USING GIS FOR FREIGHT SUPPLY CHAIN MODELLING

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1. INTRODUCTION

The use of information technology (IT) in various fields of human endeavor, the exponential growth of information and the need to respond quickly to any situation required to find adequate solutions to the problems. The effectiveness way of these is the IT intellectualization.

Transportation is an important human activity, which supports and makes possible most of the social and economic interactions among communities of the world. Maritime transportation, in particular, is one of today's most important economic activities, not only as measured by its share of nation's Gross National Product (GNP), but also by the increasing influence that the transportation and distribution of goods have on the performance of many economic sectors like wholesale and retail trade, manufacturing and production etc. The shipping and maritime transport industry is a dynamic and multi-faceted industry, very fast developing around the world.

A well-functioning freight transportation system is an essential element in any successful economy. However, at the beginning of the new millennium, the prediction is that the demand for goods movement will outstrip the rate of improvements to the physical infrastructure. Marked growth in time-sensitive freight markets will tax demands on a system that already is operating near capacity in some areas.

Key issues and challenges that will affect freight planning and logistics in the future include the following:

• The demands for freight transportation and logistics services, and the ability of the physical and information infrastructure to meet these demands;

• The role of road pricing in urban freight transportation;

• The impact of information technology on goods movement;

• New developments in logistics management.

Maritime industry includes all enterprises engaged in the business of designing, constructing, manufacturing, acquiring, operating, supplying, repairing and/or maintaining vessels, or component parts thereof: of managing and/or operating shipping lines, stevedoring arresters and customs brokerage services, shipyards, dry docks, marine railways, marine repair shops, shipping and freight forwarding services and similar enterprises.

In this paper, we discuss the possibility of strengthening the role of Geographic Information Systems (GIS) in supporting the development of integrated control systems for maritime freight logistics on the basis of a centralized repository. The paper presents the developed mathematical problem and determines the algorithm method to solve the problem.

2. INFORMATION TECHNOLOGY USING IN TRANSPORTATION

The impact of information technology on the freight transportation system has been significant and likely will increase sharply. The steadily declining prices of new technology, coupled with an increased awareness among freight operators of the technology's potential benefits, will encourage the freight industry to increase its use of information technology.

The industry already has implemented cutting-edge technologies to improve customer service and to reduce expenditures. Information technology also will have varying effects on the different modes of transportation. Carriers in all modes increasingly will rely on continuous updates on the location and status of the vehicles and containers in their system. The productivity of integrated freight transportation providers such as Federal Express and United Parcel Service (UPS) will improve with increased use of information technology.

Nonintegrated users may achieve even greater gains as electronic waybills replace the paper trail that follows freight movements and as shipper service and status requests take place via electronic data interchange. Electronic commerce (e-commerce) probably will bring about changes in both the configuration and profitability of a portion of the freight sector. It also might lead to reductions in average shipment size, corresponding increases in shipment frequency, and an emphasis on time-definite delivery.

Recent technological advances include but are not limited to:

• electronic data interchange (EDI) technologies,

• automatic vehicle and container identification systems,

• location and navigational systems,

• mobile communication technologies,

• mobile computers,

• database management and value-added data manipulation systems (e.g., data mining),

• container status information systems,

• advanced traffic information and management systems.

The result of these developments is that freight transport is moving toward operational integration, both within and between companies. Information technology will make nonintegrated transport providers more competitive with integrated ones. Appropriate sharing and integration of information will substitute for full-scale control.

The information revolution is responsible for changes that originate both inside and outside the freight transportation system. Just-in-time manufacturing and distribution systems rely on a continuous and reliable stream of information on the current and near-term status of every link in the supply chain.

Information support of maritime transport facilities should take into account the many complex, interdependent processes and congested. Successful implementation of the strategy management of objects in a large extent depends on:

1) the sharing of data management during object lifecycle;

2) the ability to effectively maintain and coordinate multi-functional work processes at the tactical and strategic levels.

Lack of integration with objects control data can lead to substantial inefficiencies. Integrated management system can overcome these inefficiencies and improve coordination and solutions profitability of objects management.

