MODELLING OF MULTI-ACTOR LOGISTIC CHAINS WITH RESOURCES MUTUALIZATION

Laurențiu HIOHI[1], Dorinela COSTESCU[2], Sergiu OLTEANU[3]

Logistic collaboration through mutualization of individual resources in multi-actor supply chains represents a method applied in order to reduce overall transport cost and CO_2 emissions. With the aim of highlighting the advantages of this method, the paper presents a collaborative centres location-allocation model that allows quantifying the effects of the resources mutualization. The developed model is exemplified for the national distribution of general palletized goods supplied by several companies. The overall transport cost and CO_2 emission are used as measures in comparative analysis of the current situation and different proposed scenarios for resources mutualisation in logistic schemes with flow consolidation in collaborative centres.

Keywords: freight transport, multi-actor supply chains; logistic resources mutualisation; logistic costs; CO_2 emissions.

1. Introduction

Due to the role of the freight transport in the economic and social environment, the enhancement of logistic chain efficiency represents an essential issue. Specialized organizations reports show that transport is the only sector from Europe whose CO_2 emissions have continuously increased since 1990 [1], situation also found in Romania, where 14% of CO_2 emissions at national level is assigned to freight transport [2]. Taking into account the objectives of CO_2 emissions reduction with 20% up to year 2020 and with 75% up to year 2050, the enhancement of logistic performances at global level appears as a critical step in achievement of these targets [3].

In the last decade, different logistic methods and schemes have been developed in order to obtain efficient logistic chain and freight transport [4]. One of these methods consists in collaborative logistic mutualization of individual resources in multi-actor supply chains. This method aims to enhance the performances both at individual actor level and global logistic network level,

[1] Eng., PhD Student, Dept. of Transport, Traffic and Logistics, University POLITEHNICA of Bucharest, Romania, e-mail: hiohilaurentiu@yahoo.com

[2] Lecturer, PhD, Dept. of Transport, Traffic and Logistics, Faculty of Transports, University POLITEHNICA of Bucharest, Romania, e-mail: dorinela.costescu@upb.ro

[3] Eng., PhD Student, Dept. of Transport, Traffic and Logistics, Faculty of Transports, University POLITEHNICA of Bucharest, Romania, e-mail: ltn_sergiu@yahoo.com

through individual resources share, jointly use of logistic capacities and freight flow consolidation.

The first part of this paper describes the features of logistic systems with collaborative consolidation centres (denoted by *CC*) and the required assumptions for modelling this type of systems. For a national distribution system, the proposed issues are:

(i) Location of the *CC*s where flows from multiple suppliers are consolidated and deconsolidated and shipments are formed to other different distribution centres;

(ii) Assigning of supplier warehouses (*SW*s) and distribution centres (*DC*s) to *CC*s.

In order to solve these problems, a model is developed for minimizing monetary resources through the mutualization of the transport and *CC* freight flow processing capacities. The model takes into consideration the transport costs from the *SW*s to *CC*s, flow processing costs in *CC*s and the transport costs from *CC*s to *DC*s.

For the simplifying assumption that the transport cost function and CO_2 emissions function are linear length depending functions, the developed model is applied to a system with many general goods suppliers distributed on the entire Romanian territory by a single logistic operator. Model results aim to demonstrate the logistic resources mutualisation advantages comparing with currently used individual independent systems.

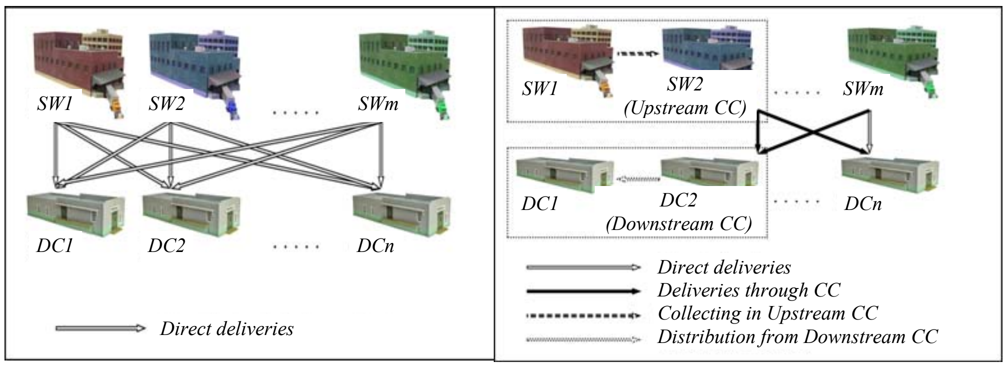
2. Characteristics of the *CC* distribution network

For analysing the goods flow consolidation possibilities which are starting from the *SW*s to *DC*s by the joint management of the logistic facility capacities through *CC*s, the following assumptions and conditions are considered.

