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Models and Algorithms for E-Marketplaces Integrated with Logistics

PhD Theses Abstract

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1. Introduction

My dissertation provides a new approach to logistical solutions in electronic commerce building upon the interrelated area of e-commerce and supply chain modelling as a background.

Business-to-Business e-commerce plays an increasingly important role in supply chain management facilitating integration and cost savings. The theoretical backgrounds include the immense literature of auction theory, among them many excellent surveys such as [B1], [B2], [B11], [B13], [B14], [B15].

Studying the literature of auction theory I have found only a few papers that dealt explicitly with the logistical aspects of auctions. A simplified model of transportation costs is included in Chen et al. [B3] and Zeng et al. [B16]. These models deal with transportation costs proportional to quantity which is a limited approach to real world problems. I have not found any procurement auction models that would include the time-bound nature of supply chain management. Warehousing is not explicitly dealt with either, although penalty on leftover goods can be regarded as a kind of storing cost. [B2].

According to my findings the electronic marketplaces of goods and logistical services are treated separately both in theory and practice. E-marketplaces selling goods either do not offer logistical solutions at all or offer a single solution or 2-3 possibilities in different time-cost ranges. The so called integrated marketplaces offer both goods and logistical services, but they are rather joint than integrated, since the goods must be selected first and then the logistics providers' market can be reached with a click. Electronic distributors undertake the task of mediating between buyers and sellers providing logistical services as well but this excludes competition from the logistics providers' side. Hence we can say that the above-described B2B models do not enable an optimisation that would include logistical costs as well. In my dissertation I address this inefficiency by creating a new model for e-marketplaces that fully integrates the markets of goods and logistical services enabling optimisation of total costs.

The main guide for my background research work, Kalagnanam and Parkes [B11] provides a framework for auction mechanisms defining the building elements as resources, market structure, preference structure, bid structure, matching supply demand and information feedback, which concepts helped me to build up a solid theoretical foundation for my theses.

From the logistics' point of view my most important resources were provided by the researches concerning virtual enterprises being carried out for many years at the Department of Materials Handling & Logistics of University of Miskolc (ME-ALT) led by Prof. Dr. József Cselényi. Several methods have been developed here to create a dynamic system to exploit the free capacities of companies grouped in clusters using e-business tools. [B4],[B5], [B6], [B7], [B8], [B9], [B10], [B12].

2. Objectives

I started my work with the vision of an electronic marketplace integrated with logistics, where third party logistics providers (3PLs) compete with each other within the frame of the goods' market to allow joint optimisation according to different criteria. To the best of my knowledge this approach has never been used in the literature before.

My primary objective was to work out the theoretical foundations of modelling e-marketplaces integrated with logistics in order to prove the feasibility of such models. Since the problem is very complex I divided it into sub-problems using the following set of goals:

1. *Identification of the relevant research area*

Content: Setting the boundaries of the problem area and the modelling space, defining the relevant entities and the relationships between them. Finding the possible starting points in the literature concerning the specialist field pertaining to both the study of electronic commerce and supply chain management.

2. *Outlining the research area*

Content: Outlining a modelling framework and defining the most important subtypes of the generic model in line with the existing categorisations of electronic commerce.

3. *Preparatory analysis on the physical level*

Content: Analysing the material flow and defining the relevant concepts and attributes that will serve as a basis for the mathematical model.

4. *Model definition for a selected sub-area*

Content: Defining the optimisation problem including the input bid structure, the objective function along with the constraints and the output structure.

5. *Optimisation algorithms*

Content: Creating one or more algorithms for solving the selected optimisation problem subtype, proving correctness of these algorithms and analysing their operation.

6. *Feasibility of the model*

Content: Investigating the feasibility of the new model from a practical point of view, formulating the economical benefits and setting up criteria for deciding about its possible implementation.

3. Methodology

First I tried to make sure that no similar model has been published so far. My primary sources were the commercial solutions available on the Internet where I spent a long time searching with no results. However this methodology cannot be regarded reliable enough to prove the non-existence of such a model. The secondary sources – papers and books, especially surveys published in the literature on electronic commerce – were a more reliable source for covering the possible similar models, since they are easier to search, but they yielded no results either. I carried out my research in English since this is the most frequently and widely used language in the science of e-commerce, and authors of different nations tend to publish their results in English as well. I have used reliable sources only, such as university sites, scientific databases and web pages of well known scientists.

