the current system in a centralized or decentralized structure?
- Is the vertical and horizontal structure of the network appropriate?
- What procedures should we outsource or insource out of or in the range of the corporation (out- and insourcing questions)?
- What indicators do we measure with the fulfilment of service level agreements in regards to outsourced procedures?
- What logistic standards should we provide our customers with?
- What product transportation methods should we apply? What vehicle fleet should we fulfil transportation tasks with?
- Which customers and products are preferable or non-preferable?
- Do we apply appropriate inventory strategies?
- Other specially occurring questions not listed here (e.g., the localization of the production plant).

Considering the above list it can be stated, that the method of complex evaluation can be expedient to apply in addition to the strategic questions in the case of the regulation and refinement of operative procedures. Furthermore, it is important to note that our article primarily examines the problem of existing networks; similar problems might occur not only in the case of existing networks but in the case of networks to be created as well. The above questions should be seen from a different view, and from a different approach.

2.1. The specification of base data

In accordance with the questions listed above, a number of basic base data is required from a technical point of view to set up a decision model capable of handling the problem. Based on our experience, gathering the data groups related to the following seven topics is recommended:

1. Basic technical, technological characteristics of *production places*, plants as the sources of the supply network essential from a logistic perspective are …

   the spatial dimension of the plants, data related to its technical condition, the characteristics of transport connections, the characteristics of production capacity and output.

2. Basic technical, technological characteristics of warehouses essential from a logistic perspective operating in the current supply network (either their own or provided by the supplier), out of which emphasizing those essential are…

   the spatial dimension of *warehouses*, data related to its technical condition, the characteristics of transport connections, the technology of goods receipt, inventory, commissioning, goods release, the basic receipt and release characteristics, and expansion options of the area/buildings.

3. Basic technical, technological characteristics of *product transportation system* (either their own or provided by the supplier) essential from a logistic perspective that is…

   basic data, loading machinery, product transport technology and receipt characteristics related to transport vehicle, loadability, equipment, operation characteristics and other occurrent specialties.

4. *The basic characteristics related to network infrastructure, in the case of which the following have to be gathered*…

   different road network and geographic features related to applied (and currently applicable) product transport methods, in consideration of supplied areas.

5. Data groups related to moved, shipped *products*, in the respect to which are especially important…

   the so-called logistic characteristics of the products, i.e., primarily the physical parameters of those, in consideration of the data of the applied packaging system (package units, shipping units, standard cargo, currently the applied intermodal unit) and of the different product handling technicalities.

6. The basic characteristics related to the *supply claimants* as the swallowers of the supply network that is…

   the spatial dimension of the supply claimants, technical, technological terms of goods receipt, and occurrent specialties related to the supply procedure (e.g., is there a transport timeframe system).

7. the characteristics of *IT solutions* applied in the management of the supply network are…

   specialities of the applied ERP's, corporate IT systems, their connection methods, data exchange solutions, the operative management systems currently applied, and solutions (e.g., patch editor systems, SCM monitoring systems, warehouse management systems, etc.).

The characteristics related to the listed characteristics feature the applied solutions of the existing network structure in the form of quantitative or qualitative data and can be integrated into the procedure of network optimization directly or indirectly, but they are absolutely inevitable in respect to the qualification of the existing network. We can work with a number of data from the ones above during the qualification that cannot be or can hardly be integrated into an optimising decision model, but can definitely be considered by the means of a certain correction during the evaluation of the results provided by the optimum-seeking model. That is they can affect the optimal build-up of the planned network.

The input data of *economic examinations* can be very complex, similar to the technical optimum seeking tasks. The following economic-type base data are required for the exact modelling and for the evaluation based on it (referring to the examination period defined in the preparatory stage of the work):

1. Sales/ production / turnover data;
2. Economic data related to inventory;
3. Economic data related to transportation;
4. Other costs data.

Basic data can be obtained in the form of questionnaires, spreadsheets, personal interviews and specific questions during the preparatory work. Here is a possible specification of the above cost groups as an illustration in the following table.