(i) We consider that *the SW locations and current DC locations remain unchanged*, aiming to identify the *CC* location in points with existing logistic facilities. The locations where *CC*s will be developed for upstream processing (suppliers flow concentration) are chosen from the set of *SW* locations and CC locations for downstream processing (used for the flow deconsolidation and deliveries to *DC*) are chosen from the *DC* set of locations. In other terms, consolidation through logistic resources mutualisation is not based on new logistic facilities development (vehicles, handling facilities, storage yards, etc.), but on upgrading the existing ones and using them more efficiently by applying various logistic distribution schemes (Fig. 1).

(ii) Logistic resources mutualisation application on a distribution network does not exclude currently done direct shipments and, therefore, does not necessarily require an additional flow interruption. Thus, there are four flow

transfer possibilities from each origin to each destination: *(i)* direct deliveries on *SW - DC* route (Fig. 1.a); *(ii)* deliveries with consolidated flows from *SW* (on route *SW - Upstream CC – DC*); *(iii)* downstream processed deliveries: *SW - Downstream CC – DC* and (*iv*) deliveries with two times processing: *SW - Upstream CC - Downstream CC – DC* (Fig. 1.b).



a) Independent direct distribution network *b) Distribution network with CC*

Fig. 1. Types of distribution network design

(iii) Connections between logistic network points are established so that the *SW* will deliver goods to a single *CC*, and a *DC* will be served only by a *CC*. Without applying this principle, processing and stock management would become extremely difficult.

The problem that we are proposing is to determine the *CC* location for minimizing transport costs (and implicitly CO_2 emissions reduction) and establishing the delivery type applied for each origin-destination pair.

3. Mathematical formulation

The problem of CC distribution network can be defined as *p*-median location allocation problem [5-9], supposing the following steps:

- Location of CCs;
- Allocation of flow origins destinations to CCs;
- Assigning of flow on the network, on *SW - CC* and *CC – DC* routes.

The solutions of these three steps are interdependent, but to make easier the mathematical solving, a sequential approach and sets of simplification are applied in practice [8]. In our study case, we suppose that transport cost per flow unit is independent of transport volume [10], even if the goal of CC organization consists in flow consolidation that lead to economy of scale.

We denote the input data as follow:

- p is the number of *CC*s having to be located;
- M – set of origin nodes (represented by *SW*s);
- N – set of destination nodes (represented by *DC*s);
- O – set of potential nodes of *CC* (candidate nodes), where $O = M \cup N$;
- T – analysis time period (in weeks);
- $O^k_{i,t}$ – volume of goods of k type ($k = 1 \div K$), supplied from node i in week t ($t = 1 \div T$);
- $D^k_{j,t}$ - volume of goods of k type ($k = 1 \div K$), shipped to node i in week t;
- $x_{ij,t}$ - goods flow on route *i-j* in week t, computed as:

$$x_{ij,t} = \sum_k x^k_{ij,t} \text{ , } \forall\ i \in M \text{ , } \forall\ j \in N \text{ , } \forall\ i \in M \text{ , } k = 1 \div K \tag{1}$$

where $x^k_{ij,t}$ represents the flow of goods of k type on the route *i-j* in week t;

- c^l_{ij} - transport cost per flow unit on the route *i-j* that transit through center l, determined by:

$$c^l_{ij} = c_{il} + C^{IN}_l + C^{OUT}_l + c_{lj} \text{ , } \forall\ i \in M \text{ , } \forall\ j \in N \text{ , } \forall\ l \in O \tag{2}$$

where c_{il}, c_{lj} are transport costs per flow unit on the upstream route *i-l*, respective downstream route *l-j*;
C^{IN}_l, C^{OUT}_l - processing costs per flow unit coresponding to *CC* input, respective output operations;

- Γ_l - transit capacity of the *CC* located in the candidate node *l*.