Studying the literature on e-commerce I have compared the relevant ideas to the methods published by the researchers of ME-ALT in the field of logistical optimisation and virtual enterprises, which led me to the problem classes described in my dissertation.

In order to set up the theoretical model I studied the literature relevant to the logistical costs from technical, financial and general managerial aspects. I also studied the tariffs of several 3PLs present on the Internet. Based on the results of these examinations I have created a new cost model that is more realistic than those currently used widely in e-commerce.

I formulated my model based on my previous research using the literature of auction theory and optimisation models created at ME-ALT. I have published my ideas at different conferences and in several journals. The feedback I received from these sources helped me to fine tune my model.

The model I have designed for integrating logistics into the e-marketplaces of goods involves a non-linear optimisation problem containing integer and binary variables. In order to solve this I have studied different optimisation methods aiming at transformations that make my problem suitable for one of the commercial optimisation software packages. The main obstacle was the discontinuous nature of the objective function which resulted in non-linear methods being unimplementable. To overcome the problem I have worked out a method to transform it into a piecewise linear function which reduced the original problem to a linear integer programming problem. I used a phased approach, first showing linearisation of a simplified model then generalising the method to more complex models.

The complexity of integer programming problems mainly depends on the number of integer variables and the structure of the problem. In my case the price I had to pay for the linearisation of the problem was the increasing number of new variables which in some cases might have jeopardised the online application. For this reason I analysed the model, calculated the upper limit of the number of variables and proved that the same results can be reached by replacing the integer variables with continuous ones. This way I reduced the problem to a mixed integer programming (MIP) task that can be solved much faster than the original problem since the number of discrete variables has been significantly reduced. Still the remaining binary variables might cause unacceptably lengthy computation times. For this reason I have studied the metaheuristic methods of global optimisation in order to find a possible template for a suitable heuristic method that could enhance my solution. Branch and bound techniques seemed to be the most promising for this purpose, so using this method I created a heuristic algorithm that reduces problems which contain an extremely large number of variables to smaller sub-problems.

I have tested the validity of my algorithms in practice. First I tried to use the quadratic optimisation model of MS EXCEL Solver but it did not work. Despite the small size of the test problems it yielded correct results only if I set the initial values close to the solution, obviously it was unable to handle the discontinuous objective function.

On the other hand, MS EXCEL Solver turned out to be a good tool for testing the linearised model since it yields correct results for MIP problems where only a small number of binary variables are present along with many continuous variables. Unfortunately I had no access to the more powerful commercial version of Solver so I could only use 160 variables, and I was unable to call the necessary routines from a program which made testing a large number of cases impossible. Still the tests I ran individually were enough to draw my attention to a few important features concerning the feasibility and the economic aspects of the model. Afterwards I was able to prove these in a theoretical way.

4. New academic results

Thesis 1.

I have defined a new model for improving the economic efficiency of Business-to-Business electronic commerce by introducing the concept of the e-marketplace integrated with logistics. I have defined the structure of three different subtypes – the buyer-oriented, the seller-oriented and the intermediary types, and created new kinds of auction algorithms that can facilitate the operation of these.

I have defined a new family of e-marketplace models that I call EMMIL for E-Marketplace Model Integrated with Logistics.

The resources to be allocated in a general EMMIL model are the following: (1) multi-unit multi-item goods that require physical transportation (2) logistical services that may include transportation, warehousing, labelling, unitising, de-unitising or other value added services. These two kinds of resources are treated separately in traditional e-marketplace models while in EMMILs a single transaction joins the goods to the entities

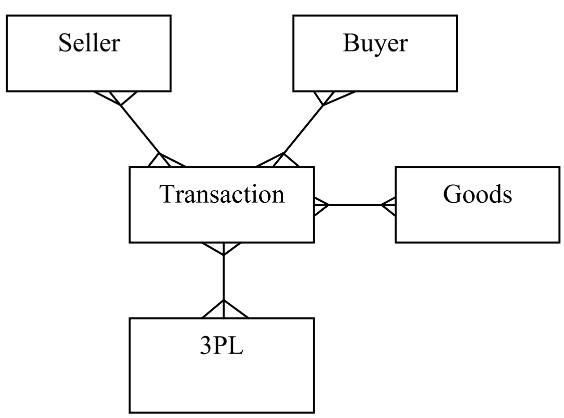

Figure 1.: Entity relationship diagram of an EMMIL transaction

of all the three sides such as sellers, buyers and 3PLs. This can be seen in Figure 1.