Table 1. Main cost groups applied during the examination

Transportation costs	Site / store costs
Rolling costs	Hiring fee of real estate
Fuel costs	Compensation of site employees
Tyre costs	Costs of warehouse machines
Service, maintenance	Costs related to the operation of the site (overhead)
Other service costs	Communication (telephone) costs
Vehicle amortization	IT costs
Compensation of vehicle employees	Tax-like costs (industrial tax, communal charge, etc.)
Tax-like expenses	Advertisement costs
Weight tax, insurances	Cost of tied-up capital
Plant running costs	

Sales and stock data downloaded from the sales and stock registration system supply the input data of turnover and inventory analysis. It has to be noted that these databases have deficiencies in a number of cases (e.g., inconsistent data, lack of movement types, unnecessary redundancies, just to mention a few), so the composition of a head database that is applicable for further analysis is a single technical task.

This data is in a close relationship with the technical characteristics, they cannot be examined apart in certain cases. It is also important to emphasize that it is not expedient to work only with costs registered by an accounting (that is only quantitative) perspective in the case of such examinations in the calculation of logistic expenses, but it is worthy of applying a controlling-type approach, where the procedure approach that is the identification of certain costs by cost centre is determinative. It follows that the obtained values cannot be compared directly with the annual financial statements; they can only be used together by applying careful interpretation and correction factors.

2.2. The modelling and optimum searching procedure

After the specification and collection of the base data, what follows is the build-up of a model complying with the methodology of the examination, during which we build a supply network model of mapping the current situation. It depends on the depth of the examination, the givens of the network and the specialities of the procedures to be modelled of how complex if a model should be created, and what data can be neglected. Our experience shows that production companies participating in different global supply networks emphasize the question in the point of the networks operated by them and in what way do the manufactured products produced by them reach the end users. A typical example of this is the new FMCG sector, where the efficiency of the developed network is of basic importance, as the competition is very strong, and there is a huge number of wholesale and retail companies trading the products of competitors as well. Thus modelling can be a quite complex task, as the types of the different supply channels belonging to different sales methods can vary quite a bit. Based on our experience it can be said that due to the industrial peculiarities and differences it is hard to develop such system that can be applied to all cases, hence the modelling of the network is a single task in all cases, only principles, the process of modelling and optimum-seeking methods can be stated. The basic purpose in all cases, during the optimum-seeking process, is that both the qualification of the current situation and optimum-seeking should happen based on: combined technical-economical views, an opportunity to examine as many alternatives as possible, and the selection of the optimal solution. The process of the modelling is examined in figure 1.

It is quite essential during the modelling and optimum-seeking process that the qualification of both the current and planned network structures should be performed by the same technical-economic terms and applied methodology, as we can evaluate compared to what and how much better results can be achieved by the reconstruction of the network. This process is called qualification procedure. Below we demonstrate the network optimization procedure applied by us by the means of a food industrial example. A model of such a typical network is demonstrated by the figure (no. 2) on the next page. It can be seen in the figure that such a complex network has to be optimized, in which „$i = 1...n$" (usually with a position fixed in space - refer to the exemption below) production plant is given, and given are the examined elements of the supply channels, that are…

- key accounts (KA's for short, e.g., TESCO, METRO etc.) in the case of which central warehouses with fixed positions, and shopping centres with fixed positions are supplied from these,
- wholesalers in the case of which the given wholesale warehouses with fixed positions, and retail units area supplied by these, and

- HoReCa's (i.e., hotels, restaurants and café's) in the case of which sales points with fixed positions.

Practice shows that in most of the cases the *base questions* are the structure of the distribution warehouse network (how many warehouses should be built, where and of what capacity?) framed in a broken line in the figure with the number „ $j = 1...m$ ”. And it should be decided whether it is optimal to have these operated by their own operation or by logistic supplier. However, according to our experience, this base question can be complemented with other additional decision problems too. This can be e.g., the dilemma in which the existing network elements of the supply channel should be used by the planned supply network to supply consumers.