These objects descriptions characterized by a large volume, complexity, interdependence and dynamism. This data can exist in disparate formats because of the availability of different data sources and the program systems. The integration of these data into a coherent and unified form is the most is critical exercise to successful objects management.

The effective integration of data can significantly improve decision making in the management of sites at operational, tactical and strategic levels. As a result, with the data integration we achieve: fitness/ availability of data; timeliness; accuracy, correctness and integrity; consistency and clarity; completeness; reducing of duplication; data processing acceleration and waiting time reduction; data collection and storage costs reduction; comprehensive solutions and the validity of the integrated decision-making.

3. DEFINITION OF GEOGRAPHIC INFORMATION SYSTEMS (GIS)

Nowadays GIS technology can be part of any IS.

Geographic Information Systems are computer-based information systems that enable capture, modeling, manipulation, retrieval, analysis and presentation of geographically referenced data (Worboys, 1997). The uniqueness of GIS comes from its ability to carry out these operations on both spatial and descriptive data simultaneously or separately. Spatial data are two- or three dimensional coordinates of points (nodes), lines (arcs), or areas (polygons) representing one aspect of a geographic reality (coverage). Descriptive data, on the other hand, refers to the features or attributes of these points, lines, or areas (Huxhold, 1991).

GIS can be used in economical planning and development, immovable property management, transportation, utilities and communication, infrastructure, land use and taxation, water resources and environment processes, natural resources, national safety, disaster recovery, healthcare and tourism, science and others.

Spatial data is at the core of most GIS and have the greatest impact on many of the decision-making processes in objects management. Data about shipping objects are always identified by geographical location and spatial relations, therefore GIS and spatial data analysis are essential tools to support processes of objects management.

By today, in most GIS implementations spatial data stored and processed in a state, personal or department geo databases, what limited the sharing and editing of data. Increasing demands on the co-processing of data for a variety of applications revealed an acute need for scalability and creating GIS space.

A GIS, or information systems for geographic information, can vary in complexity from a simple application with a user calculating driving directions with Google Maps or MapQuest web services to a very complex enterprise GIS. An example of an enterprise GIS would be software and hardware systems consisting of a geospatial database, client software, web applications, and operators of all the systems for supporting a logistics or transport organization. An example of an enterprise GIS system is shown in Figure 1.

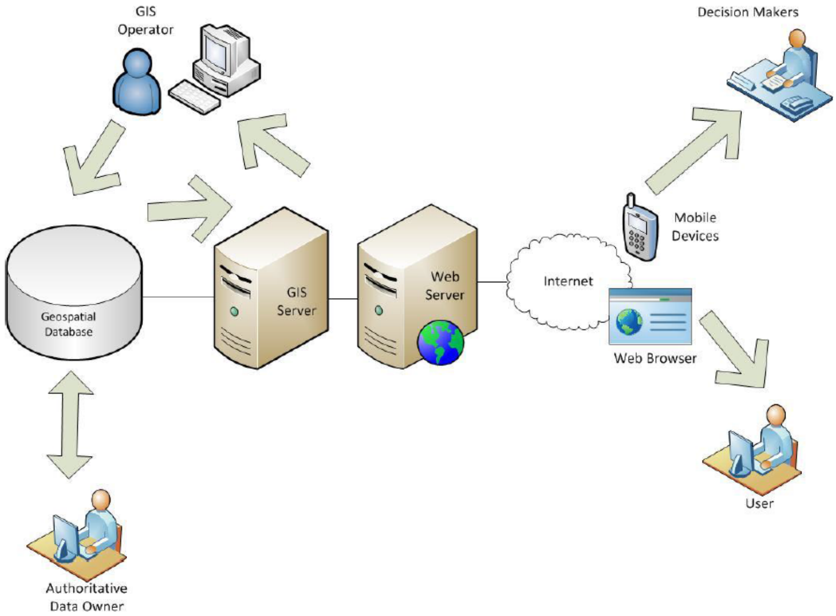

Figure 1: Enterprise GIS Diagram

All graphical data usually are in large amounts, normally they consist from layers which are combined from vector and raster graphics with links to attribute information. Data are already old immediately after they are collected, therefore it is needed as much as fast path to deliver data to the user. Good way is the Internet but this is not always usable because of accessibility and performance. Future of data publication is mobile systems and location based services.

