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BUDAPEST UNIVERSITY OF TECHNOLOGY AND ECONOMICS
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ENGINEERING

**SYSTEM MODEL OF ELECTRONIC FREIGHT AND
WAREHOUSE EXCHANGE**

PhD Theses

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1. PRELIMINARIES

In our days, with the help of the Internet, information can be sent to the participants of business processes in the fraction of a second, which, by accelerating and optimizing these processes, facilitates an easy overview and comparison of supply and demand. The possibility of the fast online business connection was the most promotional factor of the spread of e-commerce (to sell multiple products, for example with using web shops, online auction, electronic marketplaces). In these days, the proportion of e-commerce increases worldwide, both in value and in volume.

At the end of the nineties, concurrently with the spread of e-commerce, electronic marketplaces have emerged in numerous fields, such as freight exchanges in the field of carrier services, and warehouse exchanges in the field of storage services. *WANG, POTTER* and *NAIM* [FB37] emphasize the significance of the electronic logistic marketplaces. *GÜNTHER* and *CRACKE* [FB19] mention that the freight exchanges are important subfields of the e-commerce. *MCKINNON* writes that the online freight exchange is a momentous innovation [FB26] and a potential tool to decrease the empty runs [FB28]. The earliest and the most popular form of these exchanges is the so-called electronic freight exchange, in which consigners can advertise their freight tasks for shipment in the catalogue of the marketplace; similarly, freighters can make their bid for cargo holds. *NANDIRAJU* and *REGAN* [FB29] write that using catalogue and auction is a potential form to choose the most suitable offer. *IHDE* [EC8] proposes a specific auction method, which can be applicable in electronic freight exchanges. The less common warehouse exchanges - similarly to freight exchanges - sell free warehouse space/task either with a simple advertisement or by using an application which enables search function. *ZAPP* [FB41] presents the basic tasks of the electronic freight exchanges. The most complex form, these days is, when both freight and warehouse exchanges occupy a single online surface.

The main objective of the electronic freight and warehouse exchanges is the exploitation of the modern information and communication techniques. The electronic freight and warehouse exchanges facilitate a forum for logistic providers to advertise their service supply, such as transport and storage capacities (on the worldwide web); whereas consigners can choose the offer, which best suits their needs. Moreover, the consigners can display freight tasks and storage tasks, and logistics providers can choose the most suitable offer, too. Such exchange types enable to get hold of freight and warehouse capacities for goods relatively easily, and to find a transport or storage commission. There is possibility to increase the utilization of vehicles and warehouses, as well as to reduce the logistic costs.

Nowadays the most widespread form of electronic freight and warehouse exchanges on the Internet can provide only a single advertising surface for both the consigner and the logistic provider. More sophisticated electronic freight and warehouse exchanges can ensure the advertising of freight/storage capacities/tasks, as well as the filtering and evaluation of these by putting in a separate application. However, even these online freight and warehouse exchanges focus only on displaying and searching for offers in a catalogue format, and they do not ensure other forms of transactional solutions (for example tender, auction). *ALT* and *KLEIN* [FB3] write about the deficiency of available electronic freight and warehouse exchanges. They mention that the correct and detailed system plan is the most important factor, because the current exchanges are poor quality. *BOKOR* mentions [FB7] that the Internet as a new business communication opportunity is used by almost all logistics providers, nevertheless the advanced logistic e-business (for example interactive electronic freight exchange) solutions work just as a pilot project.

Therefore, the greatest shortcoming of the current electronic freight and warehouse exchanges is that those do not use the modern methods of the information technology, e-commerce, operation research and optimization. The most electronic freight and warehouse exchanges work as a simple “web-shop”. Still there has not made a complex and detailed system model of electronic freight and warehouse exchanges, which presents the new services and applications.

On the current electronic freight and warehouse exchanges, there is not available the selection of the best offer based on multi-criteria decision supporting algorithms. These algorithms are able to solve the occurring decision problems. In the database of electronic freight and warehouse exchanges there is high number of freight and storage capacity offers and tasks, which provides good optimization opportunities (route planning). Nevertheless, it can not be found mentions or realizations neither on the online exchanges nor in the literature.