We denote $Z_l \in \{0,1\}$ the decision variable for *CC location*, having the value 1 when one *CC* is located in node $l \in M \cup N$ and 0 otherwise. The following decision variables are used for flow assigning:

- $X^l_i \in \{0,1\}$ is the decision variable for flow allocated on upstream routes (*SW* – *CC*), having the value 1 if the node i is served by center l and 0 otherwise;
- $Y^l_j \in \{0,1\}$ is the decision variable for flow allocated on downstream routes (*CC* – *DC*), having the value 1 if the node j is served by center l and 0 otherwise.

The objective function is defined to minimize the sum of overall transport cost and *CC* transit cost. Therefore, over the analysis time period T we compute the cost as the sum of the components corresponding to the three logistic phases:

- upstream *CC* transport cost, denoted by C_u:

$$C_u = \sum_t \sum_i \sum_j \sum_l c_{il} \cdot x_{ij,t} \cdot X_i^l \tag{3}$$

- cost of flow consolidation/deconsolidation in *CC*, C_C:

$$C_C = \sum_l \left(C_l^{IN} + C_l^{OUT}\right) \sum_t \sum_i \sum_j x_{ij,t} \cdot X_i^l \tag{4}$$

- downstream *CC* transport cost *CC*, C_d:

$$C_d = \sum_t \sum_i \sum_j \sum_l c_{lj} \cdot x_{ij,t} \cdot Y_j^l \,. \tag{5}$$

Using the eqs. (3)-(5), the objective function is defined by:

$$\min\left(C_u + C_C + C_d\right) \tag{6}$$

subject to:

$$\sum_l Z_l = p \tag{7}$$

$$X_i^l \le Z_l ,\ \forall i \in M ,\ \forall l \in O \tag{8}$$

$$Y_j^l \le Z_l ,\ \forall j \in N ,\ \forall l \in O \tag{9}$$

$$\sum_l X_i^l = 1 ,\ \forall\ i \in M \tag{10}$$

$$\sum_l Y_i^l = 1 ,\ \forall\ j \in N \tag{11}$$

$$\sum_j x_{ij,t}^k = O_{i,t}^k ,\ \forall\ i \in M ,\ k = 1 \div K \tag{12}$$

$$\sum_i x_{ij,t}^k = D_{j,t}^k ,\ \forall\ j \in N ,\ k = 1 \div K \tag{13}$$

$$\sum_i O_{i,t}^k = \sum_j D_{j,t}^k \ ,\ k = 1 \div K \tag{14}$$

$$\sum_i x_{ij,t} \cdot X_i^l = \sum_j x_{ij,t} \cdot Y_j^l ,\ \forall l \in O \tag{15}$$

$$\sum_t \sum_i x_{ij,t} \cdot X_i^l \le \Gamma_l \cdot Z_l ,\ \forall l \in O \tag{16}$$

Constraints (7) ensure that *p* centres are located. Constraints (8) and (9) guarantee that every origin, respective destination is allocated just to one *CC*. Constraints (10) and (11) ensure that flow starting from node *i*, respective to node *j* are allocated to node l only if a *CC* is located in the candidate node *l*.

Constraints (12) – (14) ensure the equilibrium of shipped and received flow and constraints (15) guarantee the equilibrium of inbound and outbound flow on each. Eq. (16) represents the capacity constraints *SW* and *DC* allocation to *CC*.

Solving of eq. (6) consists in an optimal solution for *p* centres location in nodes where sufficient logistic facility capacities exist. The main difficulties of this model are given by the large number of decision variables and the large number of constraints.

In order to reduce the complexity of the problem, two types of additional constraints can be used:

$$d_{il} \cdot X_i^l \le D_{\max}\,,\ \forall\ i \in M\ ,\ \forall\ l \in O \tag{17}$$

$$d_{lj} \cdot Y_i^l \le D_{\max}\,,\ \forall\ j \in N\,,\ \forall\ l \in O \tag{18}$$

where d_{il} , d_{lj} are the length from a *SW*, located in node *i*, respective *DC* located in node *j*, allocated to centre *l*;

$D_{\max}$ - the maximum allowed length between *CC* and their allocated *SW* or *DC*.