Geo information space is integrated into GIS applications and automated systems and that contributes solving of number of problems, comprehensively improve level of security, continuity and reliability of sea freight transportation.

GIS automatically generates an additional set of information which explicitly defines the spatial relationships between geographic features. These are known as topological relationships. Examples are link connectivity, area contiguity (features of the adjacent areas), and area definition (connected lines enclosing an area). Creating topological relationships allows faster data processing, and also allows for performing analysis functions such as route finding, area aggregation and overlaying geographic features. (Huxhold, 1991; ESRI).

Accordingly, complete GIS can be said to have the following major elements (Marble and Arnundson 1988; Linden, 1990) (Figure 2):

1. Data input module: for collecting and/or processing spatial data derived from sources, such as existing maps, remotely sensed data and direct digital input.

2. Spatial data base module: in which location and shape data are stored and etrieved in the form of coverage (maps).

3. Attribute data base module: in which descriptive data associated with the spatial features are stored and retrieved.

4. Analysis module: in the form of a group of commands and functions which performs a number of tasks, such as changing form of the data through user defined aggregation rules, or producing estimates of parameters for transfer to external analytical type models.

5. Output module: to display the retrieved all or selected portions of the spatial database in the term of standard reports or in a variety of cartographic formats and communicate with other systems.

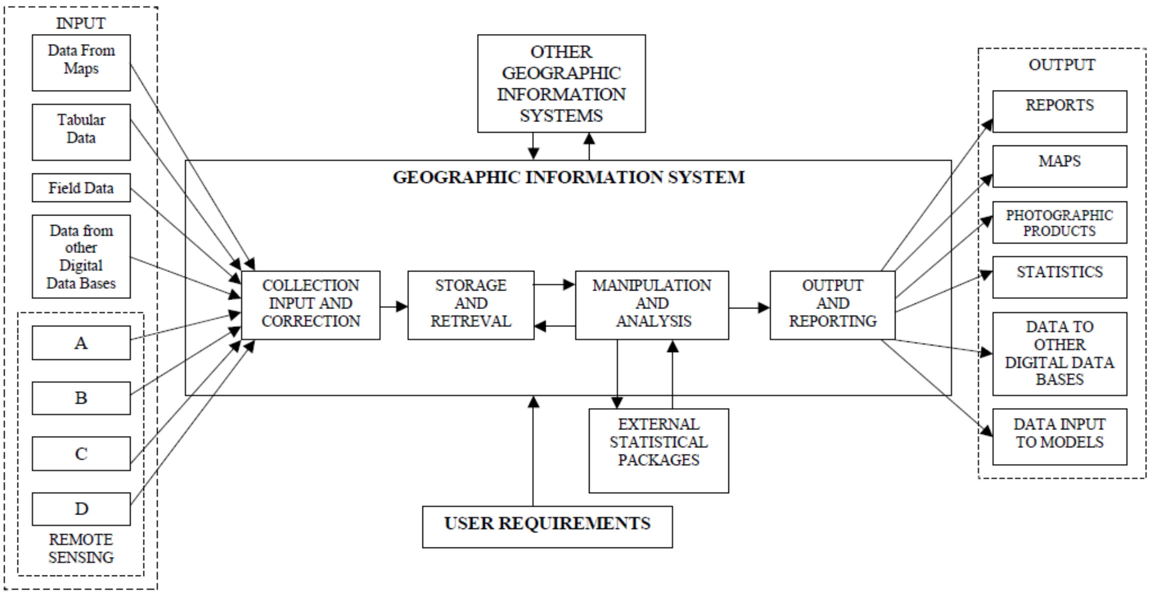

Figure 2. Main concepts of a GIS (adopted from Linden, 1990)

Besides the above-mentioned modules, for GIS to be a real useful tool as a Decision Support System (DSS), user defined procedures in the form of specialized simulation and optimization models have to be represented in the system. This can be accomplished using a general-purpose programming language supplied within the GIS environment, or even outside it, to represent these procedures.