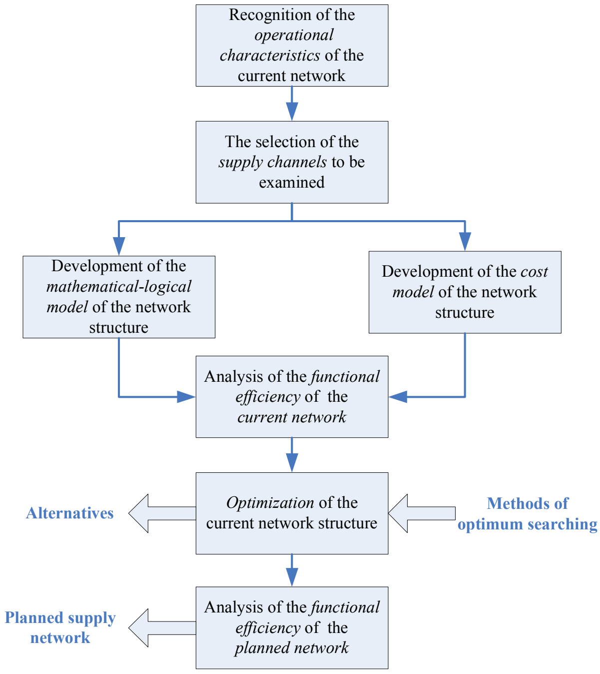

Figure 1. The process of the network structure's function and optimization.

The network modelled and to be optimized can be in fact imagined as a controlled graph in which the junctions are the elements of the network (e.g., plant, distribution centre), and the edges show the existing connections between the junctions (e.g., where from is each product shipped to). Each of the junctions and edges has their own special characteristics. The characteristics can be interpreted by the analysis and systematization of the above base data. These should be fully taken into consideration in order to achieve as precise results as possible during the optimum-seeking process.

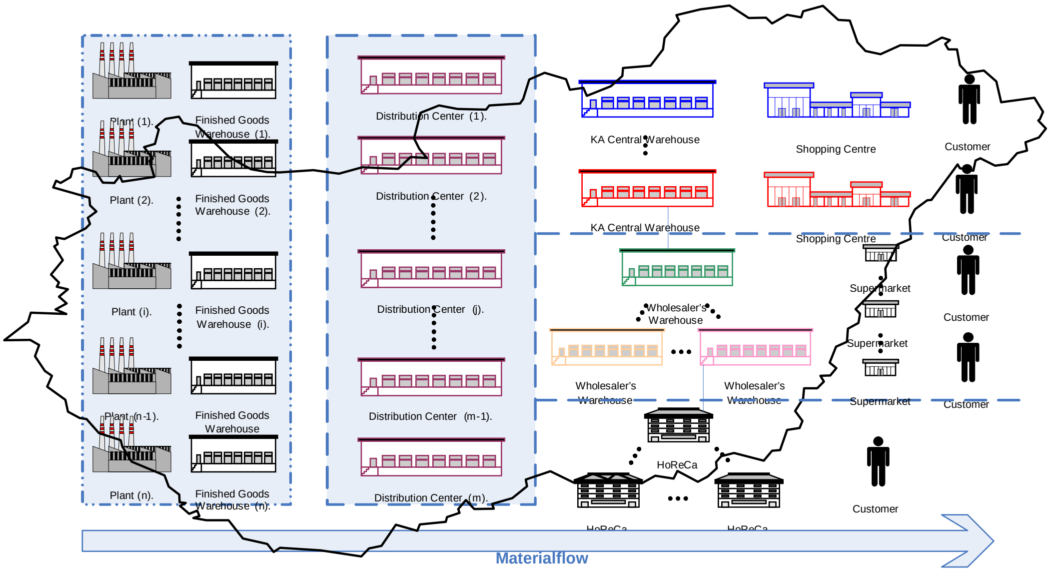

Figure 2. Diagram of the examined supply network.

3. Introduction of the optimization of a modern supply network

The complexity of the modelling and optimum-seeking task can be sensed from the above. It is considerably difficult to create an optimising model that takes into consideration all quantitative and qualitative parameters but in some regards quantitative factors from the base data listed above the mapping network characteristics in one level. Simplifications have to be applied during the development of the mathematical-logical and costs model, and the optimum-seeking process is expedient to be realised in several levels. For the sake of simplicity in our article we have only examined the case where the *base question* defined at the end of subsection 1.2 has to be answered. Even in this relatively simple issue the optimization of the network structure can be a quite complex question. One of the well-tried methods in the optimization network structures is the seeking of the minimum of storage and transport costs [4], [8], [10]. In the course of calculations it is expedient to proceed from those physical processes that realise logistic performance in the network. The target function of optimum seeking has to be mapped from the estimated value of these transport and storage performances reflected to the network and by the means of aggregated costs calculated from these after the calculation of specific costs.