However, the basic task of electronic freight and warehouse exchanges is to match capacities and demands, despite the potential, the complex logistic problems are not supported by the electronic freight and warehouse exchanges. These opportunities are mentioned in the literature but are not used in the practice. The electronic freight exchanges are used only in the field of road transport; other possibilities are either primitive (for example rail) or unexamined (for example combined transport, city logistics). *BRUNS, GÜNES* and *ZELEWSKI* [FB9] suggest that the electronic freight and warehouse exchanges can be applicable to improve the utilization of wagons. *JONKMAN, TANIGUCHI* and *YAMADA* [FB24] write that an e-auction system may be suitable to eliminate the negative effects of urban transport of goods. *HOLGUÍN-VERAS* [FB23]; *HAYASHI* and *YANO* [FB21] regard the vehicle utilization (reduction of empty runs, organization of back haul) as the most important advantage of the development, but they also mention that such electronic communication sites are perfectly suitable for organizing collecting-distributing routes, as well.

The detailed analysis of the used literature can be read in my dissertation, the references are visible in chapter seventh of this booklet ([AC1]...[AC17]: ant colony algorithm and optimization; [EC1]...[EC24]: e-commerce; [FB1]...[FB41]: electronic freight and warehouse exchanges; [MD1]...[MD31]: multi criteria decision supporting).

2. OBJECTIVES

The current available electronic freight and warehouse exchanges ensure improvement mainly in the field of demand/supply connections. But in addition, there are further development opportunities, such as tendering logistic providers, decision supporting, exploitation optimization, supporting complex logistic processes which are set back by underutilization of modern information and communication (I+C) technologies.

Therefore, the main objective of my research is developing the complex system model of electronic freight and warehouse exchanges, which is able to realize the efficient freight/storage supply/demand connection, based on modern e-commerce toolbars and manifold decision supporting/optimization algorithms. Moreover, my aim is to prove that the use of electronic freight and warehouse exchanges is expedient and promising. In addition, my purpose is to develop algorithms, which are able to support complex logistic processes and which are well suited in the practice.

3. METHODOLOGY

The complex *e-commerce (catalogue, auction, tender) toolbar* based on the literatures is an important part of the developed system model ([EC8], [EC10], [EC12], [EC15], [EC16], [EC17], [EC18], [EC19], [EC22], [EC24]).

The emerging decision problem (how to choose the best freight/storage task/capacity) can be solved with the self-developed *multi criteria decision supporting algorithm (MDA)*. MDA based on the principle of the *AHP (Analytic Hierarchy Process)*; (*SAATY* [MD17], [MD18], [MD19], [MD20], [MD21], [MD22], [MD23], [MD24], [MD25], [MD26]). MDA enables to determine the weights of evaluation aspects under examination in mathematically correct way, and then as a result the offers get a weighted performance value, where the most favourable offer has the highest value. In addition, the mathematical *maximal sensitivity analysis* is also an important method, which helps to calculate a percentage value, what features the rate of sensitivity (*PÉTER* [MD10], [MD11], [MD12], [MD13], [MD14]). Furthermore, I utilized other numerical methods to generate weights, too. Thus, I used the *FADDEEV method* ([MD4], [MD5]) and the *secant method* [MD1], to calculate the eigenvalues of the pairwise comparison matrix, as well as the *Gaussian elimination* ([MD6], [MD7], [MD8]) to calculate the eigenvectors of the pairwise comparison matrix (this gives the weights of the aspects).

There are lot of optimization problems in the electronic freight and warehouse exchanges, for example route planning and utilization optimization. These problems can be solved by *ACO (Ant Colony Optimization)*, which is a metaheuristic optimization algorithm developed by *MARCO DORIGO* based on the modelling of the ants' social behaviour ([AC3], [AC9], [AC10], [AC11]). In nature ants search for food by chance, then if they find some, on their way back to the ant-hill they mark the way with pheromone. Other ants - due to the pheromone sign - choose the marked way with higher probability instead of accidental wandering. In the electronic freight and warehouse exchange similar problem emerges as the ants' search for food: the target is the performance of freight tasks offering the higher profit. Based on this, the results of the solution variants will be important parts by creating new variants, in the course of later iterations.

I used the principle of the ant colony algorithm in the creating of optimization method which can support complex logistic processes (city logistics, combined transport); ([AC3], [AC9], [AC10], [AC11]).

4. NEW SCIENTIFIC RESULTS

I developed the following new scientific results, which can be read in my dissertation in details.

1) I created the complex modular information system model of the electronic freight and warehouse exchanges.

