Accessibility in designing centralised warehousing: Case of health care logistics in Northern Finland

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ABSTRACT

Long distances and sparse service networks set challenging conditions for material logistics in health care. Globally, health care organisations have been making structural changes towards centralised warehousing and deliveries. In Northern Finland, material logistics of the public health care system rely mainly on numerous separate order and delivery systems, although logistics needs, ordering and stock in different health care facilities correspond to each other. As centralised logistics in orders and deliveries may lead to remarkable savings, pressure for centralised management is high. This paper analyses how effectively a potential centralised warehousing system can be organised based on its spatial components. These include optimal location of one or more warehouses, delivery network coverage and efficiency of routes, as well as accessibility of health centres and hospitals. The geographic information systems (GIS) -based accessibility analytical framework described in this study applies vehicle routing and heuristic computations to location-allocation of warehouses to potential sites by optimising transport cost with a constraint to provide service to at least 90% of delivery demand. The spatial data include the road network, health care facility locations with rough estimates of freight demand nodes and potential locations of warehouse facilities. The main findings of the study show that majority of health centres and hospitals can be effectively reached by a delivery network based on one or two warehouses. Furthermore, the efficiency of the delivery network does not increase remarkably by increasing the number of warehouses, when measured as driving time.

1. Introduction

Healthcare systems in all parts of the world are under pressure to improve performance in service terms and in relation to cost efficiency. In addition to patient processes, these challenges also pertain to the various support activities such as materials management and logistics. Compared to industrial and retail organisations, the opportunities for logistics improvements have, however, received relatively little attention in the healthcare sector. There are unique features that affect the applicability of logistics knowledge from the industrial sector to healthcare (de Vries & Huijsman, 2011), but evidence shows that logistics innovations can in fact offer significant potential for performance improvements also in healthcare (e.g. Jarrett, 1998).

Cost pressures have led healthcare organisations to consider structural changes for reducing costs while still gaining value (Kaplan & Porter, 2011). Lower cost-structures and increasing service levels in healthcare are achieved in many cases by redesigning material logistics (Poulin, 2003), for instance by centralising warehouses (Kumar, Ozdamar, & Ning Zhang, 2008). Sometimes these reforms also aim at more comprehensive changes in healthcare supply chains in the manner of industry-led initiatives such as quick response (QR) or efficient consumer response (ECR) for instance (Landry & Philippe, 2004).

Designing and analysing hub locations of freight and passengers have been on fields of academic studies for 30 years (Campbell & O’Kelly, 2012) and a significant extent of research contributions
have been provided by operations research, logistics, supply chain management, operations management, geography, network design, telecommunications, regional science and economics including interdisciplinary perspectives (see Farahani, Hekmatfar, Arabani, & Nikbaksh, 2013; Geoffrion & Powers, 1995). A vast number of location-allocation models have been developed for different analytical needs, even though they share a common theoretical background (see Lei, Church, & Lei, 2016; Polo, Acosta, Ferreira, & Dias, 2015). The warehouse location optimisation problem as a spatial analysis is a subtype of graph-based facility location problems (Brahimi & Khan, 2014; Rodriguez, Comtois, & Slack, 2013: 176–179, 306–317). Thus, the warehouse location problem can be scrutinised by simulated delivery routes (Bozona & Gebresenbet, 2011; Prodhon & Prins, 2014). Geographic information systems (GIS) are applied widely to solve spatial location problems (Miller & Shaw, 2001; Tong & Murray, 2012) having relevance also in the field of health care (Cromley & McLaughlin, 2011), and in the context of freight GIS offers an adaptive framework for spatial optimisation of delivery routes and location-allocation analysis of warehousing facilities (Bozkaya, Yanik, & Balcisoy, 2010).

In this paper we focus on logistics systems in public healthcare in Finland, especially in the northern part of the country. We are particularly interested in the opportunities for healthcare organisations to adopt centralised warehousing operations, a strategy that has generated considerable savings in logistics costs (e.g. Becker, Görke, Felix, & Schmidt, 2016), reduction of environmental impacts (e.g. Kahn & Brodin, 2008), and also service-level improvements (e.g. Abrahamsson, Aldin, & Stahre, 2003) in various manufacturing and retail industry settings. Again, the sparse population and long distances create special challenges for the logistics management of healthcare organisations. In Northern Finland, 742,000 inhabitants live in the area of 172,600 km². This results in a sparse population density of 4.3 inhabitants per km², which corresponds, e.g. to Norrland in Sweden, British Columbia in Canada and North Dakota in the United States. The two largest cities, Oulu and Rovaniemi, comprise 39% of the population of the region. Distances between hospitals and health centres are long. The distance from the most remote health centre to the nearest hospital is 453 km, and to the nearest university hospital 675 km.