GIS by definition is a computer system allowing for geographic understanding and analysis to be incorporated into the decision making process. GIS provides geospatial information that could be translated into informational power if utilized effectively in the decision making process. Many organizations believe informational power is their competitive advantage, and the lack of informational power could be detrimental to their success.

FREIGHT SUPPLY CHAIN USING GIS

Various models have been developed to analyze freight transportation using operations research techniques (see, for example, Kresge and Roberts, 1971; Freisz, et.al, 1983 and Crainic, 1987). The models are purely analytical, complex to implement and place greater demands with respect to data requirements. While modeling, being the difficult task, transportation planners and other policy makers are finding a hard time to understand, interpret and analyze the results of freight demand models. There is hence a need to look for an alternative in the form of quick- and- easy- to-understandable methods, which could help to analyze the freight flows with available data.

The present study is to model marine freight flows using Geographic Information Systems (GIS) taking network characteristics of transportation infrastructure into consideration and minimizing the total transportation cost incurred during transportation. Since its inception, GIS has been an excellent tool for transportation planners helping them to analyze the transportation systems due to the spatial nature of transportation data and its excellent displaying properties. Modeling freight flows in GIS would help to visualize the results of freight demand models through maps and so it would be easy for transportation planners and policy makers to identify the bottlenecks in the transportation network and make effective policies on infrastructure improvements.

Presently there are many transportation demand modeling software packages, (for example, Tranplan, TransCAD, EMME/2, QRSII) that are capable of modeling freight flows, but these packages are often costly and require special expertise to model. The flows are assigned to the network based on minimum transportation costs, which are external inputs that a modeler has to provide. A tool of this stature is needed, considering the large amount of time and money involved in collecting and authenticating freight data and using complex freight demand modeling procedures.

Using GIS in the analysis of freight is a new concept. The popularity of GIS in freight modeling is due to its abilities of displaying data and handling of huge databases. The simplest usage of GIS for freight analysis is data display and manipulation. The GIS is usually interfaced with an external analysis program for showing the results in the form of maps. Integration of intermodal network models within GIS models provides a generic user friendly functional environment to evaluate the effects of policies and measures aimed to improve the cost effectiveness among competing modes.

Boile (2005) has presented a framework to analyze and evaluate intermodal networks in a GIS environment for auto and rail commuter networks. The method starts by generating the network specific data files necessary for the analysis in TransCAD. These files included information on network, service and demand characteristics, capacity of network facilities and cost components associated with the transportation services such as tolls, parking fees and transit fares.

Rowinski, et al. have developed a demand forecasting model for assigning multi-commodity, multi-class truck trips between various origin and destination points. The model takes into account the impacts of congestion on truck route choice and is implemented as a GIS within TransCAD and Microsoft Access. The model is basically formulated as a policy analysis tool and for only highway mode.

Standifer and Walton "Development of a GIS model for intermodal freight" is one of a kind study that the present research effort is closely followed upon, though on different approach on the Intermodal network creation. The authors have put in an exceptional effort in creating the intermodal network for Texas by merging each individual mode into one final intermodal network by using data conflation and several other techniques on the each of the mode networks. These methods included planar separation, turn penalties and dummy links. Large transfer facilities were modeled as single points using a turntable within Arc View to set turn prohibitions and turn penalties as proxies for intermodal transfer costs. The model built by them, was able to demonstrate the feasibility of GIS to model intermodal freight transportation and performed a rich set of analyses as a decision support system for shippers, planning agencies and researchers.

The literature review has made an attempt to bring the relevant studies in the field of intermodal freight transportation. It was hard to skim through the research done in freight transportation, finding literature on real-time routing of intermodal shipments on the transportation networks because of lack of a single universal modeling techniques for freight analysis. Analyzing freight demand is a complex task due to a variety of issues; it involves multiple dimensions (i.e., value, weight, volume, etc) and multiple decision makers (e.g., drivers, shippers, carriers). The proprietary nature of freight data and its commercial sensitivity makes it, formidable to model freight based on disaggregate commodity flow model. Use of GIS for transportation and incorporating in freight model would provide an invaluable tool to perform routing analysis.