The current electronic freight and warehouse exchanges, despite of the available information and communication technologies and e-commerce forms, ensure mainly just the simply display of the transportation and storage tasks/capacities. In addition, the tendering of logistics providers is an infrequent selection form. Moreover, both the scientific literature and the currently available exchanges give not opportunity for decision supporting and optimization of logistic processes. The main reason of these shortcomings is that these online exchanges are not handled as a modern information system which can support logistic processes and build connection between logistic providers (transport, storage). As well as, till our days there has not made complex high standard system model of the electronic freight and warehouse exchanges, either.

Therefore, in my dissertation I created the system model of the electronic freight and warehouse exchanges (see Fig.1). The system model supports the offer management of two logistic processes (transportation, storage), based on modern information and communication technologies, e-commerce toolbars, operation research and optimization algorithms.

I developed and tested the data model of the system in MS Access.

/Chapter 3.1. of my dissertation; [KG1], [KG2], [KG3], [KG12], [KG13], [KG21]/

2) I devised the e-commerce methodological toolbox of the electronic freight and warehouse exchanges, which provides the dynamic operation and the effective implementation of the demand-capacity connection.

One of the main tasks of the electronic freight and warehouse exchanges is to ensure the effective implementation of the demand-capacity connection. Nevertheless, I determined that the current electronic freight and warehouse exchanges represent the transportation/storage capacities/tasks as a simply advertisement.

I devised the following e-commerce toolbar: advertising and searching in a simple catalogue (freight/storage tasks/capacities); automatic offer sending (based on individual settings); tenders/auctions (just for freight/warehouse tasks).

I presented the logistic applications of the tendering through practical examples (for example tendering logistic hardware: forklift, pallet racking).

/Chapters 3.2.-3.5. of my dissertation; [KG4], [KG7], [KG9], [KG11], [KG14], [KG17]/