According to market structure EMMIL models can be divided into three different subtypes. In the buyer-oriented or procurement model (EMMIL.BM) a single buyer is facing several sellers and 3PLs. In the seller-oriented model (EMMIL.SM) a single seller is involved in transactions with many buyers and 3PLs. The third subtype is EMMIL.IM, the intermediary model.

The most important new feature of EMMIL models is the allocation procedure. I have defined a new kind of auction that enables 3PLs to integrate their bids into the bidding process that runs between buyers and sellers. With this feature the marketplace engine can optimally allocate the resources taking all aspects into consideration. I have described the necessary algorithms for all the three subtypes.

Relevant publications with my contribution are [A2], [A7], [A8], [A9], [A10].

Thesis 2.

I have investigated the cost structure of transactions integrated with logistics. I have carried out an activity based cost analysis for the buyer-oriented marketplace and proved that the cost structure of seller-oriented and intermediary types can also be modelled with the help of the elements introduced here.

In order to operate auctions successfully an incentive bid structure has to be designed. A bid structure can only be incentive if it is strongly related to the preference structure of the participants. In EMMIL models participants have individual private values that in the case of sellers and 3PLs is based on their costs. Therefore it was essential to analyse the cost structures prior to bid structure design.

In the cost analysis I have distinguished between fixed and variable costs according to the way they react to changes in volume, which is in line with the terminology of management accounting.

For costs of goods I have created a structure that can reflect both economies of scale and economies of scope. In the case of logistical costs I have decided to carry out an activity based cost analysis since decisions about the activities form part of the allocation process of the marketplace. To simplify the model I restricted the subject of trading to homogenous unit loads and specified the basic elements of the allowed logistical activities such as handling, transportation and storing. I assigned cost functions to the elementary activities first and then formulated the related costs for additional administrative and information systems and the cost of capital. I defined the formula of cost aggregation for buyer-oriented marketplaces enabling consolidation deliveries. To integrate the costs of warehousing I have introduced the concept of asynchronous consolidation delivery for collecting, storing and delivering goods available at different times and locations. Costs of traditional (synchronous) consolidation deliveries are expressed by Formula (1).

$$\begin{aligned} C^{\sigma l} &= F^{\sigma l}(\varphi,\zeta^{\sigma l},\Gamma^{\sigma l},\chi^{\sigma l}) + \left\langle \sum_{j=1}^{\chi^{\sigma l}} V^{\sigma l}(\varphi,\Phi,\zeta^{\sigma l},\Gamma^{\sigma}) d(W^{j},W^{j+1}) \sum_{r=1}^{j} Q^{\sigma l r} \right\rangle \\ &+ H^{\sigma l}(\varphi,\Phi,\rho^{\sigma l},\zeta^{\sigma l}) \sum_{j=1}^{\chi^{\sigma l}} Q^{\sigma l} (H_1^{\sigma l}(\varphi,\Phi,\rho^{\sigma l},\zeta^{\sigma l}) + H_2^{\sigma l}(\varphi,\Phi,\rho^{\sigma l},\zeta^{\sigma l})) \end{aligned} \tag{1}$$

Notations:

$C^{\sigma l}$ Cost of synchronous consolidation delivery σ. of 3PL l. [EUR]

φ Type of goods

Φ Type of unit load

$\chi^{\sigma l}$ Number of seller plants in route of synch. consolidation delivery σ. of 3PL l.

