GIS Based Run-Time Evaluation of Supply Chain Processes

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The GI_Forum Program Committee accepted this paper as reviewed full paper.

Abstract

This study develops a methodological approach for run-time analysis and optimisation of supply chain process using GIS, which is capable of process planning and scheduling of related logistics resources. It first looks into the process of a supply chain process applying IT solutions from product identification to advanced GIS, and the consequences of using these IT resources, especially from the point of view logistics related advantages and applicability of run-time replanning of logistics processes. It proposes a model of supply chain processes especially in the case of international transportation and gives a mathematical description consisting not only the system specification, but also the evaluation and optimisation parameters including cost based objective function and constraints. In the second part of the paper, an optimisation method is also discussed based on heuristic algorithm. The results of this study can be used to improve the utilisation of logistics resources, the run-time evaluation of cost structure of the logistics operations and to enhance the transparency of the whole supply chain, thus increasing business efficiency. The paper concludes with suggestions of further research directions, namely integration of the developed method into the enterprise resource planning system.

1 Introduction

Development of GIS lead to the improvement of supply chain processes, especially in the case of forwarding services. Not only the asset holders but also the carriers and operators of the supply chain applied the tools of GIS. The successful application of a geographic information system needs not only the thinking about the purpose of the business environment in which it operate, but also the permanent development of the related application areas. This fact is especially up-to-date in the serious economic crisis since the great depression, so the reengineering of supply chain processes is a hot problem of the logistics business. This demand leaded to the requirement of the scientific research of the optimisation of supply chain processes especially from the point of view cooperation possibilities. Intensification and reengineering of supply chain has been tackled as an optimisation problem in the research arena.

Modelling of supply chain has to describe the network of cooperative or competitive partners the material flow within the configuration according to a specific objective function based on algorithms (TAYUR et al. 1999). The cooperation of autonomous asset holders, carriers and operators can performed within the frame of distributed supply-chains, in which no hierarchy in decision making is enforced and where the initiatives to reach a common goal are taken by each partner, so important direction of the research is the modelling of distributed supply-chains with the aim of providing a tool for DSC decentralised optimisation (GHIRARDI et al. 2008). Efficiency of supply chains mostly depends on management decisions, which are often based on intuition and experience. Due to the increasing complexity of supply chain systems, these decisions are often far from optimum (SARIMVEIS et al. 2008). To avoid irresponsible decisions by right of experience and intuition, the optimisation and analysis of supply chains based on different objective functions and metrics is the scientific suggestible way of the operation of the system. In the literature different metrics are referred to the main disciplines, which contributed to the field of supply chain management the most: system dynamics, operations research, information technology, logistics, marketing, organization and strategy (see OTTO & KOTZAB 2003). The purpose of a lot of research work is the optimisation of supply chain based on different objective functions, but only a few of them try to integrate the supply chain with the related sub-systems of the whole business (CSELÉNYI et al. 2003). The appearance of the just-in-time philosophy lead to revolutionary changes in the production and logistics. The time factor became more and more importance and the planning of logistics and production systems based on just in time philosophy needs more attention (BÁNYAI & CSELÉNYI 2003).

One of the basic tutorial works of GIS application in the field of transportation and supply chain was presented more than 15 years ago (NIEMEIER & BEARD 1993). It was hypothesized that a GIS model would refine the process of transportation planning by yielding improved interim and final results. Following these works, a lot of research work has emerged in varying forms. However it can be argued that different applications of GIS support specific forms of the service area from groundwater investigation (VANDERPOST & MCFARLANE 2007) to the assessment of bioenergy potential (BECCALI et al. 2009), but the largest application area of GIS is the support of supply chain processes, which includes the operations of purchasing, distribution and inverse logistics. As interesting areas of these logistics related researches are the GIS based 3D route modelling software for municipal waste collection and transportation (Tavares et al. 2009), the GIS analysis of suitability for construction aggregate recycling sites using regional transportation network (ROBINSON & KAPO 2004)

To the author's knowledge there has been no research work on assignment problems that take into consideration the information of GIS to evaluate the supply chain and assign the resources to the free transportation demands run time. The main result of this work is the formalisation of an effective method for evaluating and increasing the utilisation of logistics resources in the case of cooperated supply chains. The model is able to take into account both the transportation cost of each players of the logistics business and the cost due to lost transportation assignments. The author describes a mathematical model of the supply chain, the evaluation method and the optimisation possibilities according to the objective functions subject to constraints.

