Design of hybrid multimodal logistic hub network with postponement strategy

I. Essaadi[1, 2], B. Grabot[1, 3], P. Féniès[1, 2]

[1] Mohammed VI Polytechnic University – EMINES, Benguerir, Maroc,
[2]Paris Ouest Nanterre University, France
[3]LGP/INP-ENIT – Toulouse University, France

Imane.essaadi@emines.um6p.ma, bernard.grabot@enit.fr, pierre.fenies@u-paris10.fr

Abstract. This paper aims at suggesting a method allowing to design a logistic hub network in the context of postponement strategy, postponement being performed in hubs having industrial facilities in addition to logistic ones. We propose a two-stage mathematical mixed integer linear programming model for: 1) logistic hub network design 2) postponement location on the designed hub network. The suggested model manages characteristics not yet taken into account simultaneously in the literature: hierarchical logistic structure, postponement strategy, multi-commodity, multi-packaging of goods (raw materials or components vs. final products), multi-period planning. The solutions are compared through services levels and logistic costs.

Keywords: Logistic hub, postponement, distribution chain, service level, hierarchical structure, multi-period, multi-commodity.

1 Introduction

The implementation of networks of logistic hubs usually allows to decrease transportation costs and delivery delays in comparison with direct source/destination transportation [1]. Within logistic hubs, material flows coming from different origins are sorted, consolidated depending on their destination then transported using unimodal or multimodal transport. Two families of hubs can be distinguished: pure logistic hubs, providing standard logistic services (warehousing, inventory management, packaging, labeling, orders preparation or cross-docking, sorting and transport /distribution) and combined logistic / industrial hubs, offering high added-value services on logistics (such as co-packing) and/or industrial functionalities allowing the final customization of the product.

The late customization of products (often called "postponement") was embraced for many years by some industries such as computers, printers, medical products and fertilizers [2]. Pushing this logic to its limits, multinational firms now attempt to customize their products within their distribution centers, like Hewlett-Packard producing DeskJet printers in its factory in Singapore and customizes them for the

European and Asian markets within its European distribution center near Stuttgart, Germany. In that new context, this paper aims at defining the optimal design of a network of logistic hubs with postponement strategy integration in a context of mass customization. The distribution network is supposed to be composed of four levels: production plants, regional logistic hubs, sub-regional logistic hubs, and urban/rural distribution centers. The network processes different goods with possibly different packaging (raw materials/components and finished products).

2 State of the art

The hub network design problem, also known as the distribution network design problem, was intensively studied in the literature on global distribution networks [1, 3, 4]. An analysis of this literature is summarized in Figure 1.

Paper				Proposal	Melo und stefan (2006)	Rodriguez et al (2007)	Gelareh et al (2010)	Contreras et al (2011)	Alumur et al (2012_a)	Alumur et al (2012_b)	Albareda et al (2012)	Rieck et al (2014)	Alibeyg et al (2015)	Gelareh et al (2015)
Hub network structure	Single level					×	×	×	×		×	×	×	×
	Multiple levels			×	×					×				
Hub Features	Hub capacity	Uncapacitated hub		×			×	×	×	×	×	×	×	×
		Fixed			×	×						×		
		Extensible	Based on known capacity		×									
			To be determined											
	Hub services	Logistical hubs		×	×	×	×	×		×	×	×	×	×
		Industrial hubs		×										
Allocation strategy	Static (S)/ Dynamic (D)			S	D	S	S	S	S	S	S	S	S	D
	Single (S)/Multiple (M)			M/S		S	S	S	S	S	S		M	M
Transport Organization	Means of transportation	Transport Mode	Uni-modal			×	×	×			×	×	×	
			Multi-modal	×					×	×				
		Type of fleet of vehicles	Homogenous	×		×		×		×		×		
			Heterogenous											
		Vehicles capacity	Uncapacitated			×		×	×	×	×			
			Determined	×								×		
			To be determined											
	Transport packaging	Identical containers		×										
		Heterogeneous containers												
	Commodity information	Unitype												
		Multi-commodity		×										
	Service level	Time		×		×	×		×	×				
		Distance		×		×								

