GIS Applications in Logistics: A Literature Review

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1 Introduction

Fierce competition in today’s global markets, the introduction of products with shorter and shorter design and life cycles, and heightened expectation of customers have forced business enterprises to invest in, and focus much attention on their supply chains. This, coupled with advances and evolution in the fields of information systems, communication and transportation technologies (for example, mobile communication, internet, and overnight deliveries), has motivated the continuous improvement of management of supply chains and logistics networks.

The term logistics originated in the military which was concerned with the movement of personnel and materials during times of emergency. It was later adopted by businesses and became a part of commonly used terminology in professional societies and academic programs. According to the Council of Supply Chain Management Professionals (CSCMP), logistics management is that “part of supply chain management that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services and related information between
the point of origin and the point of consumption in order to meet customers’ requirements”. In summary, companies depend on their logistics systems to move materials, goods, equipment and people among supply chain partners. Logistics covers a wide range of business functions (Bozarth and Handfield [2]) including:

- Transportation,
- Warehousing,
- Material handling,
- Packaging,
- Inventory management, and
- Logistics information systems.

CSCMP further adds that logistics management activities typically include

- fleet management,
- order fulfillment,
- logistics network design,
- supply/demand planning,
- sourcing and procurement,
- production planning and scheduling, and
- customer service.

1.1 The Logistics Network and GIS

The logistics network consists of suppliers, warehouses, distribution centers, retail outlets, as well as raw materials, work-in-process inventory, and finished goods that flow between the different facilities which are part of the network. Key strategic decisions pertaining to any logistics network configuration include:

1. Determining the optimal number of warehouses.

2. Determining the location of each warehouse.
3. Determining the size of each warehouse.

4. Allocating space for products in each warehouse.

5. Determining which products need to be transported, and in what quantities.

6. Determining the best routes for a vehicle in a transportation network.

Clearly the role of geographical information in logistics network management is all too evident. An often-cited statistic in scientific literature is that 80% of business data has a geographical element, and hence geographical information systems (GIS) are playing an increasingly important role in any area of business.

A GIS is a collection of computer hardware, software, and geographic data for capturing, managing, analyzing, and displaying all forms of geographically referenced information. Choosing sites, targeting market segments, planning distribution networks, responding to emergencies are all problems that involve questions of geography and are all relevant to businesses and the government. GIS applications cut across industry domains. It is used by businesses to provide solutions related to:

- Customer Analysis
- Market Analysis
- Site Selection
- Risk Analysis
- Territory Management
- Facility/Property/Asset Management
- Supply Chain Management
- Logistics

The use of GIS towards superior management of business logistics is a relatively new phenomenon. More specifically, GIS has been employed to answer several logistics-related business questions such as:

- What is the best route for delivery trucks?
- How should deliveries be scheduled?
• What mobile resources available are available?
• What is the best policy to optimize territory?
• Where is the best site for delivery hubs?
• How can the fleet be optimized to meet service goals and minimize costs?

The following section contains a review of the scientific literature related to GIS applications in logistics. It is sub-sectioned for the reader’s convenience.

2 Literature Review

2.1 GIS and Operations Research

Weigel and Cao [19] applied GIS in conjunction with Operations Research (OR) techniques to solve technician dispatching and home delivery problems at Sears, Roebuck and Company. Sears used a vehicle routing and scheduling system based on a geographic information system to run its delivery and home service fleets more efficiently. Although the problems to be solved can be modeled as vehicle routing problems with time windows (VRPTW) [16], the size of the problems and thus practical complexity make these problems of both theoretical and practical interest. The authors constructed a series of algorithms, including an algorithm to build the origin and destination matrix, an algorithm to assign resources, and finally algorithms to perform sequencing and route improvement. The combination of GIS and OR techniques improved the Sears technician dispatching and home delivery business. It (i) reduced driving times by 6%, (ii) increased the number of service orders each technician completed per day by 3%, (iii) reduced overtime by 15%, (iv) helped to consolidate routing offices from 46 to 22, and (v) achieved annual savings of $9 million. The success of this application also suggested a promising link between GIS and OR techniques. It also helped ESRI, the GIS consultant for the project develop ArcLogistics, a low-cost PC-based routing-and-scheduling application that brings high-end functionality to small organizations who were previously unable to afford this technology.