2 Problem Definition

Supply chain processes include the functions of development, procurement, production, sales, distribution, and recycling. The success of the operation of these functions is based on powerful IT solutions that combine ERP systems with specific IT tools, including sophisticated operation research heuristics and algorithms (KNOLMAYER et al. 2009). The supply chain process for a customer order is made up of various sub-processes used for converting raw materials or semi-finished products, or assembly parts into final products and delivery them to the retailers or directly to the users.

The purpose of this paper is to show a possible optimisation method of this last delivery phase from the point of view costs and resource utilisation. The average utilisation of road transportation resources is approx. 70%. The increase of this utilisation will effect the increase of the profit. This utilisation increase is possible in two ways: (i) optimisation of the disposition of transportation tasks before departure of trucks; (ii) run-time assignment of transportation resources to the current transportation tasks. Geographic information systems offer the possibility of run-time assignments based on the current positions of transportation resources.

The purpose of the run time optimisation problem is the assignment of free transportation resources with free capacities to the transportation demands taking into consideration the followings: (i) current positions of free transportation resources from GIS; (ii) the realisation of the contracted arrival times of the current transportations tasks, (iii) the realisation of the required departure time of the new transportation demands; (iv) the income must be higher then the additional transportation cost.

3 Model, Parameters and Assumptions

The supply chain without run-time planning and optimisation possibility is depicted in Fig. 1. In the case of this supply chain the set of the free transport demands is waiting for free transportation resources. Without the information of the current position of the resources it is not possible to assign a task (transport demand) to a truck (resource). The index i will be used for the resources and their destination and index j for the free transport demands and their destination.

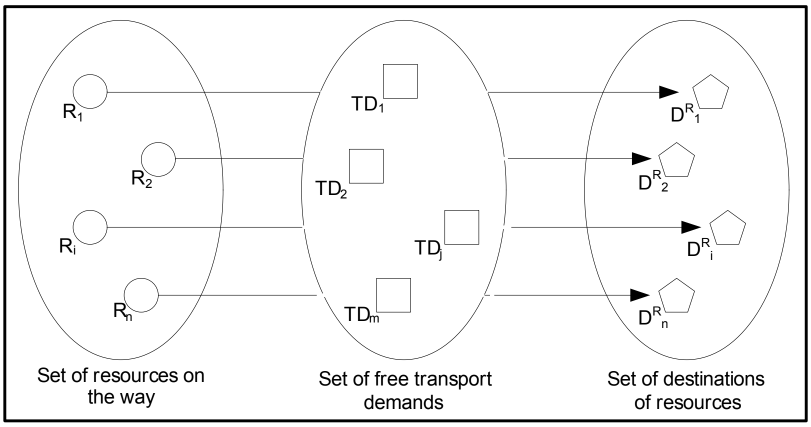

Fig. 1: Supply chain without run-time planning and optimisation

In the case of the application of GIS the potential of run-time evaluation and optimisation of the supply chain is given (see Fig. 2). The given current positions of the transportation resources offer the possibility to assign free or partly free resources to the free transportation demands near to the positions of them.