Figure 1. Logistic hub network review analysis

In the literature, few authors consider a multi-level network, like [4] while no paper addresses the integration of industrial services. Origin and destination nodes might be either allocated to a unique hub or to multiple ones: [5] considered multiple allocation of clients to located hubs while [6] studied multiple allocation of both plants and

customers to intermediate hubs. Service level can be addressed through the definition of a maximum distance between distribution center and market zone [7] or delivery delay such [8, 9]. Many papers assume the demand to be deterministic, which is seldom true, the demand usually evolving through time. Multiple commodity, allowing to consider products using different transportation means, is only considered by few researchers (cf. Figure 1).
To our best knowledge, no paper considers a physical transformation of goods while transiting a hub (from bulk material to packs or pallets for instance). [10] state that one of the main characteristics of supply chain network design models is their multi-period nature. Many studies have analyzed the advantages and disadvantages of various postponement strategies [11, 12, 13]. However, quantitative models for postponement implementation decisions are scarce: [14] consider decisions on where to implement assembly and packaging functions in a distribution network. 2) while [15] addressed the problem of facility location-allocation (plants, warehouses) considering commonality and postponement strategies in the logistic network.
This quick analysis of the literature shows that no study gathers yet all the characteristics we have chosen to address in order to answer to present real problems, summarized by the "Proposal" column in Fig. 1.

3 Problem formulation

The design of a hybrid logistic hub network involving postponement strategy implies determining simultaneously the location of the logistic hubs and of the postponement services, while defining the optimal routing of flows minimizing total logistics costs. Postponement units will have as inputs raw materials and components coming from international plants, based on their specialization and logistic costs. They will provide bagged / assembled products in response to the requirements of the market zones. These requirements may differ in terms of packaging preferences and required response time. We assume that postponement units hold sufficient component inventories for meeting the customer deterministic demands. Furthermore, we do not make a priori assumptions on the capacity of the hubs and postponement units, since we consider a new design and not the reuse of existing facilities. The capacities (processing and storage) will be determined a posteriori (through simulation) by considering the expected levels of service. Market zones are allocated to a unique hub based on logistic costs.
In this problem, the interdependence of the decisions makes it difficult to instantiate all the decision variables simultaneously. Indeed, the location of postponement units will impact the management of the logistic flow, as they constitute decoupling points. On the other hand, their location depends on the location of the logistic hubs and of the allocated demand (volume, response time and product preferences). For addressing this problem, we have chosen as a first approach to decouple the initial problem in two sub problems: definition of the logistic network, then location of the postponements facilities, even if the network structure may in theory be set into question by the positioning of the postponement units. Each sub-problem will be modeled by a deterministic mixed integer linear programming models (cf. §3.1 and §3.2)

3.1. First Sub-problem: logistic hub location problem

Within this sub-problem we have to decide: 1) the location of hub h among potential locations H using the z_h binary variable. 2) The allocation of the origin and destination nodes to the located hubs, using transport mode m represented by the $y_{o,d}{}^{m}$ binary variable. This latter is defined only if a modal link between node "o" and "d" exists i.e. Link (o, d, m) =1. 3) The flows routing within the network $x^{m,k,t}{}_{o,d}$ i.e. the amount of final product k originated from plant p and transported from node "o" to node "d" using vehicle mode m and under packaging n at period t. The generated solution must provide the best benefit considering the initial investment to open hubs, the total transportation costs including customs, the external handling cost with seaport terminal or rail terminals and the internal handling cost within opened hubs (Eq 1):

$$Min(\mathrm{Cos}\,t) = \sum_{h\in H} co_h \times Am \times z_h + \sum_{m\in M, t\in T, o\in O, d\in D} (ct_m + cd^m_{o,d}) \times NV^{m,t}_{o,d} + \tag{1}$$

$$+ \sum_{\substack{m\in M, n\in N, t\in T,\\ k\in K_p, o\in O, h\in H,\\ d\in D | o\neq h\neq d}} cm^m_h \times (NV^{m,t}_{o,h} + NV^{m,t}_{h,d}) + cm^n\_\mathrm{int}_h \times (x^{m,k,t,n}{}_{o,h} + x^{m,k,t,n}{}_{h,d}) \times f^n$$