$Q^{\sigma lr}$ Quantity of goods in distance r. of synch. consolidation delivery σ. of 3PL l. [pallet]

$F^{\sigma l}$ Fix transportation cost of synch. consolidation delivery σ. of 3PL l. [EUR]

$V^{\sigma l}$ Variable transportation cost of synch. cons. delivery σ. of 3PL l. [EUR/pallet/km]

$H_1^{\sigma l}$ Variable loading cost of synch. consolidation delivery σ. of 3PL l. [EUR/pallet]

$H_2^{\sigma l}$ Variable unloading cost of synch. consolidation delivery σ. of 3PL l. [EUR/pallet]

$d(W^j,W^{j+1})$ Distance between sellers j. and j+1. in synch. cons. delivery σ. of 3PL l. [km]

$\rho^{\sigma l}$ Technology used in synch. cons. delivery σ. of 3PL l.

$\zeta^{\sigma l}$ Type of vehicle used in synch. cons. delivery σ. of 3PL l.

$\Gamma^{\sigma l}$ Road type and conditions in synch. cons. delivery σ. of 3PL l.

The cost model of asynchronous consolidation delivery (2) consists of four parts: transportation from seller to the warehouse, storing, transportation from the warehouse to the buyer and the additional administrative costs. I proved that the total storing time can be calculated according to (3).

$$C^{\alpha l} = \sum_{\beta=1}^{G_\iota^{\alpha l}} C_\beta^{\alpha l} + \sum_{\gamma=1}^{G_o^{\alpha l}} C_\gamma^{\alpha l} + {}^{\Sigma}C_w^{\alpha l} + C_{a\lambda}^{\alpha l} \tag{2}$$

Notations:

$C^{\alpha l}$ Costs of asynchronous consolidation delivery α. by 3PL l. including handling and storing [EUR]

$G_\iota^{\alpha l}$ Number of inward synchronous consolidation deliveries in the asynch. cons. delivery α. by 3PL l.

$G_o^{\alpha l}$ Number of outgoing deliveries in the asynch. cons. delivery α. by 3PL l.

$C^{\alpha l}{}_\beta$ Cost of incoming synchronous consolidation delivery β. in the asynch. cons. delivery α. by 3PL l. [EUR]

$C^{\alpha l}{}_\gamma$ Cost of outgoing delivery γ. in the asynch. cons. delivery α. by 3PL l. [EUR]

${}^{\Sigma}C_w^{\alpha l}$ Cost of warehousing in the asynchronous consolidation delivery α. by 3PL l. [EUR]

$C_{a\lambda}^{\alpha l}$ Additional administrative costs of asynchronous consolidation delivery α. by 3PL l. [EUR]

$${}^{\Sigma}C_w^{\alpha l} = \omega_w^{\alpha l} \left\langle \sum_{\beta=1}^{G_\iota^{\alpha l}} Q_\beta^{\alpha l} (T_u^{\alpha l} - T_\iota^{\alpha l \beta}) - \sum_{\gamma=1}^{G_o^{\alpha l}-1} Q_\gamma^{\alpha l} (T_u^{\alpha l} - T_o^{\alpha l \gamma}) \right\rangle \tag{3}$$

Notations:

$\omega_w^{\alpha l}$ Unit cost of storing in asynchronous consolidation delivery α. by 3PL l. [EUR/pallet/day]

$Q_\beta^{\alpha l}$ Quantity of inward synchronous consolidation delivery β. in the asynch. cons. delivery α. by 3PL l. [pallet]

$Q_\gamma^{\alpha l}$ Quantity of outgoing delivery γ. in the asynch. cons. delivery α. by 3PL l. [pallet]

$T_u^{\alpha l}$ Date of last outgoing transport in asynch. cons. delivery α. of 3PL l.

$T_o^{\alpha l \gamma}$ Date of outgoing transport γ. in asynch. cons. delivery α. of 3PL l.

$T_\iota^{\alpha l \beta}$ Date of incoming transport β. in asynch. cons. delivery α. of 3PL l.

Relevant publications with my contribution are [A1], [A3], [A6].

Thesis 3.

Based on the cost analysis I have created incentive bid structures for the buyer-oriented marketplaces. To facilitate the allocation procedure I have formulated the general and special versions of the optimisation problem allowing combinatorial versus line-haul transportation.