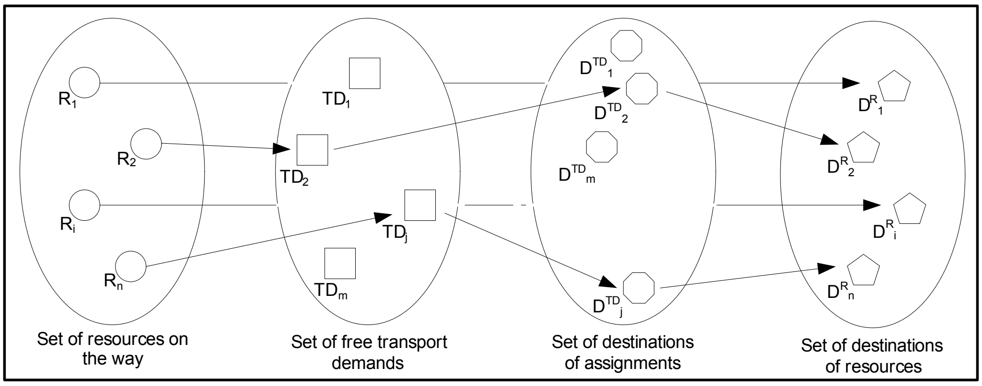

Fig. 2: Supply chain with run-time planning and optimisation option

The following notations are used in the paper:

- P_i^R : current position of the i^{th} resource,
- P_j^{TD} : current position of the j^{th} transportation demand,
- D_i^R : destination of the i^{th} resource,
- D_j^{TD} : destination of the j^{th} transportation demand,
- AT_i^R : requested arrival time of the i^{th} resource,
- AT_j^{TD} : requested arrival time of the j^{th} transportation demand,
- CAT_i^R : calculated arrival time of the i^{th} resource,
- CAT_j^{TD} : calculated arrival time of the j^{th} transportation demand,
- C_i^R : free loading capacity of the i^{th} resource,
- RC_j^{TD} : requested free loading capacity of the j^{th} transportation demand,
- ST_i^R : specific transportation cost of the i^{th} resource,
- SUT_i^R : specific transportation cost of the i^{th} resource depending on the loading weight,
- I_j^{TD} : income of the assigned transportation demand of the j^{th} transportation demand,
- α : non-linearity coefficient of SUT_i^R .

The decision variable of the problem is the following:

- $A_{i,j}$: assignment of resources to transportation demands, if $A_{i,j} = 1$, then the i^{th} resource is assigned to the j^{th} transportation demand and 0 if otherwise.

The model takes into consideration the following assumptions: (i) cooperative relation among resources; (ii) capacity constraints are not ignored; (iii) the cost function of transportation is non-linear; (iv) the drivers' conditions are ignored.

The objective function of the optimisation is the maximization of the difference between revenue and cost, and 6 constraints have to be taken into consideration (see Table 1). The objective function trades off the income of the assigned transportation demands against the transportation cost:

$$C = \sum_{i=1}^{n}\sum_{j=1}^{m} A_{i,j} \cdot \left(I_j^{TD} - L\left(P_i^R, P_j^{TD}, D_j^{TD}, D_i^R\right) \cdot \left(ST_i^R + SUT_i^R \cdot W_i^{\alpha}\right)\right) \rightarrow \min.$$

Table 1: Constraints and their explanations

Constraints	Explanations for the constraints
(1) $RC_j^{TD} \geq C_i^R \rightarrow \forall i,j \text{ if } A_{i,j} = 1$	Ensures that the free capacity of the assigned transportation resource is more than the requested capacity of the transportation demand.
(2) $CAT_i^R \leq AT_i^R \rightarrow \forall i$	Ensures that the calculated arrival time of the transportation resource is not later than the requested arrival time of them (no delay).
(3) $CAT_j^{TD} \leq CAT_j^{TD} \rightarrow \forall j$	Ensures that the calculated arrival time of the transportation demand is not later than the requested arrival time of them (no delay).
(4) $\sum_{i=1}^{n} A_{i,j} \in \{0,1\} \rightarrow \forall j$	Ensures that one transportation demand is assigned to one transportation resource.
(5) $\sum_{j=1}^{m} A_{i,j} \in \{0,1\} \rightarrow \forall i$	Ensures that one transportation resource is assigned to one transportation demand.
(6) $A_{i,j} \in \{0,1\} \rightarrow \forall i,j$	Set the decision variable binary.