Subject to:

$$\sum_{m\in M, h\in H} y^m_{h,z} = z_h \qquad \forall h \in H \wedge z \in Dz \wedge Link(h,z,m) = 1 \tag{2}$$

$$\sum_{m\in M, h_1\in H} y^m_{h_1,h_2} = z_{h_2} \qquad \forall h_2 \in H \wedge Link(h_1,h_2,m) = 1 \tag{3}$$

$$\sum_{m\in M, h_1\in H} y^m_{h_1,h_2} = z_{h_2} \qquad \forall h_2 \in H \wedge Link(h_1,h_2,m) = 1 \tag{4}$$

$$y^1_{p,h} + y^2_{p,h} \leq z_h \qquad \forall h \in H_1 \wedge \mathrm{p} \in P \wedge m \in \{1,2\} \wedge Link(p,h,m) = 1 \tag{5}$$

$$y^2_{h_1,h_2} + y^3_{h_1,h_2} \leq z_{h1} \qquad \forall m \in \{2,3\} \wedge h_1,\mathrm{h}_2 \in H \wedge \mathrm{Link}(h_1,\mathrm{h}_2,\mathrm{m})=1 \wedge \mathrm{Dist}(\mathrm{h}_1,\mathrm{h}_2,\mathrm{m}) \leq \mathrm{D(m)} \tag{6}$$

$$y^2_{h_1,h_2} + y^3_{h_1,h_2} \leq z_{h2} \qquad \forall m \in \{2,3\} \wedge h_1,\mathrm{h}_2 \in H \wedge \mathrm{Link}(h_1,\mathrm{h}_2,\mathrm{m})=1 \wedge \mathrm{Dist}(\mathrm{h}_1,\mathrm{h}_2,\mathrm{m}) \leq \mathrm{D(m)} \tag{7}$$

$$y^3_{h,z} \leq z_h \qquad \forall h \in H \wedge z \in Dz \wedge \mathrm{Link}(h,z,3)=1 \wedge \mathrm{Dist(h,z,3)} \leq \mathrm{D(3)} \tag{8}$$

$$x^{1,k,n,t,p}_{p,h_1} \leq BigM \times z_h \quad \forall h \in H1 \wedge \mathrm{p} \in P_k \wedge k \in Kp \wedge t \in T \tag{9}$$

$$x^{m,k,t,p}_{h_1,h_2} \leq BigM \times z_{h_1} \quad \forall t \in T \wedge m \in \{2,3\} \wedge k \in K_p \wedge h_1 \in H \wedge Dist(h_1,h_2,m) \leq D(m) \tag{10}$$

$$x^{3,k,t,p}_{h,z} \leq BigM \times z_h \quad \forall t \in T \wedge \mathrm{h} \in H \wedge z \in Dz \wedge k \in K_p \wedge Dist(h,z,3) \leq D(3) \tag{11}$$

$$\sum_{p\in P_k} x^{m,k,n,t,p}_{o,d} \leq BigM \times y^m_{o,d} \, \forall \mathrm{m} \in \mathrm{M} \wedge \mathrm{n} \in \mathrm{N} \wedge \mathrm{t} \in \mathrm{T} \wedge \mathrm{k} \in \mathrm{K}_p \wedge \mathrm{o} \in O \wedge \mathrm{d} \in D \wedge Link(o,d,m) = 1 \tag{12}$$

$$y^m_{o,d} \leq \sum_{p\in P_k} x^{m,k,n,t,p}_{o,d} \quad \forall \mathrm{m} \in \mathrm{M} \wedge n \in N \wedge \mathrm{t} \in \mathrm{T} \wedge \mathrm{k} \in \mathrm{K}_p \wedge \mathrm{o} \in O \wedge \mathrm{d} \in D \wedge Link(o,d,m) = 1 \tag{13}$$