For detailed analysis I have used an EMMIL.BM model with the following specifications. The auctioneer is a single buyer aiming at procuring defined quantities of specified products in unit-loads. There are many sellers that can offer one or more of the required items between given minimal and maximal quantities. There are also several 3PLs willing to undertake transportation and storing.

I have defined the bid structure of sellers and the bid structure of 3PLs in a compatible way. The generality of these bids is a new achievement compared to those in the literature of procurement auctions, since it contains time frames for all parties: pick-up time intervals for sellers, delivery time for the buyer and service completion times for 3PLs. In the sellers' bid structure in addition to item discounts I have enabled a cross-item discount as well as a function of the total purchase price.

In the bid structure of 3PLs I introduced combination delivery as a generalisation of consolidation delivery. Another new feature of the logistical bid is the structure of fix and variable costs where the fix element refers to forwarding a container / truck of specified size while the variable element is the usual unit transportation cost. I have proven that my bid structure is suitable for incorporating all cost elements discussed in Thesis 2.

The allocation in this model is aimed at minimising the total costs of the buyer. I formulated the general objective function (4) as the purchase cost payable to sellers plus the costs of logistical services. The variables are the quantities to be purchased from the different sellers (Q_i^k), and a set of decision variables (X_j^l) to identify the selected 3PLs. The objective function is quadratic since it contains the product of variables and discontinuous since the fix costs must be handled using the ceiling function. Constraints refer to time and quantity limits but they are not described in this abstract.

$$f(Q_i^k, X_j^l) = \sum_{k=1}^{M}\left(\sum_{i=1}^{N} P_i^k Q_i^k\right)\left(1-\Delta^k\right) + \sum_{l=1}^{L}\sum_{j=1}^{G^l} X_j^l \left(F_j^l \left\lceil \left(\sum_{k\in\Gamma_j^l}\sum_{i=1}^{N} Q_i^k\right) / Z_j^l \right\rceil + V_j^l \sum_{k\in\Gamma_j^l}\sum_{i=1}^{N} Q_i^k \right) = \min \qquad (4)$$

Notations:

N	Number of items (goods)
i	Item identifier
M	Number of suppliers
k	Supplier identifier
Q_i^k	Purchased quantity of product i. from seller k.
P_i^k	Unit-price of product i. at seller k. as a step function of quantity
Δ^k	Discount given as a step function after the total purchase cost at seller k.
L	Number of 3PLs
l	3PL identifier
G^l	Number of bids of 3PL l.
j	Identifier of logistical bids
Γ^l_j	$\subseteq\{1,..M\}$ route, combination of sellers' identifiers
F^l_j	Fixed truck cost of delivery on route Γ^l_j [EUR]
V^l_j	Variable cost/unit of delivery on route Γ^l_j [EUR/ pallet]
x_j^l	$\in \{0,1\}$ decision variable, $x_j^l=1 \Leftrightarrow$ offer j. of 3PL l. is selected as winner.
Z^l_j	Load capacity of vehicle applied in route Γ^l_j [pallet]
$\lceil \ \rceil$	Ceiling function

I have formulated the objective function in a simplified form as well (5), without discounts, with standard capacity vehicles and line-haul transportation only.

$$f(Q_i^k, X_k^l) = \sum_{k=1}^{M}\left(\sum_{i=1}^{N} P_i^k Q_i^k + \sum_{l=1}^{L} X_k^l \left(F_k^l \left\lceil \left(\sum_{i=1}^{N} Q_i^k\right)/Z \right\rceil + V_k^l \sum_{i=1}^{N} Q_i^k \right)\right) = \min \tag{5}$$

Notations:

X_k^l	$\in \{0,1\}$ decision variable, $X_k^l=1$ if and only if 3PL l. delivers from seller k.
Z	Standard load capacity of vehicles [pallet]
F^l_k	Fix cost of 3PL l. from seller k. [EUR]
V^l_k	Variable unit cost of 3PL l. from seller k. [EUR/ pallet]

Relevant publications with my contribution are [A2], [A7], [A8], [A9], [A10].

Thesis 4.