The calculated arrival time can be determined by the aid of the modified transportation routes, depending on the positions and departures of transportation resources and transportation demands:

$$CAT_j^{TD} = CAT_j^{TD}\left(P_i^R, P_j^{TD}, D_j^{TD}\right) \text{ and } CAT_i^R = CAT_j^{TD}\left(P_i^R, P_j^{TD}, D_j^{TD}, D_i^R\right).$$

4 Applied Algorithm

The chosen solution method of the multidimensional optimisation problem is the genetic algorithm. Rechenberg's group was able to solve complex engineering problems through evolution strategies (SCHWEFEL 1981). Following this works, a lot of research work has emerged in varying forms to present different application areas of genetic algorithm from the problems of acoustic (CHIU & CHANG 2008) to expert systems (HUANG & WU 2008). Generally, the optimisation and evaluation technique applied for the solution of the above mentioned assignment problem could be described in 5 steps: (i) generate the possible assignments among transportation resources and transportation demands; (ii) generate a number of assignments as initial population of the GA; (iii) perform GA until a termination condition is satisfied; (iv) from the population of the last GA generation, choose the best solution; (v) evaluate the best assignment set and the costs of the assignment.

The possible assignments (see Fig. 3) among transportation resources and transportation demands will be selected subject to constraints 1-3:

$$A_{i,j}^{possible} = 1 \rightarrow \forall i, j \text{ if } RC_j^{TD} \geq C_i^R \text{ and } CAT_i^R \leq AT_i^R .$$

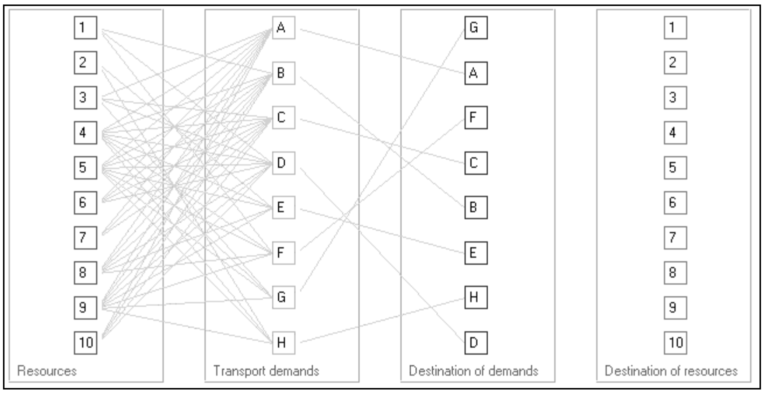

Fig. 3: Possible assignments (example in the case of 10 resources and 8 demands)

The initial assignments can be generated regarding to the possible assignments subject to constraints 4-5. The next step of the algorithm is the application of genetic algorithm with conventional GA operators for selection, recombination and mutation. The main goal of the selection mechanism is to find an efficient balance between the exploration and exploitation abilities of the search during the run. Too much selection pressure increases the exploitation and the probability of turning the population homogeneous sooner, rather than later (GEORGIEVA & JORDANOV 2009). The use of the multi-point crossover operation causes some problems related to constraints 4 and 5, so as reproduction operator the conventional one-point crossover operator was chosen (see LEUNG & WANG 2001) which combine and exchange the elements of the individuals (c_i=child, p_i=parent):

$$c_i^1 = p_i^1 \rightarrow i \leq cp \text{ or } cp < i \text{ and } p_i^2 \neq c_j^1 \rightarrow j = 1 \ldots i-1 ,$$

$$c_i^1 = p_i^2 \rightarrow cp < i \text{ and } p_i^2 \neq c_j^1 \rightarrow j = 1 \ldots i-1 ,$$

$$c_i^2 = p_i^2 \rightarrow i \leq cp \text{ or } cp < i \text{ and } p_i^1 \neq c_j^2 \rightarrow j = 1 \ldots i-1 ,$$

$$c_i^2 = p_i^1 \rightarrow cp < i \text{ and } p_i^1 \neq c_j^2 \rightarrow j = 1 \ldots i-1 .$$