Another example of the application of GIS coupled with OR for decision support can be found in Camm et al. [3] who analyzed the North American operations supply chain of Proctor and Gamble, more specifically its product sourcing and distribution system. The authors disaggregated the problem into a warehouse location component and a product sourcing and distribution component and proposed a methodology which merged integer programming and network optimization within a (MapInfo) GIS framework. By dividing the problem into two major components, simpler models could be applied. As a result of this study, P&G was able to consolidate its North American facilities by 20 percent which saved $200 million in pretax costs every year.
2.2 GIS for Vehicle Routing and Accurate Distance Calculations

Campbell, Labelle, and Langevin [4] presents a new distance approximation approach that is useful in commercial transportation contexts. The motivation for the authors was to develop a simple and accurate distance approximation for use in an interactive GIS-based decision support system (DSS) for urban snow disposal. The hybrid approximation reduces data requirements and improves travel speed by eliminating local road details, but it maintains accuracy and incorporates obstacles by including the major roadways in a reduced network. The authors report results of an application in Montreal, Canada using a particular local distance approximation function, but the approach could easily be used with shortest paths or a more complex distance function for local travel. Utilizing an improved travel distance model, the snow disposal DSS provides strategic and tactical benefits. Because travel cost is approximately proportional to travel distance, and travel cost comprises a major component of total snow disposal costs, having a more accurate distance model leads to system designs with lower costs. The savings result from better utilization of existing equipment and from a reduction in the amount of equipment required. The ability to respond in real-time to contingencies with the DSS also allows for better tactical decision-making. Finally, the availability of an interactive tool for snow disposal design allows for a more structured and timely evaluation of different levels of service (for example, setting the deadline for clearing all snow to 60 hours, rather than 48 hours) or changes in operating conditions. For example, closing snow disposal sites along water bodies has been recommended to reduce negative environmental impacts of snow disposal. Closure of such sites (which are generally inexpensive to operate) would require using more expensive sites, or opening new sites. The hybrid approach may provide advantages in a variety of different situations. For example, the shortest path in the complete urban road network may not be a realistic route when not all local neighborhood streets can be used by the vehicles of interest (for example, large trucks). This may be due to infrastructure constraints, environmental concerns, or legal conditions. Also, calculation of shortest paths in a very large network may be too time consuming for an interactive decision support environment. Another advantage is that obstacles, which may reduce the effectiveness of analytical approximations, can be incorporated explicitly in the reduced network.

Miller, Wu and Hung [12] define time-critical logistics (TCL) as the time-sensitive procurement, processing and distribution activities. Transportation networks that contain these logistic systems act as a confounding factor. This paper reports on the development of a GIS-based decision support system for dynamic modeling of congestion and routing in a TCL scenario. The system predicts network flows at detailed temporal resolutions and determines the departure time and shortest path required for a shipment to reach its destination by a given deadline. The GIS provides effective decision support through its database management capabilities, graphical user interfaces and cartographic visualization. The model developed in this paper also helps to simulate
various scenarios of network disruptions.

Tarantilis and Kiranoudis [17] presents a spatial decision support system (SDSS) which uses heuristics to solve the vehicle routing problem. The architecture of the SDSS integrates a relational database management system within a GIS (ARC/INFO of ESRI) framework. The authors report that the GIS framework allows efficient representation of the transportation network of Greater Athens, Greece, and allows for the fast implementation of routing routines which solve real-life computationally intensive vehicle routing problems quickly.

Hwang [7] contains an overview on GIS-interacted logistics and has developed a new three-dimensional GIS distance based delivery and tracking system. The same work also contains comparative research on the vehicle routing problem based on various distance metrics within a GIS framework.

