APPROACHES TO DISTRIBUTION CENTRE'S LOCATION PROBLEM AND ITS ROLE IN GREEN SUPPLY CHAIN MANAGEMENT

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Abstract

Location represents one of the five integrative areas of a supply chain management that refers to situating of facilities within a given space. Facilities of each supply chain member differ in the role one plays in supply chain and their objective function. As such, facility location problem solving accounts for different indices included into a model. Distribution centres are facilities of key importance for supply chain management. Proper location decision might add value and create value added that will significantly affect total logistics costs, service level and the whole value chain. An advanced pace in globalization, information technology development and competition results in even faster changes of consumer needs and increased demand uncertainty. This imposes even more challenge for a good location models responsive to the specific needs of the supply chain as a whole.

The aim of this paper is to provide a broad review of distribution centre location planning models from the perspective of supply chain design and to address issues these decisions have on environmental and resource utilization.

Keywords: location, distribution centre, location problems, models, green supply chain management

1. INTRODUCTION

Distribution centre (DC) can be defined as a physical facility used to complete the process of product line adjustment in the exchange channel (Bowersox et al., 1968, p.246 as cited by Hesse, 2004, p.163). Although DCs developed from warehouses their primary emphasis is placed upon product flow in contrast to storage that remains the main feature of warehouses (Bowersox et al., 1968, p. 246 as cited by Hesse, 2004, p.163). This is even more explicit in Higginson and Bookbinder (2005, p.68) when depicting DC as a type of warehouse where storage of goods is limited or non-existent. Main activities carried out in today's DCs are: Receiving; Temporary storage; Pick operations; Value added activities and production lines; Shipping; Returns processing; and data processing and office functions (Strauss-Wieder 2001, p. 10).

The problem of DC's location is a part of a more general location analysis whose origins could date back to 17th century (Hale & Moberg, 2003, p.22-23; ReVelle & Eiselt, 2005, p.5). Since then a vast number of scholars and pieces of literature emerged spanning over various academic disciplines and professions especially flourishing during the last five decades (see e.g. Daskin, 2008, p.291-292; Hale & Moberg, 2003, p.23; Montreuil, 2009, p.5-2; ReVelle & Eiselt, 2005, p.1).

As a branch of operational research, location analyses refers to the modelling, formulation, and solution of a class of problems that can be described as siting facilities in some given space (ReVelle & Eiselt, 2005, p. 1). According to the same authors, location problems can be described by the following elements: (1) customers, who are presumed to be already located at points or on routes, (2) facilities that will be located, (3) a space in which customers and facilities are located, and (4) a metric that indicates distances or times between customers and facilities (ReVelle & Eiselt, 2005, p.1).

From the supply chain management (SCM) perspective, DC's location analysis is a part of a broader facility management constrained by the set of decisions that relate to the role, capacity, suppliers and markets allocated to each facility within supply chain (Hugos, 2003, p.83). Similarly, as noted by Goetschalckx, distribution system design decisions concentrate to resolve a problem on an adequate number of DCs, their location, customer and product allocation as well as their throughput and storage capacity (Goetschalckx, 2009, p.9-2). Holistic approach to DC's location analysis involves solving interrelated logistics conflicts especially those of customer service levels and costs in order to meet objectives of the value chain of suppliers and customers.

As depicted by Bowen, DCs are the nerve centers for increasingly global supply and distribution networks (Bowen, 2008, p. 379) and nodes of the network that must be laid out as best as possible to achieve its [their] mission, and similarly be located as best as possible to leverage network performance (Montreuil, 2009, p. 5-1). Network design either of supply chain either of distribution system and their optimisation deal with solving DC's location issues and need a good location models.