$$C_{logistics} = C_{transport} + C_{storage} \Rightarrow MIN! \qquad (1)$$

3.1. The estimation of transport and storage performance, the optimization of network resources in several ways

To estimate the logistic performance related to the supply network such a function should be applied by the means of which logistic values related to transport and storage processes can be approximated as simple as possible. The bases of these calculations are provided by the base data already defined above (unfortunately incomplete in several cases). The outputs of calculations should be interpreted as the input parameters of the target function defined in (1.) that is the aggregated costs related to the network can be produced by the means of a relatively simple substitution. The base data to be applied (characteristically aggregated on a yearly basis) shall be aggregated to settlements as the preparation of the calculations in regards to the examined supply channels ($t = 1...x$), as the model does not handle the certain network elements separately, but as a simplification it aggregates the interests represented by them to geographic geo-codes. Hence an aggregated „I_t” interest can be calculated to e.g., each settlements (geo-codes). It is also an essential base data of how many alternatives we wish to examine during the optimization of the network and what basic characteristics these have. The most important of these is that how many sectors (m) do we wish to categorize the aggregated demand into. Further preparatory measures are as follows:

1. The development of the raster-network based on the geographic characteristics of the examined are (e.g., Hungary) the aim of which is the further territorial categorization of the settlements, their mapping of interests, and the further simplification of the examination. The number and the development of the rasters ($r = 1...y$) depend on the characteristics of the supplied area to a great extent. An example is demonstrated by figure 3, in which each settlement demand points are noted by a blue circle, a certain „t_r” number of demand points belong to a raster, and the demand aggregated to a raster is noted by „I_r” herein after.
2. The obvious assignment of centre areas (rasters) and the settlement of rasters determined by the location of production plants, the aim of which is to appoint „m” number of rasters including district- or distribution centre and „n” number of rasters including production plants incidentally.
3. The clusterization of settlements by the means of the developed raster-network by minimising the straight line distances (s_{jr}) between the centre of the base centre areas and the raster-centres, the aim of which is the categorisation of interest aggregated to rasters „I_r” into a number of districts depending on the examined alternatives.