Eqs. (17), (18) constrain the allocation of *SW*s and *DC* just to CC located at length less than D_{max} and considerably reduce the number of decision variables. The performed studies [11] demonstrated that for D_{max} = 50 km and more than 20 nodes, these constrains do not significantly modify the model solution. In our study case the number of *SW* is 163 and the number of *DC* is 5, thus we can use these constrains.

4. Study case

4.1. Input data

In order to evaluate the effects of logistic resource mutualization, we applied the developed model to a distribution system at Romania national level. The data gathered from our study partners helped us to build a database of general palletized goods flow (Tab. 1) supplied by 163 *SW*s to 5 *DC* (Fig. 2), for a time period of *T = 32 weeks*. It can be noticed that average weekly flow are less than the load truck capacities, fact that furthermore justifies the analysis of flow consolidation logistic schemes.

Although our goal is to demonstrate the advantage of using mutualizated resources in flow consolidation scheme, in this stage of the study we considered that the transport cost function is a linear function of length:

$$c_{ij} = \beta \cdot d_{ij}\ ,\ \forall\ i, j \in M \cup N \tag{19}$$

where β is the transport cost per flow unit/km (i.e. we have not enough data to estimate a relationship between transport cost and flow intensity in order to include in our analysis the scale effects implied by flow consolidation).

Table 1

General palletized goods flow in the analysed logistic system

DC	No. of *SWs*/*DC*	Overall input flow/*DC* (pallets)	Weekly flow/*DC* (pallets)		Weekly flow/*DC* (pallets)	
			Average	Standard deviation	Average	Standard deviation
A	163	73716	2303.63	679.12	14.13	4.17
B	163	69096	2159.25	679.05	13.25	4.11
C	163	76983	2405.72	650.43	14.76	3.99
D	163	74099	2315.59	735.13	14.21	4.51
E	163	71711	2240.97	761.84	13.75	4.67

The relatively large number of the origin/destination nodes argued the use of *Nondetailed Vehicle Routing Models (NVRM*) [12, 13] to determine the length d_{ij}. These models aim to determine distances between nodes located in one R area region and allowed us to simplify solving the objective function (6). Table 2 summarizes the obtained lengths used in the model.

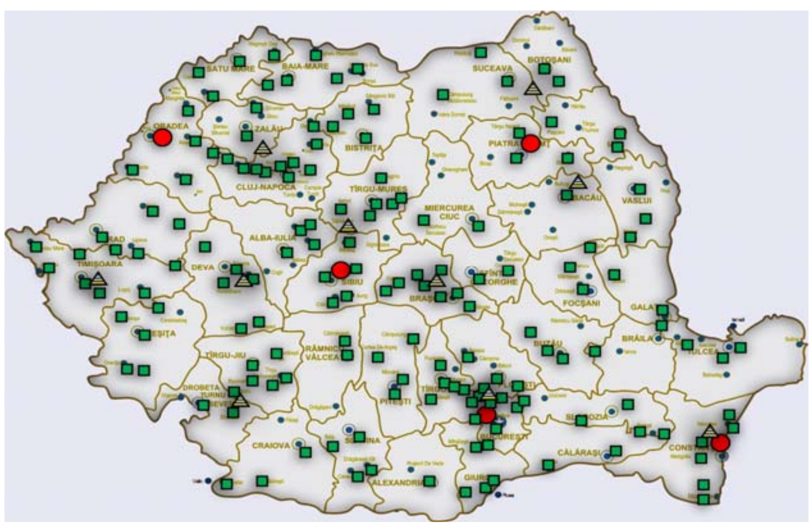


Fig. 2. Location of *SW* and *DC* in the analysed system
(*SW* - green squares; *DC* - red circles; posible *CC* location - striped triangles)

The values of transport cost per flow unit are empirical determined based on recorded and computed data by our study partners. We assume that homogeneous fleet is used, consisting of road trucks with a loading capacity of 21 tons or 28 pallets (commonly used capacities Romanian supply systems).