With the rise of consciousness on environment and on positive outcomes of the supply chain's greening - increased resource productivity, reduced waste, improved productivity and enhanced competitiveness as pointed out by Porter & Linde (Porter & Linde, 1995) - interdisciplinary research field for green supply chain management started to develop. As defined by Srivastava, green supply chain management (GSCM) represents integrating environmental thinking into supply-chain management, including product design, material sourcing and selection, manufacturing processes, delivery of the final product to consumers as well as end-of-life management of the product after its useful life (Srivastava, 2007, p.54). Green supply chain is seen as a part of wider sustainable supply chain management. As generally defined by United Nations World Commission on Environment and Development (WCED), sustainable development is development that meets the needs of the present without compromising the ability of future generation to meet their own needs (WCED, 1987, p.41). Accordingly, sustainable supply chain management can be defined as the management of material, information and capital flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e., economic, environmental and social, into account which are derived from customer and stakeholder requirements (Seuring&Müller, 2008, p.1700). related to all this, DC's design should integrate green thinking into decision ranging from the choice of an adequate location and construction materials to layout design all aimed to resource savings and minimization of negative impacts on the environment.

The aim of the paper in the parts that follow is to provide a broad review of DC location planning models and to address issues these decisions have on environmental and resource utilization.

2. DC'S LOCATION MODELS

Within wider context of supply chain management, facility location decisions, including those of DCs, should be aligned with industry company works in, type of products, as well as overall company's and supply chain's strategy. As pointed out by Bowen, the locational proclivities of warehousing establishments [as well as of DCs] reflect broader tendencies in supply chain management (SCM) (Bowen, 2008, p.379-380). In other words, there is no „one fits all solution".

The locational goal of most DCs is to select a site that offers the lowest possible transportation costs with the easiest access to the greatest number of customers. The locational process typically used in the selection of an appropriate site takes into consideration the products for which a distribution facility is desired; the market area or areas that are to be served and the degree of market penetration necessary. Just-in-time has increased significantly the importance of being within a day's travel time (500 mile maximum) of supplier and customers (Empire State Development, 2008, p.6). The most important general factors that will mainly prevail in DC site-selection decision can be found in e.g. Dixon 1999; Empire State Development, 2008, p.6.

Due to interdisciplinary nature of location research as well as many stakeholders involved into supply chain design, highly complex and data-intensive engineering design efforts are needed (see e.g. Goetschalckx, 2009, 9-1).

Since facility location problems have proven to be a fertile ground for operations researchers (Daskin, 2008, p.283), they left significant legacy, especially of algorithms, to logisticians and SCM researchers used for solving DC's location as well.

2.1. Classification of models

There are many criteria that can be used for classification of facility problems, models and their extensions. Due to space restriction of the paper, only very broad classification of models by topography or basic space in which the problem is embedded is given herein. There is vast literature dealing with specifics and in detail of many location problems.

2.1.1 Planar models

The model presumes demands and infinite set of facility's candidate locations to accommodate them that may occur anywhere on a plane while distance metrics employed between (x_i, y_i) and (x_j, y_j) is a norm either the Manhattan or right-angle distance, the Euclidean or straight-line distance, the l_{pi} - distance metric as a generalization of Euclidean distance or other (Drezner, & Hamacher, 2004, p 15; Klose & Drexl, 2005, p. 6).

The objective of the model is to determine the location of a single facility (represented by coordinates X, Y in a plane) such that the sum of weighted Euclidean distances to demand points *i* (represented by coordinates x_i, y_i) is minimized (Daskin, 2008, p. 284).

These models can be solved by nonlinear programming. Although they are insufficient for solving real-world problems, they contribute as an approximation of network model solution.

Many real-life problems are discrete or network location problems as the one of DC's location.

2.1.2. Discrete models

Discrete location models assume finite set of available candidate sites for facility establishment and arbitrary distance between nodes, derived from planar or network distances. These models are generally more difficult to solve as modelled as mixed integer programmes. A model can comprise many real-world assumptions that cannot be included into other models. A solution technique is exact (optimal) or heuristic (approximately optimal). Many of these models are NP-hard.

Discrete models can be divided into three broad areas that include - covering-based models that determine the critical coverage distance or time for serving demand in order to be counted as "covered" or "served adequately"; median-based models that minimize the demand weighted average distance between a demand node and the facility to which it is assigned and the models that can not be classified into any of the previous two (Daskin, 2008, p.285).

