GIS FOR DESCRIBING AND ANALYSING REGIONAL LOGISTICS SYSTEMS

R. Bergqvist and J. Tornberg

Logistics and Transport Research Group, Department of Business Administration, School Of Economics and Commercial Law, Göteborg University, P.O. Box 610, Se 405 30 Göteborg, Sweden,
E-mail: rickard.bergqvist@handels.gu.se
Department of City and Mobility, Chalmers University of Technology, Se 412 96 Göteborg, Sweden,
E-mail: jonas@arch.chalmers.se

Abstract

This paper provides insight into the GIS approach when describing and analysing logistics systems and exemplifies pedagogical opportunities experienced in an interactive research environment. Describing and analysing regional logistics systems present data-collection challenges due to complexity in system structures and the scope of actors in the system. To enable realistic descriptions and analyses of the system, large amounts of data are required and interactive work with affected actors is crucial.

To achieve a constructive interactive climate with decision-makers a common perception of the system is essential. Visualisation provided through the GIS approach facilitates comprehension by all actors and possibilities for the development of a common perception of the regional logistics system. Tools associated with GIS enable sufficient analytical capacity at the same time visual effects of flows, maps and infrastructure gives opportunities for system overview and analyses. A GIS-approach for modelling logistics systems combines and fulfils both private and public actors' requirements of logistics analyses. This study shows how effects such as impedances and noise can be managed and visualised using a GIS-approach at the same time economic considerations are made.

INTRODUCTION

Quite a number of researchers and practitioners call attention to trends in logistics, derived from changes in the business environment like globalisation, production patterns (Das et al., 1997; Búrca, 1997; O'Donnel, 1997) and urbanisation (Scott et al., 2003). Barry et al. (1997) and Kotler et al. (1999) state that business activities in peripheral regions have decreased significantly due to these trends. As a consequence, material flow in peripheral regions decreases, challenging the transportation system and the logistic effectiveness and competitiveness of firms in the region (McKinnon, 1997). A statement made by Sverker Börjesson, logistics manager of Volvo Powertrain in Skövde during one of our interviews can serve as an empirical illustration of this problem:

"We have to continuously justify our existence to the group's executive board due to our unfavourable logistics location"

Opportunities for re-establishing the logistic attractiveness of peripheral regions and the competitiveness of local firms must be realised, and at the same time, sustainable transportation systems must be ensured. Actions in infrastructure are often too expensive or untenable in a long-term perspective (Hansen, 2002; Bergqvist et al., 2003). How, then, can the effectiveness of transportation systems and the logistic attractiveness of regions be improved?

While awaiting direct solutions based on significant technological breakthroughs in the field of alternative energy sources or increased engine performance, other more indirect measures are useful for improving the transportation system. Increased utilisation of transportation resources, coordination and consolidation of material flows and increased use of environmentally friendly modes of transport are examples of such indirect measures. Different actors in society can combine their complimentary interests and engage in joint actions in networks, strengthening the status of the regional logistics system (e.g. Hansen, 2002). In order to identify opportunities for improvements in the regional logistics system a fundamental platform is necessary for descriptions and analyses that appeals to all actors from a pedagogical perspective.

These problems were the motivating force behind the carrying trough of two intra-regional studies in the regions Skaraborg and Sjuhärad concerning the issue of where to locate intermodal transport terminals. The location of intermodal transport terminals was believed to facilitate the use of ecological modes of transport at the same time present opportunities for coordinating goods flows to insure competitive logistics systems. From a society viewpoint the use of intermodal transport would decrease the stress from traffic in city centres and on key road infrastructure.

RESEARCH SETTINGS

A regional logistics system has many similarities with traditional firm-based logistics systems. Material flows are described based on the same variables of size, time and place; however, the regional logistics system is an aggregation of the individual firm-based logistics systems in the region and involved system-actors. A regional logistics system includes a diversity of decision-makers; regional firms, authorities of infrastructure development and planning, logistics and transport operators; making material flows, infrastructure and logistics operations important components in the system. The status of the regional logistics system is comprised by the sum of status of its individual components and by decision-makers' ability to coordinate between components in the system. Hence, the importance of a system overview combined with traceability down to logistics aspects of individual actors/firms.