The mutation operator changes one randomly chosen position of the individual in two different way: (i) if the position represents no assignment, then the position will be replaced by one of the possible assignments; (ii) if the position represents an assignment, then no assignment will be chosen:

$$\text{if } A_{i,j} \in A_{i,j}^{\text{possible}} \rightarrow A_{i,j} = 0,$$

$$\text{if } A_{i,j} = 0 \rightarrow A_{i,j} = A_{i,j}^{\text{possible}}.$$

The algorithm stops when a given computational resource is exhausted. The combination of this termination condition with other conditions (e.g. specific homogeneity of the population) can decrease the required computational time. The description of the used genetic is shown in Figure. 4.

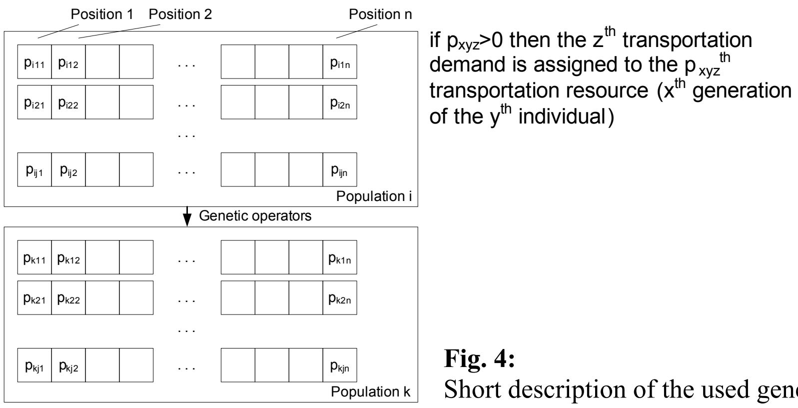

Fig. 4:
Short description of the used genetic algorithm

The adopted population size and maximal number of iterations depends on the size of the problem. The optimisation process is repeated until the termination condition (computational resource) has been reached and the optimal assignment is visualised (see Fig. 5).

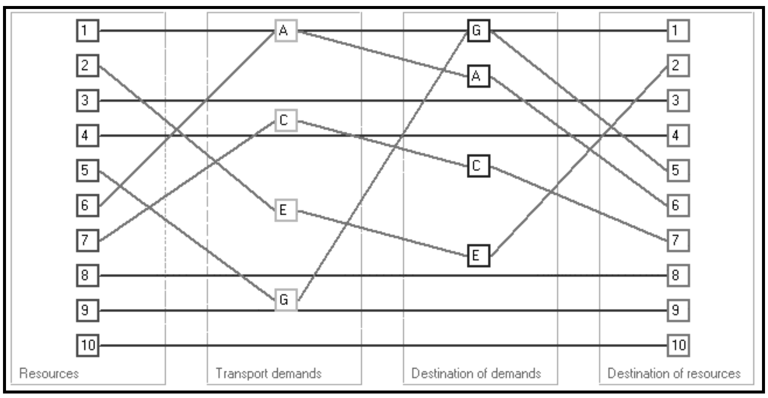

Fig. 5: Optimal assignments (example in the case of 10 resources and 8 demands)

5 Analysis and Results of Run Time Optimisation

The application based on the above mentioned algorithm makes it possible to analyse the different solutions from the point of view transportation cost, income, profit, resource utilisation and transportation routes (see Fig. 6).