2.3 GIS and Site Location

As mentioned earlier in the introduction, one of the key strategic decisions pertaining to any logistics network configuration includes site selection. For example, site selection is critical for planning a real estate development project. Different mathematical and statistical models have been proposed in the literature to support real estate developers in selecting suitable sites for development projects. Li, Yu and Cheng [9] presents a new approach that uses Data Envelopment Analysis (DEA) within a GIS framework to determine optimal site locations for real estate projects. A GIS helps users organize and combine the spatial, temporal and economical information. The DEA method builds in the query for selecting locations by maximizing the ratio of outputs to inputs. The GIS approach is able to solve site selection problems visually, while the DEA method is argued to be objective. The paper has demonstrated an application to illustrate this user-friendly system by selecting locations for a residential building project.

Vlachopoulou, Silleos and Manthou [18] recognize that the warehouse site selection decision is not merely the question of choosing sites. It involves the comparison of the spatial characteristics of a market with the overall corporate and marketing goals of the firm. The authors present a geographic information system-aided process for the warehouse site selection decision and demonstrate the use of the process with a practical example. Various factors likely to affect customer service and costs are defined and subsequently integrated into an overall evaluation.

The location of base stations (BS) and the allocation of channels are of paramount importance for the performance of cellular radio networks. Also cellular service providers are now being driven by the goal to enhance performance, particularly as it relates to the receipt and transmission of emergency crash notification messages generated by automobile telematics systems. Based on these premises, Akella et al. [1] proposes a mixed integer-programming (MIP) problem, which integrates into the same model the base station location problem, the frequency channel assignment
problem and the emergency notification problem. The purpose of unifying these three problems in the same model is to treat the tradeoffs among them, providing a higher quality solution to the cellular system design. Some properties of the formulation are proposed that provide more insight into the problem structure. An instance generator is developed that randomly creates test problems. A few greedy heuristics are proposed to obtain quick solutions that turn out to be very good in some cases. To further improve the optimality gap, the authors develop specialized heuristic techniques that build on the solution obtained by the greedy heuristics. Finally, the performance of these methods is analyzed by extensive numerical tests within a GIS framework and a sample case study is presented.

Miliotis, Dimopoulou, and Gianniskos [11] have developed a hierarchical location model for locating bank branches in a competitive environment. The authors have combined demand-covering models with a GIS to capture various geographical, social and economic criteria as well as local competition concerning the demand for banking services. The hierarchical location model involves first solving a location set covering model to determine the minimum number of bank branches followed by solving a maximal covering location problem to maximize demand coverage for individual branches. The use of a raster-based MapInfo GIS helped in organizing large volumes of data and also in transforming all the useful information to input files for the demand covering models very efficiently. The GIS framework allowed for the simulation of alternative scenarios in central Macedonia, Greece, and produced useful displays for the efficient planning of financial networks. On a related note, Nasirin and Birks [13] presents exploratory case studies reflecting GIS implementation experiences of three major British retailers for store location purposes.

Finally, Church [5] contains a review of existing work that forms the interface between GIS and location science and discusses future research directions involving both GIS and site location. The author concludes that demand for better location model functionality in GIS software will grow and the success of many site location applications in the future will be intimately linked to GIS.

2.4 GIS and Warehouse Management

Warehouse management is a key part of the overall problem of logistics management. Johnston, Taylor, and Visweswaramurthy [8] describe a geographical information system (GIS)-based software system for managing and integrating multi-facility warehousing and production systems that are distributed within a relatively large geographical area. The development of the software system is motivated by a unique warehousing environment at the Pine Bluff Arsenal in Pine Bluff, Arkansas. The arsenal scenario is characterized by a novel set of highly limiting warehouse constraints. Although motivated by this unique problem, the software system has been designed to maximize technology transfer capability into diverse general warehouse settings. The paper presents motivation, describes features, and demonstrates the efficacy of operations using the soft-
ware system. The system is verified and validated in a case study setting. It is demonstrated that the GIS platform offers unique capabilities that enhance problem solutions. In conclusion, the paper offers a contribution to the literature by presenting the use of GIS as an integration strategy in an exciting new area of application.