An elementary model is eligible during the conceptual-modelling phase of a logistics system. OECD (1992) provides one, describing the transportation system as consisting of five layers; material flow, transport operation, transport infrastructure, information operation and telecommunication infrastructure. A model used by e.g. Hansen (2002) and Wandel and Ruijgrok (1993) as a framework for analysing logistics structures and functions.

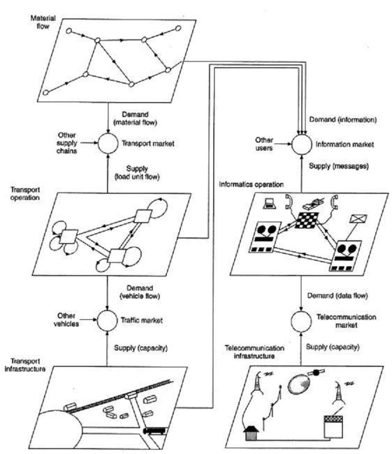

Figure 1, The 5-layer model of a transportation system (modified from OECD 1992)

Material flows are consolidated into load unit flows and operated by appropriate means of transportation. Transport operations and logistic services generate a vehicle flow that requires infrastructure capacity to realise movement, a match conducted at the traffic market. Coordination and operation of material flows is supported by information exchange using telecommunication infrastructure. The layers in the model interact and are the prerequisite for transport movements.

McKinnon (1997) argues that there is a diversification of public and private involvement and roles in the transportation system. According to McKinnon (1998) there are private decision-making interests at four primary levels: logistic and structures, patterns of trading links, scheduling of product flows and management of transport resources. Hence, private organisations traditionally focus on the layers of material flows and transport operation (McKinnon, 1998). The diversity of roles between private and public is more or less self-evident; private markets generate competition and thereby efficiency at the layers of material flow and transport operation, the public sector, however, traditionally manage infrastructure due to the scope and scale of investments and responsibilities. This diversification of roles has important implications for the choice of approach used for describing regional logistics systems; requirements concerning the level of details for each component differ between the sectors. Furthermore, to ensure a common perception of the system both private and public interests need to be analysed simultaneously, otherwise the overview is fragmentary. Visualisation based on geography as point of departure for descriptions and analyses is suitable since geography is something all actors can agree upon and relate to.

We chose to describe the regional logistics system with a similar structure, based on three components:

- material flows
- resources
- operations

Actors in the system create a demand for movements: a material flow. Resources such as vehicles and infrastructure fulfil necessary prerequisites for movement: a supply. At the layer of operations movements are conducted: an interconnection between material flow and resource. Summarised, the logical succession is; demand arises, supply exists and interconnection is created. The supply and demand components of a regional logistics system constitute the "states of nature" in the current system, whereas simulation puts special interest to the interconnection between supply and demand.

Figure 2, A 3-component model of a logistics system

This structure facilitates transferability in the modelling phase. Material flows and resources are treated as layers in the model, operations concerns behaviour and system-dynamics transferable to model-logic. Furthermore it displays a clear distinction between material and immaterial elements. With the components in place, analyses in goal variables are possible, in this research: cost estimates, environmental impact and quality aspects.

RESEARCH AIM

Decision-makers involved in a logistics system acts on available information and self-developed perceptions of the system and its components. System-overview and comprehension of system-dynamics are crucial for the functionality of the decision-process. The process requires input in terms of system-information concerning material flows, operations and resources. The quality and scope of information essential. The quality of information is, however, only as good as the level of comprehension. In regional logistics the complexity is vast and the system un-transparent since it is comprised at numerous sub-systems such as; material flows, infrastructure and logistics operations. Furthermore, a regional logistics system involves many decision-makers: infrastructure associations, regional government and local firms, often with shifting roles and complementary interests. The complexity combined with the different roles of decision-makers creates a need for a common perception of the regional logistics system and challenging requirements on the choice of modelling approach (cf. Bergqvist and Pruth, 2003). The range of models that needs to be employed has rapidly been expanded due to these requirements. The integration of transport models and techniques such as geographic information system (GIS) has become a major requirement in any process of transport planning (Dueker and Ton, 2000). This is consistent with the observations made by Dutton and Kraemer (1985) in their study of the politics of fiscal impact analysis systems using multipurpose land information systems. They found that the process of modelling was more important than the model itself. During the process of modelling the participants reached agreement on assumptions, methods, data and alternatives in advance, thereby securing commitment and establishing trust to the model outputs, which facilitated negotiation, consensus building, and conflict resolution. De Neufville (1997) made a similar study and made the point that planning methods need to reflect the understandings of users to integrate knowledge of non-technicians, clients, and the public with expert knowledge. De Neufville (1997) in general and Dutton and Kraemer (1985) in particular reinforces a stream of work on the social definition of reality and the social construction of technology.