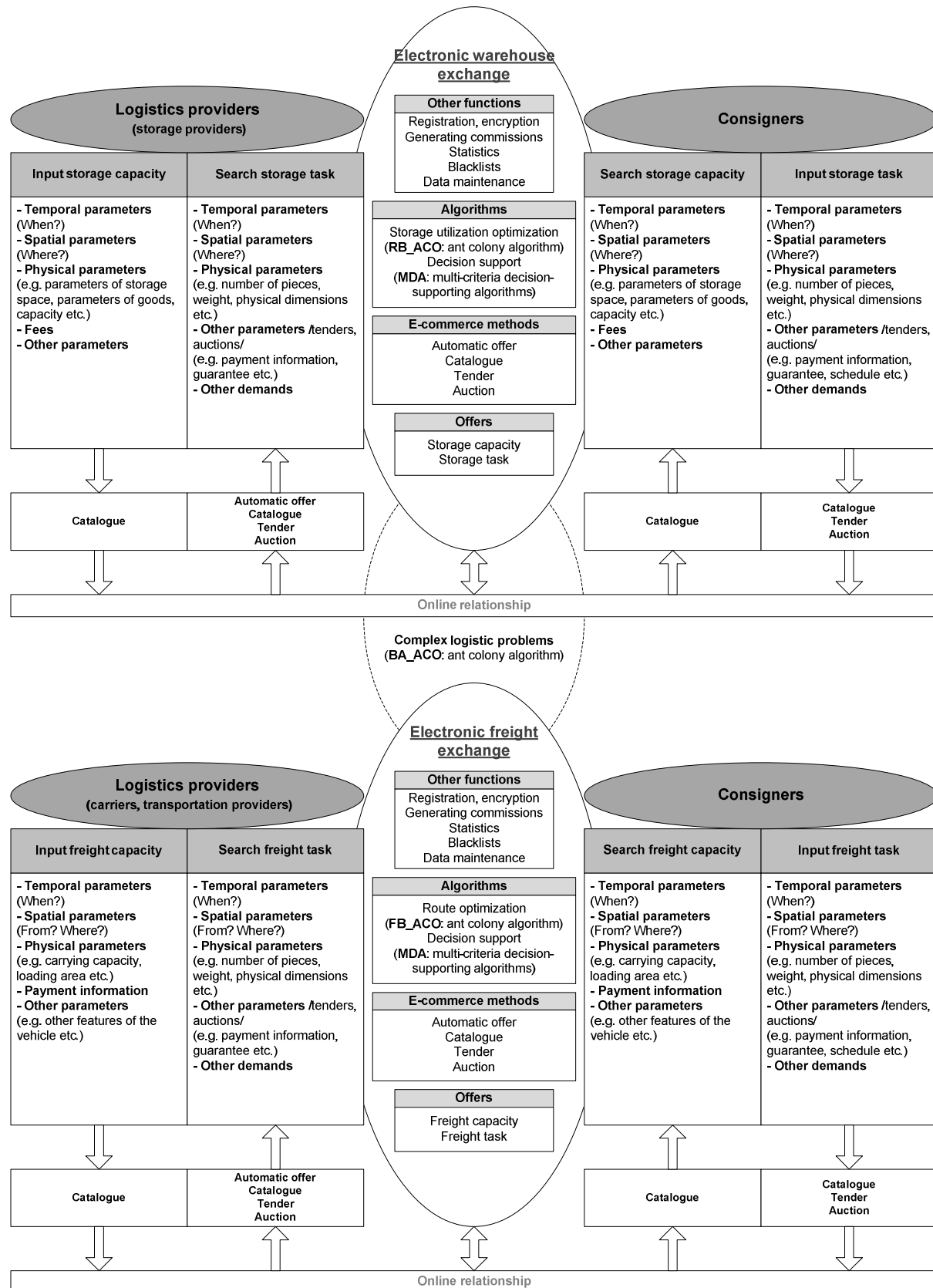


Fig. 1. The system model of the developed electronic freight and warehouse exchange

3) I proved experimentally that the decision supporting based on AHP can be used effectively in the electronic freight and warehouse exchanges to solve the occurring decision problems and to examine the effects of the human subjectivity.

If the developed e-commerce methods are used, then decision problems will emerge (how to select the best offer) on the electronic freight and warehouse exchanges. Therefore, I developed a multi criteria decision supporting algorithm (MDA) based on AHP.

The self-developed MDA is based on the evaluation aspects and the pairwise comparison matrix, which shows the result of the pairwise comparison of the aspects. With the help of pairwise comparison matrix and numerical methods, I generate the weights of aspects. Taking every main aspect (1...i...f) and sub aspect (1...j...a_i) step by step, we choose the value of the most favourable offer and we compare all other offers to this (R_{ij}^k). Based on R_{ij}^k and the generated weights of the aspects (w_i, w_{ij}), the offers get weighted performance values (\hat{E}_k), where the most favourable offer has the highest value:

$$\hat{E}_k = \sum_{i=1}^f \left\{ w_i \cdot \sum_{j=1}^{a_i} [w_{ij} \cdot R_{ij}^k] \right\} \Rightarrow \text{MAX!} \quad (1.)$$

Based on the above detailed weight-calculation method, I assign relative values to the non-quantifiable aspects.

To examine the effects of subjectivity, I developed a sensitivity analysis, which examines what happens to the order of offers (how is changing the best alternative) if weights are changed (there are four groups: E-1, E-2, E-3, E-4). In addition, based on the mathematical maximal sensitivity analysis, I developed an equation to calculate a percentage value, which features the rate of sensitivity. Using the examined weights (1...i...v), the weights dependent on those changes (v+1...j...f) and the weighted performance values on the basis of sub-aspects (c_i, c_j), we can calculate the maximal sensitivity value of alternative k.:

$$S_k(w) = \frac{\sqrt{\sum_{i=1}^v \left\{ c_i - \sum_{j=v+1}^f \left[\frac{w_j \cdot c_j}{\sum_{j=v+1}^f (w_j)} \right] \right\}^2} \cdot \sqrt{\sum_{i=1}^v \{w_i^2\}}}{\sum_{i=1}^v \{w_i \cdot c_i\} + \sum_{j=v+1}^f \left\{ \left[1 - \sum_{i=1}^v (w_i) \right] \cdot \frac{w_j \cdot c_j}{\sum_{j=v+1}^f (w_j)} \right\}} \quad (2.)$$

MDA is a VBA-based (Visual Basic Application) system; I tested it through real tenders (logistic hardware) and experimental runs in MS Excel, too.

/ Chapter 4. of my dissertation; [KG5], [KG6], [KG8], [KG9], [KG10], [KG14]/

4) I proved experimentally that the ant colony algorithms can be used effectively in the electronic freight and warehouse exchanges to optimize the processes (routes, utilization) of the transportation and storage providers.

In the database of such online fairs there are high number of freight and storage capacity offers and tasks, which provide good optimization opportunity for providers. By the reason of dynamic processes, real time data and automatic reservation are necessary.