$$\sum_{\substack{m\in M,\\ p\in P_k}} x^{m,k,n,t,p}_{p,h} = \sum_{m\in M, z\in Dz, h'\in H} x^{m,k,n,t+\Delta(p,h)+\theta,p}_{h,z} + x^{m,k,n,t+\Delta(p,h)+\theta,p}_{h,h'} \quad \forall k \in K \wedge \mathrm{h} \in H \wedge t \in T \tag{14}$$

$$\sum_{\substack{h_1\in H,\\ m\in M}} x^{m,k,n,t,p}_{h_1,h_2} = \sum_{z\in Dz, m\in M} x^{m,k,n,t+\Delta(h_1,h_2)+\theta,p}_{h_2,z} \quad \forall k \in K_p \wedge t \in T \wedge \mathrm{h}_2 \in H \tag{15}$$

$$\sum_{m \in M, h \in H} x_{h,d}^{m,k,t} = \mathrm{D}_{z}^{k,t} \times \mathrm{y}_{h,d}^{m} \qquad \forall k \in K_p \wedge t \in T \wedge d \in D \tag{16}$$

$$NV_{o,d}^{m,t} \geq \sum_{k \in K_p} \frac{x_{o,d}^{m,k,t}}{CT_m \times f^n} \quad \forall t \in T \wedge o \in O \wedge d \in D \wedge m \in M \wedge n \in N \tag{17}$$

Constraints (2, 3, 4) express the single allocation of nodes to hubs. Constraints (5, 6, 7, 8) control the allocation mode to physical links. Outgoing hub flows exist only if the hub is active (9, 10, 11) and require that this modal link should be already activated (12, 13). Constraints (14, 15) ensure flow conservation at each period of time where Δ (o, h) +θ is the sum of the transports to h and transit time within h. Outgoing flows toward distribution centers must be equal to their respective demand (16). Equation (17) computes the number of modal vehicles within the network where CT_m is the capacity of a vehicle.

3.3. Second Sub-problem: postponement location problem

Given a set of located hubs Hl {h∈ H/žh=1} ∪ Dz and a set of active links L={(o, d, m); o∈ O, d∈ D, m∈ M/ $\hat{y}^{m}_{o,d}$=1}, we have to select the suitable location of postponement units in the designed distribution network. Location can be either on regional hubs, sub-regional ones or on local distribution centers, in order to minimize the total logistic costs (Equation 18) where $b^{e}{}_{h}$ is a binary variable equal to 1 if the postponement unit is located on hub h at echelon e, while Bin (H, e) is a Boolean value equal to 1 if hub h is located at level e.

$$Min(\mathrm{Cos}t\_postp) = \sum_{h \in Hl, e \in E} co_h \times Am \times b_h^e + \tag{18}$$

$$[\sum_{m \in M, t \in T, o \in O, d \in D} (ct^1{}_m + cd_{o,d}^m + cm_m^1) \times NBV_{o,d}^{m,t} + \sum_{m \in M, t \in T, k \in K_b, o \in O, d \in D} cm_m^1\_\mathrm{int} \times x^{m,k,t}{}_{o,d}] +$$

$$[\sum_{m \in M, t \in T, o \in O, d \in D} (ct^2{}_m + cd_{o,d}^m + cm_m^2) \times NCV_{o,d}^{m,t} + \sum_{\substack{m \in M, t \in T, k \in K_c \\ , o \in O, d \in D, p \in Pk}} cm_m^2\_\mathrm{int} \times \overline{x}_{p,o,d}^{m,k,n,t}]$$