The term GIS-T, which standards for GIS for Transportation, emerged in the 1990s (Dueker and Ton, 2000). GIS are proving to be effective in integrating the data needed for transport modelling and data management (Hesse and Rodrigue, 2004). The choice of a GIS-T approach in this research was judged by the overall ability of modelling complex regional logistics systems with special attention to infrastructural prerequisites and opportunities for visual representation. Since the research is conducted in close collaboration with public and private decision-makers in the Skaraborg and Sjuhärad regions the pedagogical aspects of the approach are of outmost importance. The abilities incorporated into the approach were perceived as favourable in an interactive research process.
GIS have been used to describe and analyse regional logistics systems and it is the pedagogical experiences from that application that this paper concerns. Dueker and Ton (2000) states that the visualisation tools of GIS enable editing and quality control of inputs to models and displays models results that facilitate interpretation and use.

The aim of this paper is:

- To develop the statement made by Dueker and Ton (2000) on an empirical basis. Explicitly, the purpose is to illustrate and exemplify pedagogical advances using a graphic information system (GIS) approach in a logistic context.

The study is geographically demarcated to the Skaraborg and Sjuhärad regions and the logistics system in respective region. The purpose is explored for issues concerning the dynamics of good flows in relation to capacity-constrains of infrastructure and the impact on traffic and the effects of traffic-generated impedance. Furthermore, opportunities for evaluating noise effects of different terminals locations from a pedagogical point of view are explored as an attempt to include social aspects into analyses of terminal locations and regional logistics systems.

METHODOLOGY

Conceptual Model

The existing regional logistic systems are named S_1 (Skaraborg) and S_2 (Sjuhärad). These systems can be described according to the same essential variables as earlier mentioned. This enables a study of a subset of S_1 and S_2, called S_M. S_M is described according to same essential variables based on material flows and infrastructure. S_M constitutes a generalised model for analysing regional logistics systems, in this study S_1 and S_2. This model is a platform for computing, comparing and evaluating regional logistics systems. Descriptions of S_1 and S_2 are comparable since they are based on same descriptive dimensions (S_M), hence, the possibility of comparing the analysis of S_1 with that of S_2. A Similar analogy has been developed by Jensen (2004) for conceptually describing intermodal transport systems. The remainder of this section sets out to explain the model platform and the model-logics for evaluating the regional logistics systems according to the goal variables, i.e. cost estimates, environmental impact and quality aspects.

The Model Platform

The model platform is constructed based on the same three components of a logistics system as displayed in Figure 2. Analyses and descriptions of regional logistics system requires extensive and complex data collection; especially concerning *Operations* since it consist of numerous qualitative aspects of logistics service providers' behaviours and system designs. Hence, the initial step before starting the research process was to construct multi-sectoral reference-committees in both Skaraborg and Sjuhärad. The committees consist of decision-makers that have substantial interest in, and power to affect, the regional logistics system, e.g. large manufacturing firms, regional governments, etc. The members in the committees assist in data-retrieval, analyses and possess valuable knowledge of the system, hence, also an important source for validation.

Material flows

Hesse et al. (2004) identify two geographical dimension of logistics; time and space. This paper treats logistics from a cooperating perspective; putting opportunities for coordination of material flows into focus. Consequently dimensions of coordination have to be considered. Hence, descriptive variables of material flows are derived from Time and Space but also Size and Type to determine coordination possibilities. The space aspect is comprised by variables of origin and destination of material flows. Size can be measured in units of weight or volume and provides important information of possible means of transport on specific relations. Type contains information of the type of material the shipper needs to transport. The Type-dimension affects shippers' choice of transport and requirements for handling and hence, determines the physical opportunities for coordinating material flows with that of other shippers.

The Time-dimension contains many variables derived by shippers' logistics requirements. There are two categories of time variables incorporated in the logistics system; lengths of time and variation of time. Transportation lead-time is a typical "length of time" variable, whereas, variables of time-windows are of "variation of time" character. "Variation of time" variables seldom take on a particular value; rather it is measured in terms of intervals since it is often a tolerance parameter expressed by the shipper.