2.1.3. Network models

Network location models assume network space composed of nodes and links. Nodes are points of the network where demands occur while links are where travel between demand sites and facilities occur. New facilities can be sited anywhere on the network (absolute centres) while the distance between two points is computed as the shortest distance on the network. The objective of the problem is to determine the location of *p* facilities on network such that the demand-weighted total distance between the facilities and the nodes is minimized. Therefore, the demand is assigned to the closest facility. This class of problem is termed as *p*-median problem on the network for which exists at least one optimal solution that has all *p* facilities located solely at the nodes of the network – node centers (ReVelle & Eiselt, 2005, p.7-9).

For the formulation of the problem (see e.g. Daskin, 2008, p. 287; Marianov & Serra, 2009, p.4; ReVelle & Eiselt, 2005, p.7).

Logistics engineering benefits from these problems and algorithms set. As stated by Goetschlackx the objective of the distribution system design is to minimize the time-discounted total system cost over the planning horizon subject to service-level requirements. The total system cost includes facility costs, inventory costs, and transportation costs. The facility costs include labor, facility leasing or ownership, material handling and storage equipment, and taxes (Goetschalckx, 2009, 9-2).

In that order the following models for distribution system design can be distinguished (Goetschlackx, 2009, 9-9 – 9-15).

2.2. K-Median Model

This model solves the problem of number and location of DCs and the customer allocations with objective of minimizing the total system cost. It assumes establishment of DCs anywhere over distribution area as it is wholly covered by the set of customers (planar problem). Model assumes binary variable status of DC, no capacity restrictions to DCs and no upper bound for customer allocation. The problem can be formulated as in (Goetschlackx, 2009, 9-9).

The problem can be solved with a mixed-integer programming solver. The advantages of the model are its practical usage for realistic problems solving, control delivery to designer of the system over upper bound of DCs to be established and assignment costs. The main disadvantages of the model are a single time period usage and an exclusion of site-related costs.

2.3. Location-allocation models

This model delivers solution to location and customer allocation problem considering transportation costs only. Beside DCs and customers, it considers sourcing facilities (plants) and flows between them, as well. Unlike the previous, this model allows uncovered design area and capacitated DCs. Location allocation model is conducted by two sub - algorithm /phases. The first, allocation phase, starts with predefined DCs locations for which network flow algorithm calculates the transportation distances d and allocate customers within the available DCs capacity. The second, location phase, determines the new locations for DCs by computing the minimum sum of the weighted distances for each flow between each plant and DC. The problem can be formulated as in (Goetschlackx, 2009, 9-12).

While the network flow formulation can be solved by a linear programming solver, the solution of the location phase is iterative and represents an approximation of the DC location dependable on the DCs initial phase configuration.

The advantages of the model are inclusion of capacity variables and establishment of DCs even in those areas not covered by customers. Moreover, it locates DCs within design area without considering its feasibility within the area (e.g. due to natural or artificial obstacles of terrain) turning this to its disadvantage. Besides this, it gives an approximate solution to DCs siting and suffers from the same deficiencies as K-median problem.

2.4. Warehouse Location problem

This model sets DCs within a finite set of candidate locations (discrete model; a site-selection model) for which site- dependent costs are also known and can be included into the model. It assumes no capacity restrictions. Decision on location of DCs represents a trade-off between fixed and variable transportation costs. The problem can be formulated as in (Goetschlackx, 2009, 9-12).

The model can be reformulated to include site-dependent costs or to evaluate savings of the opening of new DC (Goetschlackx, 2009, 9-12).

2.5. Geoffrion and Graves Distribution System Design Model

This model includes constraints on capacity and single-sourcing. It is formulated as (Goetschlackx, 2009, 9-14):

$$Min \sum_{ijkp} c_{ijkp} x_{ijkp} + \sum_{j} \left(f_j z_j + h_j \sum_{kp} dem_{kp} y_{jk} \right) \qquad (1)$$

$$s.t. \sum_{jk} x_{ijkp} \leq cap_{ip} \qquad \forall ip \qquad (2)$$

$$\sum_{i} x_{ijkp} = dem_{kp} y_{jk} \qquad \forall jkp \qquad (3)$$

$$\sum_{j} y_{jk} = 1 \quad \forall k \tag{4}$$

$$TL_j z_j \leq \sum_{pk} dem_{kp} \; y_{jk} \leq TU_j z_j \;\; \forall j \tag{5}$$