Mathematical Modeling of freight transportation

There are many issues that must be considered when addressing transportation routing. The major factor is the cost of freight transportation. Transportation cost covers the carrier's fuel costs, equipment costs, crew costs, overhead costs, and general and administrative costs. When different modes of transportation are used, a transfer cost is incurred for transferring freight from one mode of transportation to another. Transfer costs can be fixed or variable. They may depend upon the transfer point at which they occur, as well as the incoming and outgoing modes at a transfer point. The transfer cost may also depend on the type and the quantity of commodity that is being shipped. The freight shipped may have effect on the best mode or combination of modes of transportation.

Several components must be examined in modeling intermodal transportation systems. Various factors can affect the reality and the complexity of the model. One factor that must be investigated by the modeler is the combination of single or multiple routes, available for shipment between origin and destination. By considering each additional path, there is a large increase in the complexity of the model, besides there are already a number of modes available at each end in the freight transportation network. Also consideration of linear versus nonlinear transportation costs adds another dimension to complexity. Linear costs are fixed on the basis of weight and distance traveled. Non-Linear transportation costs are more realistic, but much more difficult to model. Multiple objectives may also need to be considered, when modeling. Different objectives may include minimizing total time, minimizing total cost, and / or maximizing service level. The information needed by the carrier in order to determine the various cost/times of transporting goods is often very hard to determine. This imprecise nature of the information can also add to the complexity to transportation models.

Authors suggest to use for route optimization following mathematical model (Mavlins, 2010). Mathematical model designed for route optimization. To create it, determine the system's key elements:

Ports $O = \{O_1, O_2, \dots, O_n\}$,

- The volume of freight in the port (*VO*);
- Loading / unloading price in the port (*L*).

Routes $R = \{R_1, \dots, R_{n-1}\}$, $R_1 = \{O1, O2\}$ $R_2 = \{O2, O3\}$, $R_{n-1} = \{O_{n-1}, O_n\}$,

- Transport (*T*);
- Distance (*D*);
- The time for each route $(t_r,\ r \in R)$.

Load $M = \{m_1, ..., m_k\}$

- $m \in M$ freight handling speed at the port ($o \in O, I^O{}_m$).

Transport $T = \{S, Z, Q\}$, *S – vehicle, Z – railways,* J_m *– sea*

- Speed (A_T);
- The load (m_T);
- The volume (V_T);
- Capacity (V_{max}), G_s – 24t, G_z – 3575t, G_j – 5000t;
- Price (C).

$$\boldsymbol{Q = \Sigma\ (priceL * VT + VT + priceT * VT + priceO * (VT + VO) \rightarrow min} \quad (1)$$

R1 = (O₁, O₃, O₄);

$R1 = (O_1, O_3, O_4);$
$R2 = (O_2, O_5, O_4);$
$R3 = (O_1, O_2);$
$R4 = (O_4, O_1).$

$$\boldsymbol{Q = \Sigma\ (T * V + L * V)} \quad (2)$$

here T – transportation cost;
L – the price of handling;
V – volume.

$Q_1 = T_1 * V_1 + L_1 * V_1 + T_2 * V_1;$
$Q_2 = T_3 * V_2 + L_2 * V_2;$
$Q_3 = T_5 * V_3 + L_3 * V_3 + T_4 * V_3;$
$Q_4 = T_6 * V_4.$

Target's mathematical formulation

The goal is to reduce transport costs throughout the chain and to achieve this, the target established mathematical formulation:

$$\begin{cases} Q = \sum\left(T * V + L * V\right) \rightarrow min \\ R \rightarrow min \\ T \rightarrow min \\ V \rightarrow min \\ V \rightarrow min \\ \Delta t \rightarrow min \end{cases},$$

Here $R \rightarrow min$ (count of routes);
$T \rightarrow min$ (number of transport phases);
$V \rightarrow min$ (batch loading volume);
$L \rightarrow min$ (number of handling);
$Dt \rightarrow min$ (total trip time).