I have created a solution algorithm for the specialised optimisation problem that involves line-haul transportation only. I have proven that the quadratic integer problem can be reduced to a linear mixed integer programming problem. I have specified the algorithm of linearisation and analysed the complexity of the linear model.

I have linearised the quadratic objective function (5) by constructing a $g_k(Q)$ piecewise linear best logistical cost function for each seller (Figure 2.) Based on four lemmas I proved the validity and short execution time of the construction algorithm. Then I formulated the linearised form of the objective function (5) along with the relevant new constraints and proved that the new, linear programming task is equivalent to the original problem.

I have proven that the constraint setting quantities as integer is not needed since the results will be integers anyhow. This relaxation significantly accelerated the solution of the linear programming task as its speed will depend only on the number of binary variables.

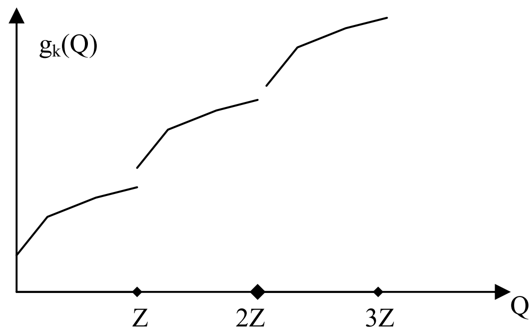

Figure 2. General scheme of the minimal logistical cost function from seller k.

I have generalised the linearisation algorithm to cases involving quantity discounts as well and proved the correctness of the solution. I also outlined the method for working with non-standard truck sizes.

Relevant publication with my contribution is [A5].

Thesis 5.

I have reduced the optimisation problem of cases involving combinatorial transportation to the line-haul model. I have created a branch and bound algorithm to handle problems with an extremely large number of variables. I have also developed a faster version of this algorithm applicable to a special class of the problem.

I solved the handling of the combinatorial bids by introducing pro forma sellers assigned to combinations of sellers where prices are set to the lowest ones in the combination. This way I have reduced the combinatorial model to the line-haul model at the cost of a significant increase in the number of sellers

To solve the optimisation problem in the case of very large numbers of sellers I have designed a branch and bound algorithm that compares the cost consequences of selecting different combinations of sellers to buy from.

The algorithm exploits the internal structure of the problem which enables significant simplifications. The only constraint is that an upper limit of number of winning sellers should be given (S_{max}) which is reasonable from a business point of view as well. The algorithm is based on traversing a multiple tree data structure where the number of trees is equal to the number of sellers. Figure 3. illustrates the data structure and the traversing path for M=4 és S_{max} =3. Bounding is done by stepping to the right using the minimal costs occurring in a sub-tree.

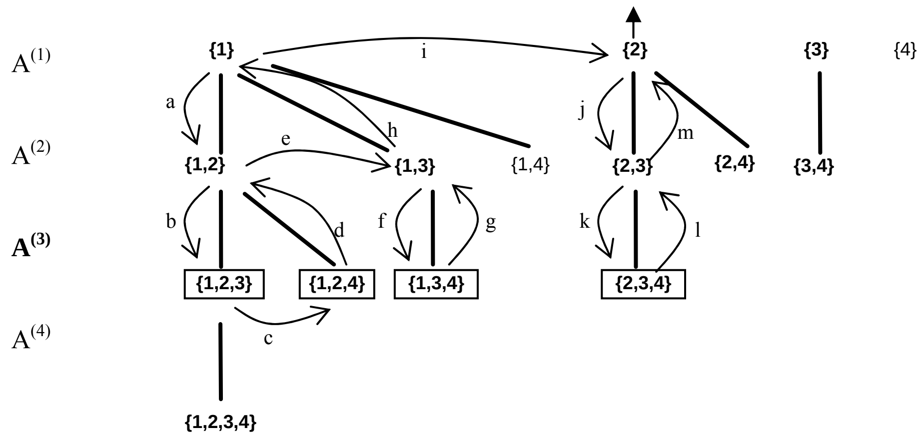

Figure 3.. Traversing P({1,2,3,4}) if S_{max} =3

Under special conditions the algorithm can be accelerated by cutting sub-trees at downward steps as well. I proved that an e-marketplace fulfils these conditions if all the sellers have enough quantities of the items they offer to satisfy the buyer's needs.