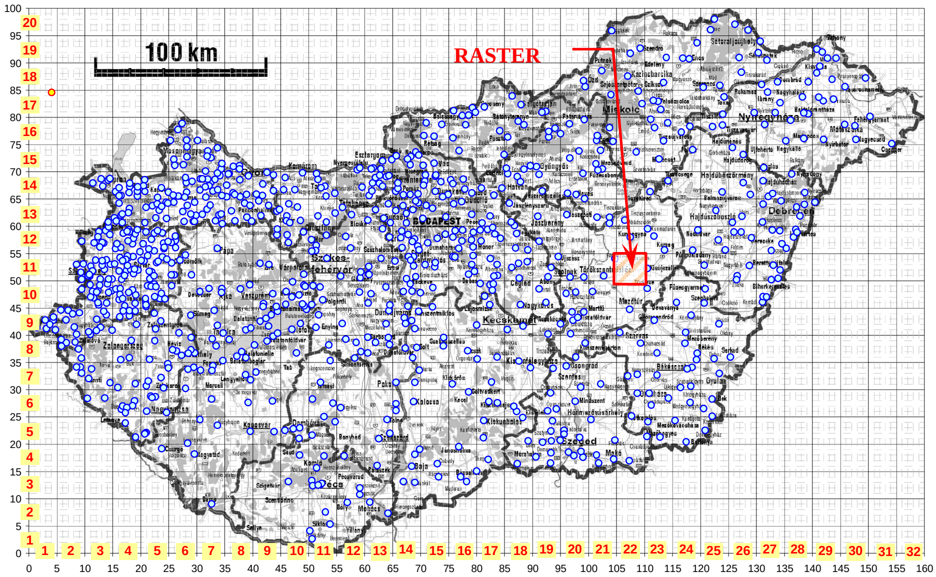

Figure 3. An optional solution to the raster

The optimization of the network occurs in *two steps* after the preparations. First a so-called *centre-seeking* [7] shall be performed by the means of an iteration process in regards to the „m” number districts that is we should decide starting from the accidentally adapted district categorisation which settlements will be supplied from which central warehouses and where these warehouses will be located. Iteration is performed by *a genetic algorithm combined with local search* [6] in which we have performed the local search with the *centre seeking* [5] of Jándy. The location of the centre area and the capacity of distribution centres realised in it changes continuously during iteration due to the „clusterization” of the demand. The stopping of this „movement” and the process of „realignment” means the end of iteration (this is the optimum). Special iterational standards (originating from the characteristics of the generic algorithm) provide the opportunity to measure this. The definition of the so-called *distribution transport performance* gives the target function of the optimum-seeking process. It is an essential boundary condition that the demand of any „t” demand point belonging to raster „r” can be fulfilled from a certain distribution centre in all cases that is any raster number „r_j” (and „t_j” number demand point) defined can belong to any j centres that is

$$\sum_{j=1}^{m} t_j = x \quad , \qquad (2)$$

and

$$\sum_{j=1}^{m} r_j = y \quad , \tag{3}$$

is realised.

Furthermore, any centres to be realised should be of unlimited capacity (e.g., a greenfield site) that is any size of demand can be assigned to it. So that the target function can be put down in the following form:

$$P_{transport}^{distribution} = \sum_{j=1}^{m} \sum_{r=1}^{r_j} I_r \cdot s_{jr} \Rightarrow MIN! \quad , \tag{4}$$

where

$$I_r = \sum_{t=1}^{t_r} I_t \quad . \tag{5}$$

The outcome of the first optimization step is the position of the optimal centre areas (refer to figure 4 - the size of the „bubbles" is proportional with the demand aggregated to the raster), and the output intensity of the distribution centres to be placed on them, which can be put down in:

$$I_j = \sum_{r=1}^{r_j} I_r$$

(6) form.

Network resources shall be optimised by the solution of a so-called *assignment*, also known as *transportation* problem [1], [11] as a second step that is it has to be decided which distribution centres have to be supplied from which production plant by the location and the output intensity of the production plants (I_i) given, and the material demand of a certain distribution centre can be fulfilled from different production places at the same time. This process is called inventory and it is characterized by the so-called *inventory transport performance*. The optimisation of the resources means the solution of a simple linear programming task, which can be solved by any simple application that can perform optimum seeking (e.g., MS Excel Solver). The target function can be put down in:

$$P_{transport}^{replenishment} = \sum_{i=1}^{n} \sum_{j=1}^{m} I_{ij} \cdot s_{ij} \Rightarrow MIN!$$

(7) form, where

I_{ij} : the intensity of material flow between (i) production place and (j) distribution centre;

s_{ij} : the distance between (i) production place and (j) distribution centre.

The outcome of the second optimization step is the *aggregate transport performance* of the distribution and inventory performance related to the network, which can be calculate as follows:

$$P_{transport} = P_{transport}^{distribution} + P_{transport}^{replenishment} . \tag{8}$$

Figure 5 shows the development of aggregated transport performances in the case of certain alternatives (different area codes).

In the measurement of the *aggregated storage performances* the planned inventory, storage and release and/or commissioning performances necessary to operate the planned supply network shall be basically taken into consideration. These characteristics can be characterized as a result of a complex optimum-seeking task similarly to the above. The inputs of the calculations will be the results of the above optimum-seeking methodology (related to the transport system), the functional parameters (e.g., planned inventory turnover speed) demanded from the planned system (defined in advance) and the output results of the statistical examinations performed on the base data.