Data for this layer is dual-sourced; from carriers operating in the studied regions and survey-retrieved data from shippers in the regions. The locations of origins and destinations are made by geocoding individual addresses of work-places. Geocoding is a method for applying geographic coordinates to data based on geographic land records, e.g. zip codes and addresses.

Resources

There exist two types of variables in this component: infrastructural and mobile resources. GIS effectively stores and manage topologically structured geographic data such as transportation networks, a prerequisite for calculating e.g. route-systems. There are a couple of software packages available for managing topologically structured data, e.g. ArcInfo Workstation from ESRI Inc (ESRI, 2005). The transportation network is based on the transport infrastructural database TeleAtlas, constructing the geometric network with links and nodes and the logical description of link directions (Zeller, 1999). The network is later extended with data containing information of infrastructural variables related to other modes of transport, e.g. rail.

Variables of mobile resources relates to capacity of the means of transport and work-related time restrictions. These variables are regarded in the final step of the research process to determine potentials and realistic structures of solutions.

Operation

The layer of operation contains decisions of system behaviours, i.e. model logic. For example, is the route-system based on shortest (length), fastest (time) and/or cheapest routes? There are several algorithms that find least-cost path through a network, one of the most well-known algorithms is generally credited to Djikstra (1959). Through developing logics that systematically combine variables, the model can become more realistic and dynamic, e.g. as mobile resources utilise infrastructure the impedance is affected. TeleAtlas contains information about speed-limits and bearing capacity of infrastructure on each link; this enables us to calculate the optimal flow capacity of specific links. The Swedish Road Administration (Vägverket) has twenty-four hour data of vehicles utilising specific links. This information can be connected to the database TeleAtlas, thus creating time-related impedances. When impedances reach predetermined levels the model logic can modify either the speed limit on infrastructure or change the speed capabilities of the mobile resources which utilises the affected link. For example, the number of vehicles on a specific link and time can determine the level of impedance and through predetermined levels in the model logic the speed limit of those specific vehicles can be adjusted accordingly. The route choice decision principle in the model is of "fastest route" character.

Evaluating Goal-variables

For each region there are a number of available locations for an intermodal terminal. Initially, areas in connection to rail infrastructure is divided into cells of 600*600 meters. These cells have a large enough area to contain an intermodal terminal. The first stage of exclusion of cells is based on the presence of buildings and the existence of road infrastructure in the cell.

After the first stage of exclusion, evaluation of goal variables for the different cells is carried out. For cost estimates: a weight-distance calculation is made. The data for goods volumes is retrieved from the survey. Distances are available trough the database TeleAtlas. Goods flows are created in the model using the "fastest road" principle. With regard to impedances incurred by traffic, the path chosen by goods flows will change in situations of congestion. Consequently, the model has an element of dynamics which can be displayed over time using maps based on geographic data, making it a visually useful tool. As the route chosen will have a longer transport-time than in less impedance situation the variable of throughput-time will change accordingly. Furthermore, the distance travelled will change, affecting the emissions to air caused by vehicles.

The issue of environmental impact consist of two components: emissions to air and noise. Emissions to air are directly linear to the transported distances and the transport-time. Noise is an environmental impact not measured in scale but in scope, i.e. it is not the volume of noise that is of utmost importance, rather the extent of noise during a time-period. The scale aspect