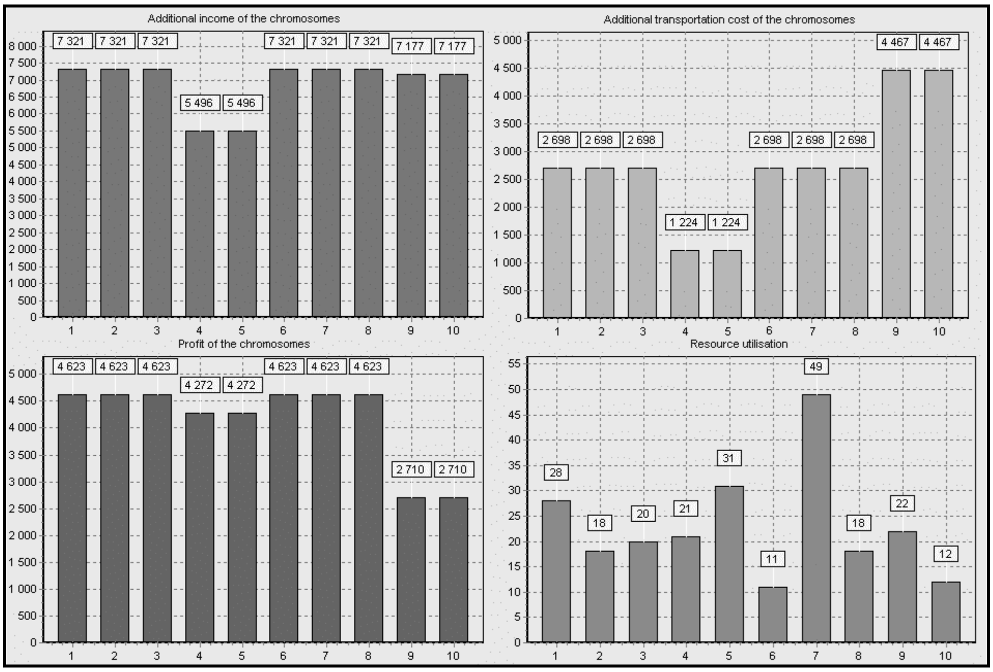

Fig. 6: Example charts of the application

The GIS based run-time assignment makes it possible to increase the utilisation of transportation resources and to get extra profit. The effect of transportation cost, income on the assigned demand was analysed by the aid of some test problems by varying the parameters.

Table 2: Comparison of optimisation results

Specific transportation cost	Profit	Specific transportation cost	Profit
Income=1000		Income=2000	
5	4888	5	12701
10	3153	10	9684
20	2071	20	6532
30	633	30	3338

As the comparison of test results shows, the additional profit depends on the parameters. If the supply chain setting is “low specific transportation cost and high income”, then the extra profit is available. The numerical results of the words "low" and "high" are determined in the case of a chosen layout in Table 2. The coefficient of determination in the relation of specific transportation cost and profit is near to 1 (see Fig. 7) and it indicates that the regression line almost perfectly fits the data.

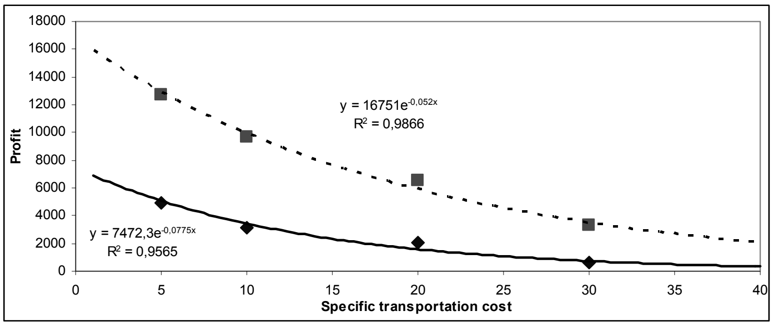

Fig. 7: Regression of the profit-specific transportation cost relations

6 Summary

The application of different IT tools and IT solutions makes it possible to increase the efficiency of the logistics operations of supply chains. The GIS offers a good possibility to apply run-time scheduling and assignment methods to increase the technical and economical utilisation of the processes. Applying the above mentioned model of run-time assignment users are able to optimise supply chain from the point of view profit maximisation.

7 Further Research Directions

Here the multi-assignment of transportation resources and transportation demands is ignored. This simplified representation is near to the reality, but a measure of how well the run-time assignment increase the extra profit the solution of a multi-assignment model will be useful. The integration of this application into the enterprise resource planning system will increase the efficiency of the developed method.

Acknowledgements: This work was supported by the National Office for Research and Technology within the framework of the Pázmány Péter Program.

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