However, as these optimum calculations result from the solution of the fairly complex and complicated optimum seeking tasks (refer to [3]) only the most essential outcomes of these calculations are demonstrated due to the limitations of content being presented at this time:

- inventory and release performance:

$$P_{stockpiling} = \left[\frac{\text{stockpiling}}{\text{period}}\right],$$

$$P_{release} = \left[\frac{\text{release}}{\text{period}}\right],$$

- planned average inventory level:

$$Q_{average} = [\text{quantity unit}] ,$$

- order picking performance:

$$P_{order\,picking} = \left[\frac{\text{picking}}{\text{period}}\right].$$

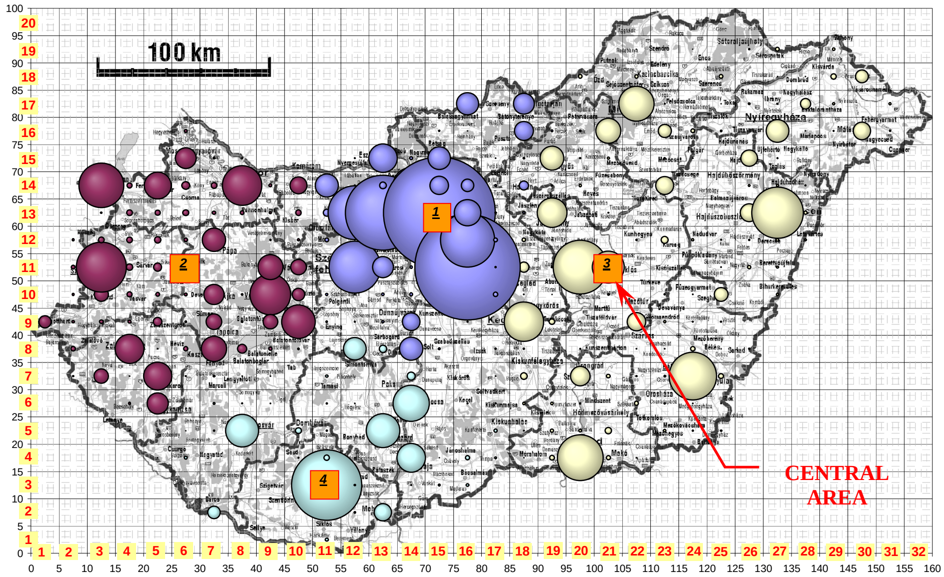

Figure 4. The optimal solution of a centre-seeking problem of four districts

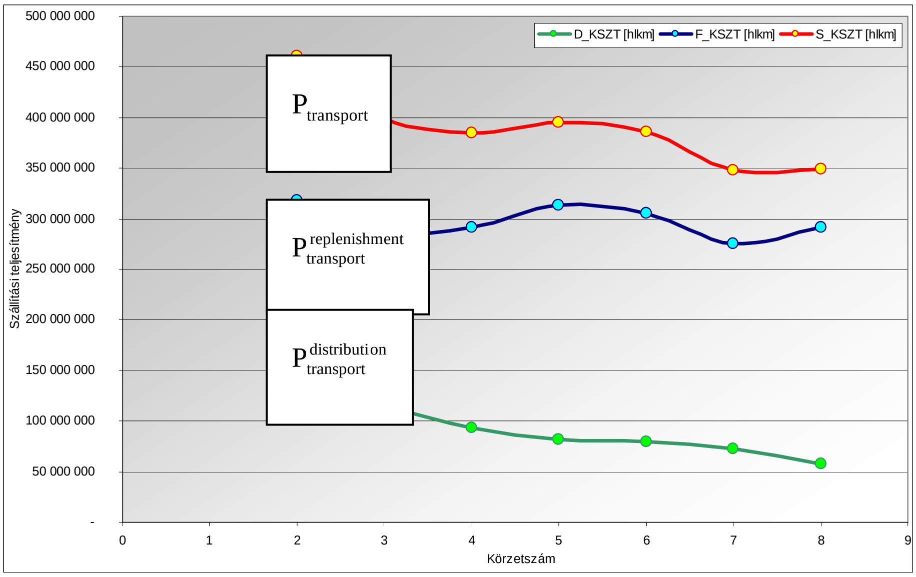

Figure 5. Transport performances belonging to certain alternatives

3.2. Costs related to solution alternatives

Performance has to be taken into consideration as defined in (8) at the calculation of complex transport performance. The dimension of quantity and period can be different (e.g., hl, pcs, and year, month, etc.), considering the specialization of the certain company. With the help of the methodology outlined in the previous section, the detailed logistic natural characteristics of a certain part process (e.g., hl-km/year dimension) are available and the specific costs (e.g., HUF/hl/km) can be created by the means of database analysis during financial examinations, by simple calculations, by the means of developing logistic and financial models of the historic performance and of cost data. The costs related to the certain process from either the costs side or the performance side and the filtering of characteristic activities is a challenge. In staying with our example, to determine the inventory, transport performance and costs in the past, e.g., the performance of cross-docking activity and the costs to be allocated to it have to be determined and have to be left out of consideration. The fraction-type specific indicators costs (counter) side can be generated by the means of the corporate costs-registration systems and supplementary expert estimations. The past transport performances in the denominator are unavailable in most of the cases, as e.g., in the case of transport to be performed by subcontractors, the companies don't register the exact running performances, so that e.g., hl-km type indicators cannot be generated. Hence the model outlined above is applicable to estimate past performances as well - indicating the versatile applicability of the model to these types of problems -; running with fixed centres adequate to the situation in the past (with distribution centres). The simplified draft of the above method is demonstrated by the following figure (no. 6).