I developed a route planning method (FB_ACO) based on the ant colony algorithm. Many freight tasks (1...i...l) may be included into the route, but a new freight task may be commenced only after the completion of the previous one (observe the limiting conditions). At the calculation of profit, the costs of getting to the departure point of the freight task (k^c), the costs of actual transport of goods (k^a), the costs of the vehicle's return way to the depot (k^v) and the remuneration for the completion of the freight task (FD) shall be considered. The objective function is to reach the maximum profit (how much profit the

selection and sequence of freight tasks will bring from the aspect of the route/solution; H_p^{kapcs}). I developed the principle of the complex benefit (\mathbb{H}), which is the quotient of the actual (H_p^{kapcs}) and the best profit ($H_{\text{max}}^{\text{kapcs}}$). It is possible to complete the \mathbb{H} benefit with other aspects $/\mathbb{H}=f(H_1, \dots, H_h, \dots, H_{oh})/$, for example with the utilization of the vehicles (η_{jm}):

$$\mathbb{H} = \frac{H_p^{\text{kapcs}}}{H_{\text{max}}^{\text{kapcs}}} \cdot \eta_{jm} = \frac{\sum_{i=1}^{\ell} \{FD_i\} - [\sum_{i=1}^{\ell} \{k_i^e\} + \sum_{i=1}^{\ell} \{k_i^a\} + k_{\ell}^y]}{H_{\text{max}}^{\text{kapcs}}} \cdot \eta_{jm} \Rightarrow \text{MAX!} \quad (3.)$$

I created an equation to calculate the task selection probability ($p_{r,s}$, the probability that the r. freight task /or the vehicle location/ will be followed by the s. freight task; $t=1 \dots s \dots L$, L: the number of optional freight tasks), see (4.). The pheromone ($\varphi_{r,s}$, information from searches) is more important than the heuristic information ($d_{r,s}$, reciprocal of distance, to achieve the smaller distance). Parameters α and β are controlled by the importance of this information ($\alpha=2$, $\beta=1/3$.) and these are based on lot of runs:

$$p_{r,s} = \frac{\varphi_{r,s}^{\alpha} \cdot \left(\frac{1}{d_{r,s}}\right)^{\beta}}{\sum_{t=1}^L \left\{ \varphi_{r,t}^{\alpha} \cdot \left(\frac{1}{d_{r,t}}\right)^{\beta} \right\}} \quad (4.)$$

I created an equation for the updating of the pheromone vector. Parameter \mathcal{B} ensures balance between conservative and explorer search (I suggest: $\mathcal{B}=5/36$); $\mathbb{H}_{\ell(r,s)}$ is the best benefit if the r. freight task will be followed by the s. freight task; parameter ρ is the rate of pheromone abrasion (I suggest: $\rho=0,1$):

$$\varphi_{r,s} = [\varphi_{r,s} + \mathcal{B} \cdot \varphi_{r,s} \cdot \mathbb{H}_{\ell(r,s)}] \cdot [1 - \rho] \quad (5.)$$

I also developed a storage utilization optimization method (RB_ACO), which is based on the ant colony algorithm. In the warehouse exchange, those having free storage capacity wish to choose storage tasks from the available storage tasks by setting the goal of ideal exploitation of capacity (\mathbb{H} , which is the quotient of the actual and the best utilization). In this case, during the task selection probability calculation, instead of the reciprocal of distance, the quantity to be stored/of goods will appear as heuristic information (the fewer number of storage tasks, good utilization).

FB_ACO and RB_ACO are VBA-based (Visual Basic Application) algorithms; I tested them through experimental runs in MS Excel.

/ Chapter 5. of my dissertation; [KG17], [KG18], [KG19], [KG21], [KG23], [KG24]/

5) I proved experimentally that the electronic freight and warehouse exchanges (with the help of ant colony optimization and complex criteria system) are able to support complex transportation systems and green logistics principles.

Over the current known applications, the electronic freight and warehouse exchanges are able to provide such logistic processes, in which the information and communication deficiencies between the participants cause the more significant problem. Based on this, the electronic freight and warehouse exchanges are able to organize collecting and distributing routes and divide the certain transport/storage capacities between the logistic providers. It is suitable for organize the transport and storage processes of the multimodal logistic centres (combined transport and city logistics). Therefore, these exchanges can provide the green logistics principles, mostly through the decreasing number of the trucks and the decreasing measure of the exhausted fumes.