Subject to:

$$\sum_{e \in E} b_h^e = \hat{z}_h \qquad \forall \mathrm{h} \in H \wedge Bin(H,e) = 1 \tag{19}$$

$$\sum_{m \in M, p \in P_k} \mathrm{x}_{h_1,h_3}^{m,k,t} \leq \mathrm{BigM} \times \overline{y}_{h_1,h_2}^{m} \times \mathrm{b}_{h_3}^{3} \qquad \forall t \in T \wedge k \in K_b \wedge h_1, h_3 \in Hl \tag{20}$$

$$\sum_{m \in M, p \in P_k} \mathrm{x}_{h_1,h_2}^{m,k,t} \leq \mathrm{BigM} \times \overline{y}_{h_1,h_2}^{m} \times (\mathrm{b}_{h_2}^{2} + \mathrm{b}_{h_3}^{3}) \quad \forall \mathrm{t} \in \mathrm{T} \wedge \mathrm{k} \in \mathrm{K}_b \wedge h_1, h_2, h_3 \in Hl \tag{21}$$

$$\sum_{m \in M} x_{h_2,z}^{m,k,t} = \sum_{\substack{m \in M, k' \in K_c, \\ p \in P_k}} \hat{y}_{h_2,z}^{m} \times \overline{x}_{p,h_2,z}^{m,n,k',t+\Delta(h_2,z)+\theta} \times Conv(n) \times Cs(k,k') \times b_z^3 \tag{22}$$

$$/\forall t \in T, h_2 \in Hl, z \in Dz, k \in K_b$$

$$\sum_{m \in M} x_{h_1,h_2}^{m,k,t} = \sum_{\substack{m,m' \in M, \\ k' \in K_c, \\ p \in P_k, z \in Dz}} \hat{y}_{h_1,h_2}^{m} \times \hat{y}_{h_2,z}^{m'} \times \overline{x}_{p,h_2,z}^{m',n,k',t+\Delta(h_1,h_2)+\theta} \times Conv(n) \times Cs(k,k') \times (1 - b_{h_1}^{1}) \tag{23}$$

$$/\forall t \in T, h_1, h_2 \in Hl, k \in K_b$$

$$\sum_{m\in M} x_{h_1,z}^{m,k,t} = \sum_{\substack{m\in M, k'\in K_c, \\ p\in P_k, z\in Dz}} \widehat{y}_{h_1,z}^{m} \times \overline{x}_{p,h_1,z}^{m,n,k',t+\Delta(h_1,h_2)+\theta} \times Conv(n)\times\ Cs(k,k')\times(1-b_{h_1}^{1}) \qquad (24)$$

$$/\forall t\in T, h_1, h_2 \in Hl, k\in K_b$$

$$NBV_{o,d}^{m,t} \geq \sum_{k\in K_b, p\in P_k} \frac{x_{p,o,d}^{m,k,t}}{CT_m^1} \times NV_m \ ;\forall t\in T \wedge m\in M \wedge h\in Hl \wedge h_3 \in Dz \qquad (25)$$

$$NCV_{h,h_3}^{m,t} \geq \sum_{e\in E} b_h^e \times [\sum_{k\in K_c, p\in P_k, n\in N} \frac{\overline{x}_{p,h,h_3}^{m,k,n,t}}{CT_m^2 \times f^n}] / \forall t\in T \wedge m\in M \wedge h\in Hl \wedge h_3 \in Dz \qquad (26)$$

$$NCV_{h_2,h_3}^{m,t} \geq (b_{h_1}^1 + b_{h_2}^2)\times[\sum_{\substack{k\in K_c, \\ p\in P_k, n\in Pg}} \frac{\overline{x}_{p,h_2,h_3}^{m,n,k,t}}{CT_m^2 \times f^n}] / \forall t\in T \wedge m\in M \wedge h_1, h_2 \in Hl \wedge h_3 \in \mathrm{Dz} \qquad (27)$$

$$\forall z\in Dz \qquad (28)$$

$$\Delta(z) = \sum_{m,m',m''\in M, h_1, h_2\in Hl} [(\Delta(m,h_1,z) + \delta_{h_1} \times \frac{D_z^{k,t,n}}{f^n} + \theta_{postp} \times D_z^{k,t,n} \times Conv(n)) \times \overline{y}_{h_1,z}^{m}$$

$$+(\Delta(m,h_1,h_2) + \Delta(m',h_2,z) + (\delta_{h_1} + \delta_{h_2}) \times \frac{D_z^{k,t,n}}{f^n} + \theta_{postp} \times D_z^{k,t} \times Conv(n)) \times \overline{y}_{h_2,z}^{m'}] \times b_{h_1}^1$$