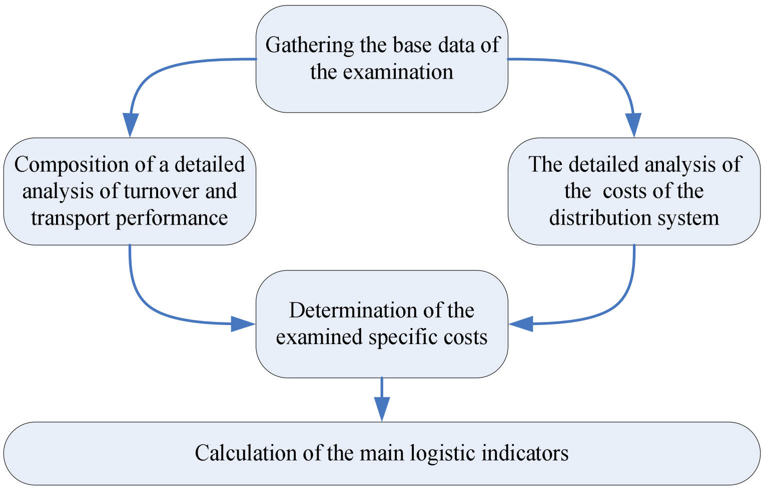

Figure 6. The relationship between the methodology used during the analysis and the calculations and the base data required for the calculation and the result indicators.

The estimated specific transport costs to be generated by the aggregated transport costs and natural terms [HUF/hl/km] indicator. The different accounting costs are divided into *fix* and *variable* costs at the definition of storage costs. The value of the alternative costs of the tied-up capital in the stock related to the examined period can be calculated by taking as a basis the average inventory values and the rate of interest of the alternative investment (characteristically around 10% in the recent years). Variable costs are

$c_{\text{stockpiling}} =$ [HUF/hl/year],

$c_{\text{store-in}} =$ [HUF/loading unit],

$c_{\text{store-out}} =$ [HUF/loading unit], and

$c_{\text{order picking}} =$ [HUF/picking].

These types indicators are the result, which are then multiplied by the natural values stated in the previous section and we get all the variable storage costs of the examined alternatives. In addition, due to the peculiarity of the storage system, the sites also have *fix costs* ($C_{\text{storage, fix}}$) that are independent from the realised turnover and grow almost linear with the number of sites. The transport and storage total costs of the certain alternatives can be determined by the means of the natural output of the network model and the specific costs mentioned above, and all of the logistic costs of the corporation produced as the total costs of these are:

$$C_{\text{logistics}} = (c_{\text{transport}} \cdot P_{\text{transport}}) + C_{\text{storage, fix}} + C_{\text{storage, variable}}, \tag{9}$$

where

$$C_{\text{storage, variable}} = c_{\text{store-in}} \cdot P_{\text{store-in}} + c_{\text{stockpiling}} \cdot Q^{\text{stock}}_{\text{average}} + c_{\text{store-out}} \cdot P_{\text{store-out}} + c_{\text{order picking}} \cdot P_{\text{order picking}} \tag{10}$$

You can analyse the effects of the change of certain input parameters by so-called sensibility-examinations. It is important to note that such type of elasticity examinations are valid in certain environments, consequently the bigger scale modification reduces the reliability.