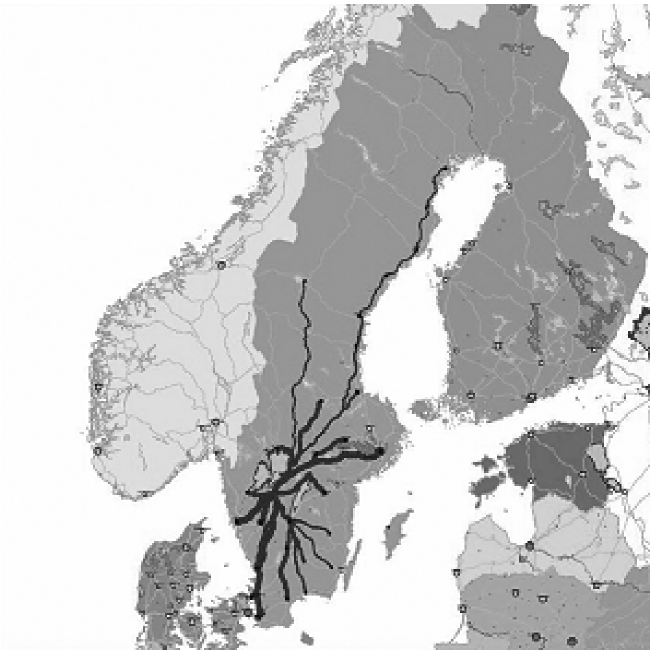

Figure 3, Incoming material flows to the Skaraborg region

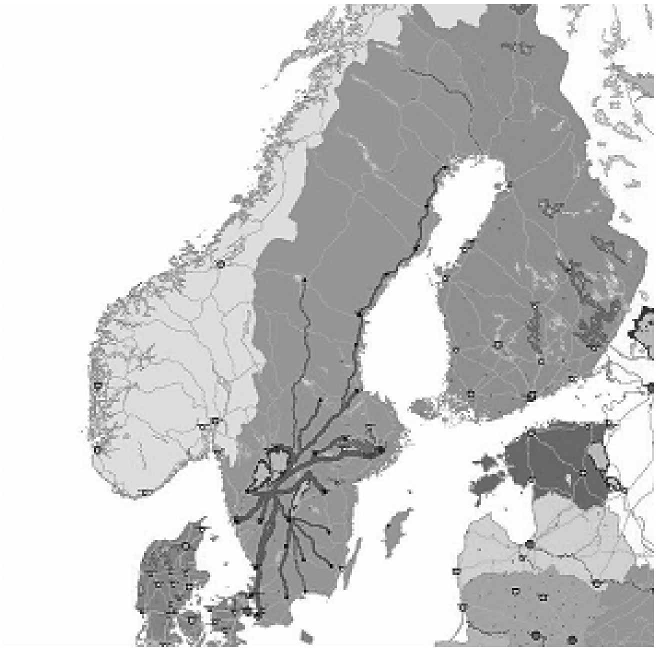

Figure 4, Outgoing material flows from the Skaraborg region

of noise is typically managed by regulations of vehicle-construction and is not regarded in this study. The scope of noise in the model is managed by tracking the amount of vehicles and the number of inhabitants passed on the way to and from the terminal. Different location alternatives can thereby be evaluated on the basis of noise impact on inhabitant in the region. This analysis is enabled by the use of a detailed database from SCB (Statistics Sweden) containing information of population-density and property notation.

The element of quality in the logistics system is evaluated on the basis of throughput time for goods. The transport time for each goods flow combined with the size of goods flows offers an opportunity for evaluating the quality aspects in element of total throughput-time. The element of throughput-time is also affected by the presence of congestion in the system and is therefore dynamic in the situation of changing congested conditions. Each location alternative is then evaluated on the basis of total throughput-time for the logistics system.

THE EMPIRICAL RESULTS

This section sets out to describe the experiences from the research and illustrate at its best pedagogical and analytical capabilities of the simulation process in GIS. Figure 3 and 4 are examples of material flows geocoded and routed according to the GIS-model.

Pictures such as figure 3 and 4 serve as a platform for discussions with the reference-committees. The reference-committee can help assign material flows to proper infrastructure with assistance from visual representations such as figure 3 and 4. This is one example of the pedagogical opportunities incorporated in GIS that facilitate interactive discussions with the reference-committees and in the end improves the description and analysis of the regional logistics system. Hitherto, system-dynamics and material flow structures are the aspects that have attracted most interest from the reference-committees. Members are often surprised by aspects such as material flow imbalances and shows great enthusiasm in identifying interesting aspects of “mal-functions” in the system or situations that are disadvantageous from a regional perspective. Members in the reference-committee in Skaraborg have used pictures generated in GIS in arguments with infrastructural associations; a warrant of the visual capabilities of GIS. A GIS analysis of different terminal locations in Skaraborg has assisted in the decision-process between the regional government in Skaraborg and Banverket (the authority responsible for rail traffic in Sweden)**.** Besides determine the volume of transport movements between alternative locations it also displays the distance of shippers in relation to terminal locations. This geographic information have important implications for the market analysis, e.g. number of firms located within the radius X. GIS modelling also enables analysis of noise aspects, something desired by public actors. The approach for analysing noise is a combination of databases and a good example of GIS effective data management. By combining databases of population density and impedances on traffic links a platform is constructed for noise analysis. The process of analysing noise is illustrated by pictures below.