$$[\Delta(m'',h_2,z) + \delta_{h_2} \times \frac{D_z^{k,t,n}}{f^n} + \theta_{postp} \times D_z^{k,t} \times Conv(n)] \times b_{h_2}^2 \times \overline{y}_{h_2,z}^{m''}$$

$$+\theta_{postp} \times D_z^{k,t} \times Conv(n) \times b_z^3 \leq \Delta L_z$$

Constraint (19) translates that a postponement activity can only be located on activated hubs, at only one level. “Continuous flows” $x^{m,k,t}_{o,h}$ exist only if postponement units are located before that hub if a modal link is activated (20, 21). (22, 23, 24) express a flow balance at each period and on each hub and computes the ingoing discrete flows to each hub depending on location of postponement units. Conv(n) is the conversion ratio from unit of packaging product under n commodity to a continuous unit (tons for example) and Cs(k, k’) is the amount of component k needed to produce a unit of product k’. (25, 26, 27) assess the number of bulk and container vehicles within the network. Let ΔL_z be the requirement of a market zone on the level of service. (28) expresses the requirement on the service level where Δ(m’, h, z) is the transportation time from postponement units, δ_h the transit processing time within transited hubs and θ_{postp} the unit postponement time.

4. Illustrative study

This case study aims to illustrate the application of the proposed models. It concerns the location of blending units within East Africa for specific industries involving hybrid (discrete-continuous) flows, like the fertilizer industry. Three production zones located in Morocco, Ethiopia and Nigeria and considered. Five Regional hubs are defined: Kenya-Angola-Tanzania-Djibouti, so that ten sub-regional hubs: Nairobi-

Kisumu-Dodoma-Arusha-Tabora-Kuito-Tete-Lichinga-Kigali. The considered data are summarized in Tables 1 and 2. The demand (aggregated on one year) varies for each zone. We assume that shipment is done every month and that all the market zones require the same service level. Distances and traveling times are extracted from Google Maps. The problem was solved using the Xpress-IVE solver tools. The results of models 1 and 2 are summarized in Tables 3 and 4.

Table 1. List of transport cost parameter

Parameter	Discrete flow	Continuous flow
Transport capacity-sea	50 palette	30000 Tons
Transport capacity-rail	40 palette	25000 Tons
Transport capacity-road	40 palette	25000 Tons
Rail unit transport cost	0.06/train/km	0.04/Train/km
Road unit transport cost	3.75$/truck/km	2$/truck/km

Table 2. List of other cost parameters

Cost	Regional hub	Sub-regional hub
Hub Location cost ($/year)	5760000	2880000
Blending location	30000	30000
Intern handling (bulk)	15$/Tons	35$/Tons
Extern handling (rail)	100 $/train	120 $/train
Intern handling (discrete)	5 $/palette	10 $/palette
Extern handling (rail) (discrete)	40 $/train	50 $/train

Table 3. Results of sub-model 1

Located hub	Plant	Sub-hub	% DC
Kenya	Morocco Ethiopia	Kisumu- Lichingua	25%
Mozambique	Morocco	Tete	10%
Angola	Nigeria	luau	10%
Tanzania	Morocco Ethiopia	Kuito-Kigali	10%

Total logistic cost	216 M$
Sea Transport	9.52 M$
Rail Transport	8.75 M$
Road Transport	21.97 M$
Intern handling	109.45 M$
Extern handling	26890.5 $
Location	66.3 M$

Table 4. Results of sub-model 2

Blending location	Kenya-Mozambique-Angola-Tanzania
Level	1

Total logistic cost	157 M$
Total bulk costs	47.1 M$
Total discrete costs	109.9 M$

5. Conclusion et research perspectives

In the context of mass customization, postponement activities may provide an answer to fulfill customized orders, increase customer responsiveness and increase service level. However, the literature combining design of logistic hub networks and implementation of postponement facilities is scarce and usually assumes that the location of the distribution centers are already known. In order to address the problem, we have developed and tested a two-phase deterministic mathematical programming model where, as a first step, we design incapacitated discrete logistic hub, then allocate postponement services on some hubs. In our future work, this model will be coupled with a discrete event simulation model in order to take into consideration uncertainties on the demand and on the availability of the resources. Simulation will also allow to assess postponement capacities and to refine logistic costs, these results being re-injected in the mathematical model as new constraints.