Table 2

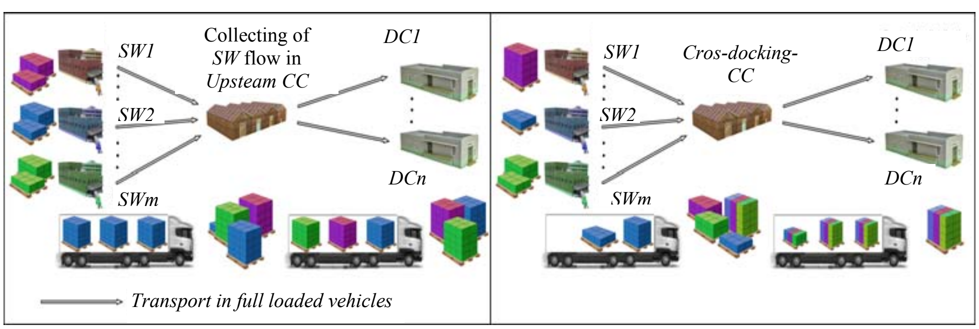
Lengths between logistic system nodes

DC	No. of *SW*/*DC*	*SW- DC* length (km)	
		Average	Standard deviation
A	163	307.5	113.3
B	163	251	134.4
C	163	278.4	112.4
D	163	202.1	95
E	163	227.9	117.3

In our analysis, besides costs, CO_2 emissions are used as measures of logistic resources mutualization effects. The CO_2 emission are estimated as linear function of length and coefficient $\lambda_{road} = 0.03321\ kg\ CO_2/\ km\ pallet$ [14, 15].

4.2. Analysis scenarios

Use of the entire vehicle load capacity (complete vehicles) leads to transport cost and CO_2 reducing, but may be complemented by additional costs generated by the increased stock level and the invested inventory capital. Consolidation of the inventories of several suppliers in one CC could diminish the disadvantages of full load vehicle distribution [16]. Taking into consideration this assumption, the first proposed scenario for analysis (*Scenario 1*) consists in *Upstream-CC* location and organization, i.e. centres where flow from multiple *SW*s are consolidated and complete vehicles to *DC*s are formed (Fig. 3.A).



a) Scenario 1: distribution with complete vehicles on "SW – Upstream CC – DC" routes *b) Scenario 2: distribution through cross-docking-CC*

Fig. 3. Scenarios for resources mutualization analysis

This type of organization generates higher levels of stock both in *Upsteam-CC*s and *DC*s and implicitly higher inventory costs. In this case, the values $C_1^{IN} = C_1^{OUT} = 57.45$ *euro/truck* and $\beta_1 = 1.83$ *euro/km·truck* are used in logistic cost computing. We used a constant value of *0.513 mills. Euro* per *Upstream-CC* organization (regardless of its potential location).

In the second scenario (Scenario 2), we consider *CC*s organized as cross-docking platforms (Fig. 3.b), where goods unloading/sorting/load-grouping are performed with mutualizated resources of several suppliers located in the same geographical zone. In this type of logistic network, the upstream-suppliers flow are consolidated in *CC*s, the goods are sorted function of their destinations and regrouped accordingly to the downstream demand, without intermediate stock accumulation. Taking into account that goods transit through *cross-docking-CC* are processed in short time period (less than 24 hours), complete vehicles are not necessarily used on upstream and downstream transports.

The inbound flow can transit through *cross-docking-CC* without or with processing (the pallet load having several destinations is unpacked, sorted and cross packed on other pallets, obtaining consolidated loads to each destination). Consequently, in this scenario the costs are expressed in *euro/pallet*: $C_2^{IN} = C_2^{OUT} = 1.81$ *euro/pallet* and $\beta_2 = 0,065$ *euro/km·pallet*. We used the value of *0.401 mills. Euro* per *cross-docking-CC*.

4.4. Results

The previous presented model was applied to the two scenarios, ranging *p* in the [1, 10] interval, for those 10 potential *CC* location nodes (Fig. 2). For each case we calculated logistics cost and *CC* development cost (Fig. 4), and CO_2 emissions (Fig. 5). We not considered the costs and emissions associated to the unload vehicle trips and handling and transit operations in *CC*s.