$$x_{ijkp} \geq 0 \;,\; y_{jk} \in \{0,1\},\; z_j \in \{0,1\} \tag{6}$$

where:

c_{ijkp}	Unit transportation cost of servicing customer *k* from supplier *i* through depot *j* for product *p*.
f_j	Fixed cost for establishing a DC at candidate location *j*.
h_j	Unit handling cost for DC at candidate location *j*.
cap_{ip}	Supply availability (capacity) of product *p* at supplier *i*.
dem_{kp}	Demand for product *p* by customer *k*.
TL_j, TU_j	Lower and upper bounds on the flow throughput of DC at candidate location *j*.
z_j	Status variable for DC at candidate location *j*, equal to 1 if it is established, zero otherwise.
y_{jk}	Assignment variable of customer *k* to DC at candidate location *j*, equal to 1 if the customer is single –sourced from center, zero otherwise.
x_{ijkp}	Amount of flow shipped by supplier *i* through DC *j* to customer *k* of product *p*.

Constraint (1) minimizes the sum of the transportation cost, fixed facility costs, and DCs handling costs.

Constraint (2) ensures sufficient product availability at the suppliers.

Constraint (3) ensures that the customer demand is met for each product and ensures conservation of flow for each product at the DCs.

Constraint (4) forces every customer to be assigned to a DC.

Constraint (5) ensures that the flow through the DCs does not exceed the throughput capacity and that, if a DC is established, it handles a minimum amount of flow.

This problem formulation is solved by Bender's decomposition and can be used for many real-world situations. Although advances in computer processors and commercial software do not impose use of Benders decomposition, it is still necessary in cases of largest problems or uncertainty (for details see e.g. Goetschlackx, 2009, 9-15).

Besides mentioned, there are many other models that do not include real-world assumptions and the limitation. In spite of that they can be used as a simple and good starting point for determining candidate location for DC's siting. These include *locational cost-profit-volume analysis* that indicates the best one among many candidate locations by analysing total cost, total profit and break-even output level, *the transportation model*, *factor rating* or *center-of-gravity method* (Stevenson, 2009, p.385-388; Swink et al, 2011, p.329).

3. CONCLUSION

A broad review of distribution centre planning models from the perspective of supply chain design has been presented in this paper. Various approaches to distribution centre's location have been provided as well. Due to long tradition and interdisciplinary nature of the location research many location models, their variations and extensions have been developed so far and incorporated into a huge location research area. As simplifications of reality, models presented herein represent very broad basics used to solve a wide spectrum of real-world problems that are not restricted only to geographically siting of distribution centres.

Due to strategic importance of location decisions and many stakeholders included and affected by them, location research continues to be a very vivid study area dealing with research topics and models as new issues emerge. Environmental issues, as land resources use and green transportation, are some of them.

Modern distribution systems and supply chain design require adequately located facilities that will minimize costs of opening and operating them as well as costs of outbound and inbound transportation costs while maintaining the service level demanded by customers. Since many of the current supply chain management practices have been questioned from the perspective of green and sustainable, especially in relation to land use and transportation, new solutions have already been designed and implemented, at least by the most successful actors. Support of information technology in this field is inevitable. All this transform a location deciding to a business process that enables sustainable or at least green differentiation, competitiveness and overall prosperity.