To prove my thesis, I develop an ant colony algorithm (BA_ACO). In case of freight and warehouse exchanges, we have to define a complex objective function. On one part of the total transport route, the freight tasks are transmitted together and then with the help of a combi terminal the freight tasks are transferred (multimodal transportation with rail/river). The objective functions (H): minimal transportation performance increase (Q^{CF}); maximal total mileage reduction (F^{CF}); maximum use (K^{CF}) of the rail/river vehicle. I completed the modelling logic with a factor, which helps to take into consideration the demand of the surplus logistic services (RI^{BF}). The \mathbb{H} benefit (H_{\max} is the best results):

$$\mathbb{H} = \frac{H}{H_{\max}} = \frac{RI^{BF} \cdot K^{CF} \cdot \frac{F^{CF}}{Q^{CF}}}{H_{\max}} \Rightarrow \text{MAX!} \quad (6.)$$

The difference compared to FB_ACO and RB_ACO is that the task selection probability contains the reciprocal of the quantity of goods as heuristic information (to maximize the total mileage reduction).

BA_ACO is a MS VBA-based algorithm; I tested it through experimental runs in MS Excel.

/ Chapter 6. of my dissertation; [KG15], [KG16], [KG18], [KG20], [KG22], [KG23]/

5. PRACTICAL APPLICATIONS, FURTHER RESEARCHES

I established that just the simply search and selection are provided by the currently available electronic freight and warehouse exchanges. Moreover, logistics providers regard these online exchanges as new marketing channels. Because of these shortcomings, I developed new services of the electronic freight and warehouse exchanges, to increase the practical applicability and to extend the suitability for supporting complex logistics processes.

There is opportunity to have a freight/storage commission through tender and auction. Experiences show that tenders for high- value and/or repetitive freight/storage tasks are worth advertising on the electronic freight and warehouse exchange. One of the chief values of the developed electronic freight and warehouse system is the application of multi-criteria evaluation methods and the sensitivity analysis. The developed mathematical method called multi-criteria decision-supporting algorithm (MDA) helps to evaluate tenders/auctions and helps to choose the best offers from the catalogue, thus these opportunities can be also used by the logistics providers.

The developed ant colony algorithm in the freight exchange is based on the following objective function: those having free freight capacity (freighters) wish to establish routes providing optimal profit from the freight tasks appearing in the freight exchange (FB_ACO). In the warehouse exchange those having free storage capacity (storage providers) wish to choose several from the available storage tasks by setting the goal of ideal exploitation of capacity (RB_ACO algorithm).

I developed new application fields of electronic freight and warehouse exchanges:

- to organize collecting/distributing routes;
- to support the sharing of capacities between logistics providers;
- to promote the combined transport and city logistics.

With the help of collecting/distributing routes the logistics providers can improve their own logistics processes; moreover, the capacities are harmonized by the sharing of transport and storage capacities (virtual alliances are formed). The role of freight and warehouse exchanges

in complex logistics problems (city logistics, combined transportation) may be viewed as the route planning systems: the processes (e.g. tours, utilization) can be optimized (with ant colony algorithm, BA_ACO) by handling demands and capacities in one system. In this case, the users are complex logistic providers (transportation, storage). The main advantage (aside from better utilization of vehicles) is that the electronic freight and warehouse exchanges are able to support the environmentally friendly logistics systems (city logistics, combined transportation). Thus, the green logistics principles can be realized.

The scientific results can be used in education of Transportation and Engineering (BSc, MSc). The system model and its operation is taught in Logistics Information Systems, the route planning algorithms (FB_ACO, BA_ACO) are taught in Transport Logistics, the decision supporting algorithm (MDA) is used to compare the different plan versions (a variety of subjects).

The research is also connected to other PhD dissertations, which are in progress, too. Therefore, the results can be used for example in researches connected to the city logistics (BA_ACO algorithm) or in the researches deal with artificial intelligence, by the developed optimization algorithms.

The main direction of the further development is first of all the exposing of the new practical application opportunities (mainly creating the prototype systems of the combined transport and/or city logistic supported by these exchanges), and the refining of the algorithms. On the field of the optimization, the most promising opportunities are the elaboration of the solving methods of collecting/distributing routes and system optimum. There can be created a nonlinear, discrete, multivariate mathematical model based on the Bellman principle ([AC7], [AC16]), for the previously mentioned optimization tasks. BÓNA's works ([AC4], [AC5], [AC6]) also gives a good base, for example in the field of inventory control system (connections with electronic warehouse exchanges).

Further research opportunities can be appear in the connection of legal and financial fields. Interesting development directions can be raised by the possibility of the demand influence, which is known in the field of the community transportation. It gives a suitable example and chance to involve other departments and special areas in the research of the electronic freight and warehouse exchanges.

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