Infrastructural impedances displayed over time in a “geologistics” system are one example of an analysis valuable for both private and public decision-makers in the region. Figure 5

Figure 5, Heavy traffic impedances around the cities of Skara and Skövde in the Skaraborg region

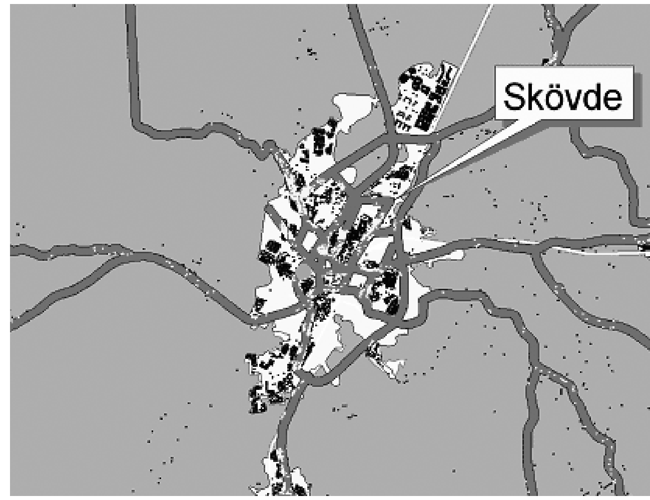

Figure 7, Noise buffer according to traffic links around the city Skövde in the Skaraborg region

illustrates the traffic impedances around the cities of Skara and Skövde. This information is obtained from a database of traffic impedances. Since the model only considers heavy traffic, data of light traffic is essential in order to do analysis of capacity constrains and congestions in the regions. Information of impedances is then used as input for the routing logic. Traffic links with high impedances have a decrease in speed limits. The routing will change accordingly due to the choice of fastest route and the costs of the transportation system will be affected. The knowledge of traffic impedances is the first step in the process of analysis impact of noise on habitants.

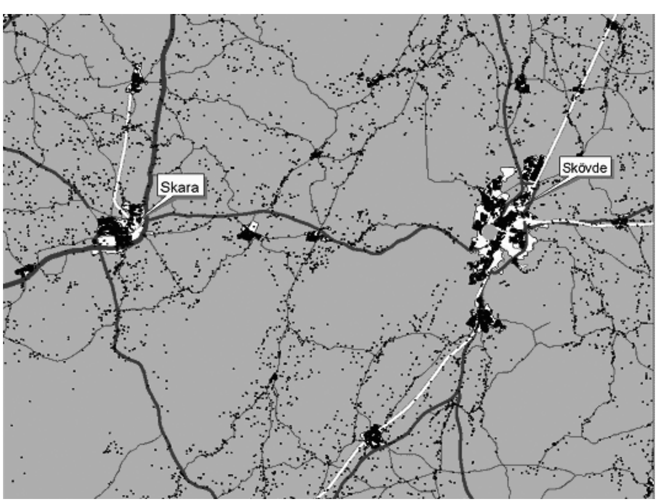

Figure 6, Population density around the cities of Skara and Skövde in the Skaraborg region

With known traffic impedances the next step is to consider the population-density in the studied region. Figure 6 displays where inhabitants have their residence and how many habitants are located in specific residences. This data is obtained from a population database provided by Statistics Sweden.

The final step to analyze the impact from noise is to decide upon restrictions for the construction of buffers. In the case of Figure 7 the buffer is constructed within a distance of 100 meters from traffic links. There are 10262 habitants within the buffer. Combined with the fact that there is an average impedance of heavy traffic of 2802 vehicle per day the traffic/population ratio can be calculated, in this case 0,27. Depending on the type of traffic resources used in the analysis the buffer restriction can be adjusted accordingly. For example, if the vehicles chosen are of light character the distance could be lowered. Furthermore, restrictions should be made so that heavy vehicle are not allowed to pass through city centers. Consequently, the pathfinders choose routes of longer distances, resulting in increased costs of the transportation system. These are restrictions where GIS proves its capability of combining public and private interests and requirements on modeling. In the case of noise and impedance analysis the GIS approach exemplifies how analysis of costs, environmental impact and quality can be simulated and managed simultaneously.