Relevant publications with my contribution are [A3], [A4].

Thesis 6.

I have carried out a sensitivity analysis of the EMMIL.BM model for cost and volume parameters. Assuming normal parameter distribution I have also analysed the effect of increasing the number of entities involved. I have defined criteria on which to base decisions concerning the economic feasibility of introducing the model. I supported my theoretical results with a test implementation using the MS EXCEL Solver program.

I have analysed three types of costs for sensitivity, the prices of the sellers, the fix and the variable logistical costs. I have formulated the changes of the total cost induced by a small change in any of these parameters. Next I have examined the changes of the total costs caused by relaxing the volume constraints slightly.

I have also formulated the effect that the increment of the number of entities has on the complexity of the problem. I have proven that the number of 3PLs contributing to the minimal cost function of an individual seller cannot be higher than 6 if the variable cost follows a normal distribution. This can significantly limit the increases in complexity.

For normally distributed parameters I have created a simple decision support system to decide about replacing traditional e-marketplace models with EMMIL models. To be able to do this I expressed the estimated changes in purchase costs and logistical costs with the help of the expected mean and variance. Based on the criteria I set up, part of the cases can be regarded as good candidates for switching to EMMIL, in other cases it is definitely not worthwhile to introduce EMMIL, and there is an uncertain area where more detailed examinations are needed prior to switching to EMMIL.

I have created a test implementation using MS EXCEL. The program consists of two parts, the first one is aimed at testing the construction of best logistical cost function since this precedes setting up the linear programming problem. The tests have underlined those features of the costs functions, which I had deduced theoretically beforehand.

The second part of the program can be used to test my decision support system since it enables the setting up of the linearised form of the objective function given in (5) along with the necessary constraints. The solution is calculated with the help of the Solver utility. The tests I ran demonstrated that my decision support system is risk avoiding. Forecasted profits proved to be realisable, but a part of the uncertain cases were also profitable even if the system was unable to forecast it.

5. Utilisation of the results

The EMMIL.BM model is aimed at optimising the allocation according to the interests of the buyer but it can offer several advantages to other stakeholders as well, while it also requires investments and can cause losses to other stakeholders. The following table summarises the possible effects of using EMMIL.BM.

Stakeholder	Advantages	Costs, disadvantages

Buyer	▪ The total cost is aggregated and minimised
	▪ The logistical costs can be reduced
	▪ Requirements can be published easily
		▪ Costs of e-marketplace
		  ▪ Systems development
		  ▪ Changeover
		  ▪ Maintenance

Sellers	▪ Increasing market opportunities ▪ Negotiations can be automated by a program ▪ Better bargaining position (in advantageous geographical location)	▪ Costs related to e-commerce ▪ Worse bargaining position (in disadvantageous geographical location)

Third party logistics providers	▪ Increasing market opportunities
	▪ Negotiations can be automated
	▪ Improved utilisation of resources
	  ▪ Transportation capacity
	  ▪ Storing capacity
		▪ Costs related to e-commerce

Society	▪ More efficient economy	▪ Unemployment might grow

Environ-ment	▪ Decreasing waste of energy and consumption of natural resources
	▪ Decreasing pollution
	  ▪ Air pollution
	  ▪ Noise
	  ▪ Waste from amortised transportation devices	

My dissertation forms an integrated part of the researches going on at ME-ALT not just by building upon previous publications at the department but also being the foundation of subsequent research agendas [C1]. A graduate dissertation [C2] has also utilised my work and its author will continue his research in the PhD school.

The EMMIL model is also integrated into the research program of the Centre for Parallel Computing at the University of Westminster and the Parallel and Distributed Laboratory of MTA SZTAKI. As it is indicated by publications [A2], [A4], [A7] the EMMIL.BM model will be exploited by the planned Grid based E-marketplace designed in the framework of joint research projects.

The real world implementation and usage will uncover the possible shortcomings and pitfalls of my algorithms and set further requirements for them but I believe that the approach suggested in my theses will be an accepted form of electronic commerce.

Further information: lkacsuk@ibs-b.hu

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