Methodologically a number of *notes essential* to the practice need to be added to the above:

- It can be often useful to verify the outcome results by detailed on-site surveys besides data request, and to gather missing data, as we have noted before, the frequent deficiency of corporate information systems might cause serious problems

- It is also important to emphasize here that it is expedient to include activities of the broadly considered logistics into the processes of logistics, e.g., the elements of marketing activities related to general corporate management and distribution as well. According to our experience, the entire logistic costs of trade companies that calculate it this way is 0,5-2% higher in comparison with the total turnover, depending on what cost centre we allocate the certain cost elements to. This interpretation approach of logistic costs is justified by the fact that the activity of the certain participants and the related costs also form the inseparable part of the total value-production process within a given supply network
- The standard methodology approach is also justified by the fact that based on the results produced by the means of this, the logistic performance of the company becomes not only valuable, but commensurable as well with the similar indicators of other companies of the same profile (benchmarking)
- The following indicators have to be emphasized in the evaluation of the development of costs:
    - Economies of scale: as in the case of all economic processes, the principle of growth of returns to scale might affect the economic efficiency to a significant extent, to come up with a theoretical example, a regional or a country distribution can be characterized with different values from a scale economies perspective
    - Significant scale and variability of site costs:
        - Due to the settlement peculiarities of the classic accounting systems, the larger part of the costs is allocated to the sites. Hence site costs are usually more significant than transportation costs. On the other hand, while no significant differences can be experienced in transportation costs at a country level, costs related to real estate may vary (even to a ratio of 1:3)
        - The affect of the change of certain on-site cost elements to certain logistic costs aggregates (e.g., inventory costs) can be analyzed by the means of a flexibility examination due to the usual “overlap” of the trade/production and logistic function on a site (the costs of each activities cannot be exactly distinguished and divided)

3.3. The selection of the optimal decision alternative

Seeking the solution of the optimal network development means in fact the selection from the examined decision alternatives. It is quite essential to perform the qualification of the current network structure prior to the selection (by the method defined above) by the application of the developed mathematical-logical and costs model. The primary aim of this is that the efficiency of optimum seeking can be measured in comparison to the current situation that is there should be a base of reference. The qualification can be easily performed by substituting the performance parameters characterizing the current network, calculated from the base data into the (8), (9) and (10) functions above. The total logistic costs calculated by the method defined in (9) is the primarily examined characteristic during the selection process as the result of the above process, however the selection can be „burdened” (but at the same time disburdened too) by a number of other characteristics (e.g., infrastructural factors, workforce supply, growth factors related to the examined area, etc.) as well, that can be taken into consideration in either quantitative or qualitative forms. Characteristically the main view is to emphasize directly „cost-able” factors that are collaterally considerable in the first round, so that an aggregated cost can be calculated, which is closer to the cost of the examined alternative by superponating to the aggregated logistic costs in the form of aggregated „other costs” (C_{other}). Finally, other factors can be taken into consideration by the means of value analysis measures supporting the multi-factor decision-making [9], [11], by the means of which optimal decision alternatives (occurrent alternatives) can be appointed.

4. Conclusions

We have participated in a number of innovative researches (e.g., [2]) in which we had to develop such methods and procedures given by multinational corporations with a significant infrastructural background and long history where the application of which could answer the question how can the optimal structure of a supply network with pre-defined functional parameters and boundary conditions be planned or re-planned. It has been proved during the research that the handling of the complex modelling problem examinable from many perspectives is a quite complicated task, as the „beauty” of such problems given by its uniqueness that is in all cases its most serious „enemy” of the development of such modelling systems and tools, that can be applied successfully under all circumstances (e.g., in the case of two corporations with different logistic background). There obviously are such factors and processes that show significant similarity in the structure and operation of supply networks, however it can be said that the technical „fineness” and novelty of the models developed by us so far arose due to the differences in most of the cases. Based on our research and on the experiences from the concrete network optimization projects it can be said that the logic of modelling and the applied optimum-seeking logic and the applied procedures can be shaped quite well, but we are (contrary to many others) considerably sceptical in regards to the possibility of the development of a software by the means of which any network modelling, and optimum-seeking problem can be handled.

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