GIS AS A TOOL FOR ANALYSING AND DESCRIBING REGIONAL LOGISTICS SYSTEMS – A RESEARCHER'S VIEWPOINT

In this section of the paper, the authors would like to formulate a number of hypotheses related to the experience of using a GIS approach. Emphasis is on the opportunities and capabilities, crystallized by the approach in the field of logistics and in an interactive research process.

The first hypothesis is based on GIS's ability to cope with requirements of vast infrastructural data management:

Hypothesis 1: GIS that incorporates infrastructural databases such as TeleAtlas provides a richness of details that contribute to a realistic view of regional logistics systems

The level of details concerning infrastructure have limited the need for rough assumptions, e.g. speed limits, impedances, road topology, this has increased decision-makers' confidence on the correctness of analyses and descriptions. Decision-makers have used visual representations developed with GIS for own purposes and as discussion-material outside the reference-committee, a warrant of trust towards the approach.

Hypothesis 2: GIS as approach is very efficient in its data management

With the GIS approach the layers in the model are based on large databases. GIS have proven capable of coping with demands for aggregated visualisations as well as analysis and visualisations based on detailed data. This feature enables tailored analyses and visualisations to individual requirements of decision-makers. GIS can effectively isolate the data from a specific firm which makes discussions with individual actors much more in-depth and the feedback more specific and valuable. Furthermore, the capability of effectively managing large amount of data has proven valuable when doing "what if" scenarios where effects on inhabitants and infrastructure are considered. A "what if" scenario of the speed limit on road-connections would in this case not only displayed the increase in lead-time but also calculate the affect on infrastructural impedances and noise impact on inhabitants. These analytic capabilities and data management of the GIS approach strongly improve the dynamics and level of detail of the model and, thus, the reliability of the approach.

Hypothesis 3: GIS presents opportunities for visualising goods flows, infrastructure, impedances and noise, simultaneously.

Visualisation provided through the GIS approach facilitates comprehension by actors and possibilities for the development of a common perception of the regional logistics system. Actors in the reference-committees have gain more understanding of other actors' situation and the way they contemplate on logistics, especially the regional logistics system. A private actor from a regional company no longer act isolated from their situation but takes other firms' situations and public interests into account when they analyse the regional logistics system. This effect is very important in order to enable common actions directed to realising logistics system solutions.

Hypothesis 4: GIS incorporates capabilities for complex transport modelling and simulation

Tools and Solvers associated with GIS enables sufficient analytical capacity at the same time its visual effects of flows, maps and infrastructure gives opportunities for system overview.

CONCLUDING REMARKS AND FURTHER RESEARCH ISSUES

On the basis of the constructed hypotheses we would like to formulate a final hypothesis related to the aim of this paper:

Hypothesis 5: The GIS-approach for modelling logistics systems manages infrastructure, impedances, noise, and goods flows effectively, thus, realising simulations of all three layers of the logistics systems simultaneously. This ability makes GIS not only an analytically sufficient approach but also a pedagogical opportunity.

The hypotheses formulated in this paper indicate that logistics system simulations and planning can be made with regard to both private and public interests simultaneously. Hence, the possibility of including social and health aspects into private actors economically oriented planning process and the possibility to include economical aspects and considerations into public actors planning of infrastructure development. These opportunities for integration of various interests are of great value for the development of a better consideration to social issues in logistics planning. All layers in the logistics system (material flows, operations and infrastructure) are evaluated on the basis of cost efficiency, environmental impact and quality.

Overall, the authors hope to have stimulated researchers and practitioners in the field of logistics to reflect upon the pedagogical opportunities incorporated in GIS when deciding on a modelling approach. Furthermore, this paper illustrates that GIS approaches can have substantial pedagogical advantages in an interactive research process. In the field of geographic information systems, the authors hope that this research has broadened the application of GIS by providing unconventional illustrations where a GIS approach can be useful.

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R. Bergqvist, Ph.D. student in the Logistics and Transport Research Group, School of Economics and Commercial Law, Göteborg University. The research area is regional logistics systems. The research focuses on modelling and simulation of logistics systems with the purpose of identifying and evaluating alternative logistics solutions.

Jonas Tornberg, Civilingenjör från Chalmers, driver sedan 12 år tillbaka metodologisk utveckling och tillämpningar av geografisk informationsteknologi inom främst trafik och hållbar utveckling vid Chalmers Arkitektur.