4. REFERENCES AND SOURCES OF INFORMATION

1. Bowen, J.T.Jr.: Moving places: the geography of warehousing in the US, Journal of Transport Geography, Vol. 16, No. 6, November, 1, 2008
2. Chhajed, D.; Francis, R.L.; Lowe, T.J.: Contributions of Operations Research to location Theory, College of Commerce and Business Administration, University of Illinois at Urbana-Champaign, 1992
3. Daskin, M.S.: What You Should Know About Location Modelling, Naval Research Logistics, Vol.55, No. 4, 2008
4. Daskin, M.S.; Snyder, L.V.; Berger, R.T.: Facility location in supply chain design in
5. Langevin, A.; Riopel, D., eds: Logistics Systems: Design and Optimization, Springer, New York, 2005
6. Daskin, M.S.: Network and Discrete Location: Models, Algorithms, and Applications, John Wiley & Sons, Inc., New York, 1995
7. Dixon, R.: How to Select an Optimal Distribution Site, Site Selection Magazine, September, 1999
8. Drezner, Z.; Klamroth, K.; Schöbel, A.; Weselowsky, G.O.: The Weber problem in Drezner, Z.; Hamacher, H.W., eds.: Facility location: application and theory; Springer-Verlag, Berlin-Heidleberg, 2004
9. Empire State Development: Development profile for Warehouse/Distribution/Logistics Center Sites, State of New York, New York, August, 2008

10. Goetschalckx, M.: Distribution system design in Taylor, G.D., ed.: Introduction to logistics engineering, Taylor & Francis Group, LLC, Boca Raton – London - New York, 2009
11. Hale, T.S.; Moberg, C.R.: Location Science Research: A Review, Annals of OperationsResearch, Vol.123, No. 1-4, October, 2003
12. Hesse, M.: The city as a terminal: the urban context of logistics and freight transport, Ashgate Publishing Company, Aldershot – Burlington, 2008
13. Hesse, M.: Land for Logistics: Locational dynamics, real estate markets and political regulation of regional distribution complexes, Journal of Social and Economic Geography / Tijdschrift voor Social en Economische Geografie, Vol.95, No.2, April, 2004
14. Hesse, M.; Rodrigue, J.P.: The transport geography of logistics and freight distribution, Journal of Transport Geography, Vol.12, No. 3, September, 2004
15. Higginson, J.K.; Bookbinder, J.H.: Distribution centres in supply chain operations in
16. Langevin, A.; Riopel, D., eds: Logistics Systems: Design and Optimization, Springer,
17. New York, 2005
18. Hugos, M.: Essentials of Supply Chain Management, John Wiley and Sons, Inc., Hoboken, New Jersey, 2003
19. Klose, A; Drexl, A.: Facility location models for distribution system design, European Journal of Operational Research, Vol.162, No. 1, April, 4, 2005
20. Marianov, V.; Serra, D.: Median problems in networks in Eiselt, H.A.; Marianov, V. eds: Foundations of Location Theory, Springer, New York-Dordrecht-Heidelberg-London, 2011
21. Montreuil, B.: Facilities location and layout design in Taylor, G.D., ed.: Introduction to
22. logistics engineering, Taylor & Francis Group, LLC, Boca Raton – London - New York, 2009
23. Porter, M. E., and Claas van der Linde. " Green and Competitive: Ending the Stalemate." Harvard Business Review, Vol. 73, no. 5, September–October, 1995.
24. ReVelle, C.S.; Eiselt, H.A.: Location analysis: A synthesis and survey, European Journal of Operation Research, Vol. 165, No. 1, August, 16, 2005
25. Segetlija, Z.: Uvod u poslovnu logistiku, II. izmjenjeno i dopunjeno izdanje, Ekonomski fakultet, Osijek, 2008
26. Seuring, S.; Müller, M.: From a literature review to a conceptual framework for
27. sustainable supply chain management, Journal of Cleaner Production, Vol. 16, No. 15.,
28. October, 2008
29. Srivastava, S.K.: Green supply-chain management. A state-of-the-art literature review,International Journal of Management Reviews, Vol. 9, No. 1, February, 28, 2007
30. Stevenson, W.J.: Operations management, 10th edition, McGraw-Hill/Irwin, New York, 2009
31. Strauss-Wieder, A.: Warehousing and Distribution Center Context. NJPTA Brownfield
32. Economic Redevelopment Project. Prepared for the New Jersey Transportation Planning
33. Authority, February, 2001
34. Swink, M.; Melnyk, S.A.; Cooper, M.B.; Hartley, J.L.: Managing Operations Across the
35. Supply Chain, McGraw-Hill/Irwin, New York, 2011
36. World Commission on Environment and Development: Our Common Future, August, 4, 1987