We offer the following parameters:

$R_1 = (O_1, O_2);$
$R_2 = (O_2, O_3);$
$R_3 = (O_3, O_4);$
$Q_1 = T_1 * V_1 + L_1 * V_1 + L_4 * V_3$
$Q_2 = T_2 * V_2 + L_1 * V_2 + L_2 * V_2 + L_3 * V_3$
$Q_3 = T_3 * V_2$

The mathematical formulation of the task:

$\Delta t = \sum\left(\frac{D}{A} + \frac{V}{I}\right.$ I) – the *objective function*, here

$\Delta t_1 \rightarrow min$ (total trip time);

Δt_1 = time to R_1;

Δt_2 = time to R_2;

here D – distance between ports;
A – speed of the ship;
V – volume of the batch;
I – landing speed;
E – loading speed.

$$\Delta t_1 = \sum\left(\frac{D_1}{A_1} + \frac{V_1}{I_1} + \frac{V_1}{E_1} + \frac{V_3}{E_2} + \frac{D_1}{A_1} + \frac{V_3}{I_3}\right)$$

$$\Delta t_2 = \sum\left(\frac{D_2}{A_2} + \frac{V_2}{I_2} + \frac{V_4}{E_3} + \frac{D_2}{A_2} + \frac{V_4}{I_4}\right)$$

General solving algorithm:

Before you draw up the supply chain model we need to define the necessary data, herefore it is necessary to:

1. determine sets of *T* and *V*;
2. determine sets *L* and *V*.

To solve the task authors offer the following algorithm:

V – the amount of freight

- *Step 1* – Task A. Choose transport modes R_T.

  Vehicle costs: C1 + C2 + C3 + C4 = C_a
  C1 – driver's salary;
  C2 – the cost of fuel;
  C3 – vehicle depreciation costs;
  C4 – transport manager services.

  Railway transport costs: C1 + C4 + ... = C_z
  C1 – driver's salary;
  C2 – the cost of fuel;
  C3 – vehicle depreciation costs.

  Maritime transport costs: C1 + C2 + ... = Cm
  C1 – Maritime shipping costs;
  C2 – Cargo transshipment port area;
  C3 – Vehicle rental costs in one country;
  C4 – Vehicle rental costs in another country territory;
  C5 – rigging wagon.
  T = min (C, Cz, Cm)
- *Step 2* – Task B – determine the best way to go to the selected mode R by selected T transport mode. $R_T = s / v \rightarrow min$;
- *Step 3* – Task C – calculate the maximum capacity for each R_T;
- *Step 4* – Task D – calculate the time $R_{Tt} = \{t_{tr} + t_{landing/loading}\}$;
- *Step 5* – Task E – calculate the required number of vessels;
- *Step 6* – Task F – calculate the number of trips.

The research proceeding is following. Objectives are met in a specific order. First settled by the appointment and task defined attendance points. Modes are selected for each stage of the supply chain (Task A). The following is definitely the most favorable routes sets T and

V (Task B). Then calculate the maximum of load capacity for each mode of the supply chain (Task C). Solving tasks B and C we solve also sets V and L. Then going the route time designation R_{Tt} (Task D). From the results obtained calculate the required number of vessels in each phase (Task E). The final step – depending on the data obtained, to calculate the required number of trips (Task F).

The developed model allow not only to analyze the individual logistics operations, but also the supply chain system as a whole – the route selection strategy based on the choice of the base port, as well as load distribution between the ports and the optimization of these factors. Model is based on a regular cycle and the principle that it:

- provide a rational approach for complex goods chains:
- provides a common information sharing between supply chain members;
- improve the company's operational planning.

CONCLUSIONS

Freight movement uses local, regional, national, and international systems. Cooperation between private and public sectors – requiring changes in both – will be needed to ensure a transportation system that meets the freight needs of businesses and consumers. Because customers will require one-stop shopping, freight movement increasingly will be intermodal and multimodal. This trend will accelerate cooperation and coordination between modes and transportation companies. Successful freight transportation providers will offer an increasingly wide array of logistics services or they will partner with well-equipped logistics management firms. In short, the roles are changing for freight transport users, transport providers, and policy makers interested in ensuring the swift and efficient movement of goods, which is vital to the strength of our economy and the prosperity of our communities.

Although increased coordination and involvement has started in some regions, a greater effort is needed to achieve a shared vision for freight movement and different type of IS using for it. GIS may be a real useful tool for decision support and reducing of transportation costs.

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