2.5 Other miscellaneous applications

Gardner and Cooper [6] suggested a need in the supply chain literature for a mapping convention or set of mapping conventions that will help executives to instantly recognize the kind of map being considered and some knowledge of the database underlying the map. This paper proposed a definition of a supply chain map that indicates boundary setting and a strategic view. Compelling reasons to create a map were suggested. The need for a supply chain mapping convention was demonstrated. These conventions were necessary for instant recognition of the type of map and the purpose of the map, yet they permit customization by the user. Based on a review of the literature and discussions with managers, the authors called for the development of a managerial mapping procedure for developing and modifying a strategic supply chain map. Finally, the paper suggested a methodology to strategically determine future supply chain configuration and the progression from what the current structure is to what a redesigned supply chain should be.

Scientific research into GIS applications in asset management and territory optimization aspects of logistics management does not seem to exist. Salim, Strauss and Emch [15] outlines the use of GIS in conjunction with Artificial Intelligence techniques for asset management in a transportation context. This involves the allocation of resources, including personnel, equipment, materials, and supplies. This paper presents heuristic based AI methodologies to optimize transportation asset management procedures. Specifically, the authors outline and illustrate a GIS-based intelligent asset management system using the case study of snow removal for winter road and bridge maintenance in Iowa, USA.

Table 1 summarizes a majority of the literature reviewed in this report in terms of the logistics sub-problem addressed and the GIS software used towards development of the solution framework.

3 Conclusion and Directions for Future Research

Technical barriers to the widespread use of GIS in business decision making have eroded over the last decade due to reduced cost of computing power, increased availability of digital map data, availability of softwares, integration with corporate databases, and growth in use of the Internet for sharing software and data. However numerous opportunities to exploit geographical relationships and constraints within activities in the supply chain and to support different levels of logistics decision-making still exist. This review clearly reveals the fact that research into GIS applications
Table 1: Literature Review Summary

<table>
<thead>
<tr>
<th>Reference</th>
<th>Logistics Sub-problem</th>
<th>GIS Software Used</th>
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<tbody>
<tr>
<td>[19]</td>
<td>Vehicle Routing, Asset Management</td>
<td>ArcLogistics, ESRI</td>
</tr>
<tr>
<td>[3]</td>
<td>Product sourcing and distribution</td>
<td>MapBasic, MapInfo</td>
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<tr>
<td>[12]</td>
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in logistics is still at a nascent stage. While some applied research exists in the domains of site location and vehicle routing (which marries theoretical operations research optimization models with GIS), the development of GIS-aided theoretical models related to territory optimization and asset management is largely unexplored and serves as a future research direction. The lack of research in these areas can perhaps be explained by the fact that the greatest use of software packages with an element, or component, of GIS technology is at an operational level, for example, routing, scheduling, or, navigation. It is pertinent to mention here that several case studies that describe the application of GIS in routing and scheduling, asset tracking, site selection, territory optimization and planning, and supply chain management can be found at [http://www.esri.com](http://www.esri.com), [http://www.mapinfo.com](http://www.mapinfo.com), and several such websites. Mennecke [10] contains several examples of the use of GIS in a variety of industry segments to address logistical problems. For example, it cites Pennsylvania Power and Light’s use of GIS to track locations of their meters, Coca Cola Company’s use of GIS to support transportation logistics and shipment tracking, Yellow Freight’s use of GIS to create service maps and to perform terminal service area analysis, and also the use of GIS by car rental agencies such as Avis and Hertz to provide in-vehicle navigation systems.

Finally, the greatest use of GIS technology appears in to be in companies with large numbers of customers, large networks of facilities, and a large geographical spread. Smaller businesses seem to outsource their warehousing and distribution to third party logistics (3PL) providers. While some research into the growth of the 3PL industry in Europe exists in the literature (Peters, Cooper, Lieb, and Randall [14]), spatial analysis of such industries in terms of their growth, clustering and other such aspects (worldwide and within the United States) provides another unexplored domain.
References