The analysis of the study considers locating centralised warehouse(s) within areas characterized by long distances and relatively low demand, by location-allocation applying optimal routes of delivery vehicles. The study aims also to disclose the relationships (trade-offs) between service accessibility and delivery costs by optimising the spatial components of the logistics delivery network. Methods of the study consist of vehicle routing problem-based location-allocation analysis implemented in GIS. The aim of the study is approached through two research questions. 1) How extensive must a delivery network be to produce adequate logistics services for healthcare in sparsely populated areas? 2) What is the most efficient spatial distribution of centralised warehouses with objectives to minimise the number of facilities opened and to minimise transport costs when the constraint is to provide service to at least 90% of delivery demand?

2. Healthcare logistics and accessibility analysis

A basic definition describes logistics as the task of coordinating material flow and information flow across the supply chain (Harrison & van Hoek, 2005). Logistics includes activities connected to the transformation and circulation of goods, such as the material supply of production, the core distribution and transport function, wholesale, retail as well as the related information flows (Handfield & Nichols, 1999). The mission of logistics management is to plan and coordinate all those activities necessary to achieve desired levels of delivered service and quality at the lowest possible cost (Christopher, 1998).

In the healthcare context logistics research is generally divided into two genres by the unit of analysis. Most of the research focuses on patient flows and care processes (de Vries & Huijsman, 2011) while research on supporting material flows has been quite limited (Olsson, Wiger, & Aronsson, 2014; Vissers & Beech, 2005: 26). This has been attributed to the complex nature of health care supply chains and merely a supporting role of logistics in health services (Abdulsalam, Gopalakrishnan, Maltz, & Schneller, 2015; Beier, 1995; Jarrett, 1998). However, the importance of material flows in healthcare systems is gradually becoming recognised and the potential improvements that can be accomplished are also getting attention in the academic research of logistics and healthcare management (e.g. Jarrett, 1998; Kumar et al., 2008; Landry & Philippe, 2004).

Optimisation is at the heart of designing efficient logistics systems (Geoffrion & Powers, 1995; Graves, Willems, & Zipkin, 2000). In a healthcare logistics context, for instance, optimisation can mean that facility locations are designed in a manner that total logistics costs of material deliveries to hospitals and other healthcare units are minimised at required service levels (Jarrett, 1998). Increasing the number of service points in a distribution network generally leads to quicker responses and therefore a better service level. This raises customer satisfaction, but on the other hand increases total logistics costs such as inventory costs, transportation costs and facility costs (Heizer, Render & Munson, 2017: 497; Croxton & Zinn, 2005). In logistics decision-making this kind of trade-off analysis is embodied in the total cost concept (Ballou, 2004: 44), representing the cost patterns of various activities with characteristics that frequently set them in conflict with one another. However, the trade-off analysis also applies to the relationship between service level and logistics costs (e.g. Christopher, 1998: 51). A critical point to consider is that the costs normally grow exponentially as the service level increases in a linear manner.

The reasonable optimum between costs and service can be found by focusing on the core dimensions of transport geography: networks, nodes/locations and flows (Hesse & Rodrigue, 2004). Transport geographic accessibility analyses include a wide set of methods analysis and optimisation methods (Páez, Scott, & Morency, 2012) which are applicable to analysing and solving location-allocation problems of the health care sector (Coffee et al., 2012; McGrail & Humphreys, 2014; Mestre, Oliveira, & Barbosa-Povoa, 2015). However, analysis considering freight delivery by land transports and optimisation of deliveries is more infrequent within transport geography (see Rodrigue, 2006), and particularly in the case of low and dispersed demand. Geographical optimisation of freight deliveries is applied to logistics occasionally (Melo, Nickel, & Saldanha-Da-Gama, 2009), and recent examples can be found from the food distribution industry at the scale of a city region (Gebresenbet, Nordmark, Bosona, & Ljungberg, 2011), in state-level food transports (Bosona & Gebresenbet, 2011) and from intermodal routing of container freight at a regional scale (Zhang & Pel, 2016). In this context, the GIS framework is a powerful tool for implementing location-allocation analyses with spatial data (Miller & Shaw, 2001; Rodrigue et al., 2013: 317–322).

A large variety of optimisation methods are developed to serve strategic, tactical, and operational needs of freight transport planning. Operational planning is performed on a detailed level and dynamic environment, and tactical planning focuses on developing the performance of the existing system. This paper considers a level of strategic planning covering a wider time horizon, includes larger investments and determines development policies and operation strategies, and thus also develops the physical distribution network and location of main facilities (see Crainic and Laporte, 1997).
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