References

1. S. Alumur and B. Y. Kara, Network hub location problems: The state of the art, European Journal of Operational Research, 190(1), pp. 1–21, 2008.
2. H.-W. Wang, R.-Q. Chena, and Y. Li, Case study on the application of postponement strategy and managerial insights, Asia Pacific Management Review, 11(3), pp. 141–153, 2006.
3. J. F. Campbell and M. E. O'Kelly, Twenty-five years of hub location research, Transportation Science, 46(2), pp. 153–169, 2012.
4. S. A. Alumur, H. Yaman, and B. Y. Kara, Hierarchical multimodal hub location problem with time-definite deliveries, Transportation Research Part E: Logistics and Transportation Review, 48(6), pp. 1107–1120, 2012.
5 S. Gelareh, R. Neamatian Monemi, and S. Nickel, Multi-period hub location problems in transportation, Transportation Research Part E, 75, pp. 67–94, 2015.
6. H. Sohrabi, B., Montreuil, and W. Klibi, On Comparing Dedicated and Hyperconnected Distribution Systems: An Optimization-Based Approach. ILS 2016, 1-4 June, Bordeaux, France, 2016.
7. M. T. Melo, S. Nickel, and F. S. Da Gama, Dynamic multi-commodity capacitated facility location: a mathematical modeling framework for strategic supply chain planning, Computers & Operations Research, 33(1), pp. 181–208, 2006.
8. S. A. Alumur, B. Y. Kara, and O. E. Karasan, Multimodal hub location and hub network design, Omega, 40(6), pp. 927–939, 2012.
9. V. Rodriguez, M. J. Alvarez, and L. Barcos, Hub location under capacity constraints, Transportation Research Part E: Logistics and Transportation Review, 43(5), pp. 495–505, 2007.
10. M. Albareda-Sambola, E. Fernandez, and S. Nickel, Multiperiod Location-Routing with Decoupled Time Scales, European Journal of Operational Research, 217(2), pp. 248–258, 2012.
11. B. Yang and N. Burns, Implications of postponement for the supply chain, International Journal of Production Research, 41(9), pp. 2075–2090, 2003.
12. R. I. Van Hoek, The rediscovery of postponement a literature review and directions for research, Journal of operations management, 19(2), pp. 161–184, 2001.
13. J. Hsuan Mikkola and T. Skjøtt-Larsen, Supply-chain integration: implications for mass customization, modularization and postponement strategies, Production Planning & Control, 15(4), pp. 352–361, 2004.
14. F. Schwartz, S. Voss, and J. A. Ceroni, Designing distribution networks taking into account aspects of postponement, in The Development of Collaborative Production and Service Systems in Emergent Economies, Proceedings of the 19th International Conference on Production Research, 2007.
15. L. Schulze and L. Li, Location-allocation model for logistics networks with implementing commonality and postponement strategies, in Proceedings of the International Multi Conference of Engineers and Computer Scientists, 2, pp. 1615–1620, 2009.
16. I. Contreras, J.-F. Cordeau, and G. Laporte, Stochastic uncapacitated hub location, European Journal of Operational Research, 212(3), pp. 518–528, 2011.
17. J. Rieck, C. Ehrenberg, and J. Zimmermann, Many-to-many location-routing with inter-hub transport and multi-commodity pickup-and-delivery, European Journal of Operational Research, 236(3), pp. 863–878, 2014.
18. A. Alibeyg, I. Contreras, and E. Fernandez, Hub Network Design Problems with Profits, Transportation Research Part E: Logistics and Transportation Review, 96, pp. 40-59, 2015.
19. S. Gelareh, S. Nickel, and D. Pisinger, Liner shipping hub network design in a competitive environment. Transportation Research Part E: Logistics and Transportation Review, 46(6), pp. 991-1004, 2010.