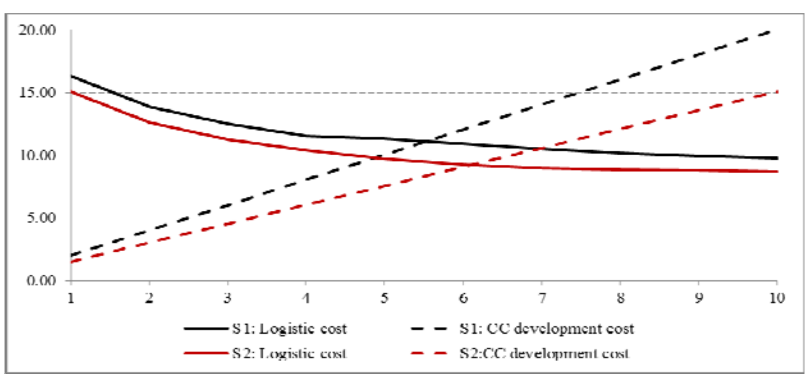


Fig. 4. Cost variation function of number of *CC*s

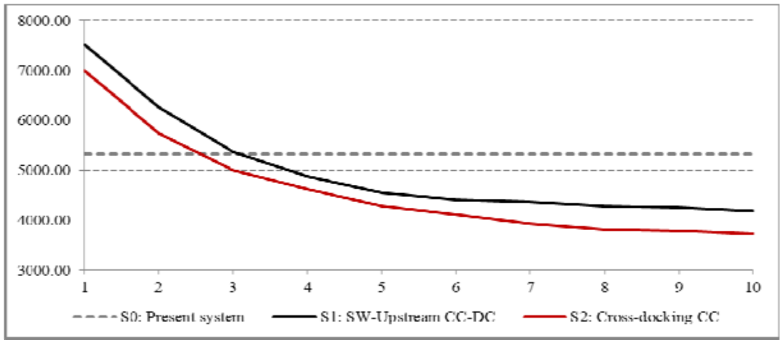


Fig. 5. CO_2 emission function of number of *CC*s

Analysing the obtained data, the proposed scenarios lead to better performance in terms of emissions. Reductions of 7% up to 44% of CO_2 emission are obtained comparative to the current situation, when 5321.5 kg are estimated in the analysis time period (T = *32 weeks* emissions are measured (Fig. 5).

In the first scenario, $p = 5$ *CC* (located in Bucureşti, Braşov, Cluj, Timişoara and Bacău) represents the optimal solution from point of view of social cost criterion. In the second scenario, the optimal solution is obtained for $p = 6$ *CC*s (in Ploieşti, Arad, Cluj, Constanța, Filiaşi and Bacău).

Even if the first scenario leads to better ecological performances (7% of CO_2 emission reducing) than those in the current situation, the resulted financial performances are weaker. This outcome could be mainly explained by the increasing of the inventory level both in *SW*s and *CC*s, deficiency not compensated by the increase of the vehicle loading rate. Instead, the second scenario offers better financial performances and the advantage of the delivery frequency increase by reducing intermediate stocks and their associated costs (however implying slight increase of the handling and preparation of loads).

5. Conclusion

Several factors, such as costs decreasing (through stock reduction and production relocation to more competitive areas in terms of labour force), more stringent requirements on delivery terms and constraints imposed to environment protection have led to low efficiency of the most current applied logistics management methods. Obviously, at each actor level unused capacities that could contribute to logistic efficiency enhancement exist.

Therefore resources mutualization in logistic system with collaborative centres consolidation of freight flows represents a solution in order to reduce transport costs (through more efficient use of transport capacity and shorter overall transport length) and pollutant emissions.

Applying such measures is quite difficult due to the complexity of the logistics chains, resource heterogeneity, but also to the main actor reticence. For that reason, mathematical models are necessary in order to emphasize the effects of resources mutualisation and flow consolidation and to convince decision makers to apply this logistic scheme. These models have to allow quantifying costs and emissions for different scenarios and leading to solutions to minimize them.

Proposing these goals, we developed a model in order to identify the optimal location of the collaborative centres in a “many-to-many” logistic system. The study for a distribution system of palletized general goods at national level presented in the paper demonstrated the utility of the model. Two scenarios with different technologies applied in the collaborative centres were proposed. The model results illustrate logistics configurations (number of *CC*s and their location) that can lead to better performances than those obtained in the current situation, with individual distribution schemes for each supplier.

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