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Simulation Modelling of Multi-Agent Logistics Model in AnyLogistix Environment

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ABSTRACT

This paper presents the supply chain as a complex logistics system analyzed in the AnyLogistix environment, which includes production centers, warehouses, distribution centers, suppliers, retailers or trade chains. Simulation modelling within scientific research, economic and social processes is presented as one method for creating an agent-based simulation model. The assigned software agents operate in the simulation context, according to a prescribed flowchart of a typical agent-based model. An analysis was made of the elements of the supply chain management system and their interaction according to the assigned agents, namely: supply acquisition agent, logistics agent, transport agent, planning agent, supply agent, dispatcher agent, etc.

Keywords: agent-based modelling and simulation, supply chain, logistics system, Any Logistix.

INTRODUCTION

Supply chains include production centers, warehouses, distribution centers, retailers or trade chains, and the management of this logistics system is realized by processing the flows of goods and services to the end user. The optimization of these circuits is defined theoretically by its main interaction elements as: Planning (managing all resources to satisfy customer demand for a given product), supplier selection (supplier attractiveness analysis), production motives, supply and logistics (schemes and types of supply of raw materials and materials, as well as processing the corresponding information), reverse logistics (network for the return of defective, surplus or unwanted goods), etc.

An essential element in the optimization of supply chains are the methods of planning the routes of the vehicles in the distribution of goods.

For example, by applying heuristics and meta-heuristic methods and a genetic algorithm with classical heuristics - "Clark&Wright", as well as "Algorithm for splitting the coded decision into vehicle trips" can optimize routing vehicles with different payloads (with C# urban area delivery routing application and tested on static test tasks) [1, 2]. In another study, the occupancy and distribution of emergency medical assistance vehicles was successfully simulated using MS Excel [3].

The boundary values of the agent's behaviour, such as agent-based modelling can be realized

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either by means of universal or specifically designed software or programming languages, such as: spreadsheets (Excel with Visual Basic Applications (VBA), etc.); mathematical computing systems (MATLAB, Mathematica, etc.); specialized agent development environments (Repast, Swarm, MASON, AnyLogistix, Simio, etc.); object-oriented programming languages(C++, Java, Python, etc.).

The main scheme in agent modelling is presented in the block diagram for a typical structure of agents (Fig. 1).

In the present considerations, some theoretical rationales are demonstrated below for modelling that simulates the flow of products in a multi-echelon supply chain network through the Any Logistix software product.

Model-based decision making in supply chain management

Decision making in supply chain management involves the use of qualitative and quantitative methods (Fig. 2). Quantitative methods are usually based on optimization or simulation.

The main task is to identify a management problem, which is the starting point of the solution for the process simulations and ultimately to find the solution. The next step is to transform the real problem into a mathematical model. For this purpose, the complexity of reality must be reduced. This is necessary to represent the control problem for the needs of the mathematical model. This model can then be solved using existing algorithms.

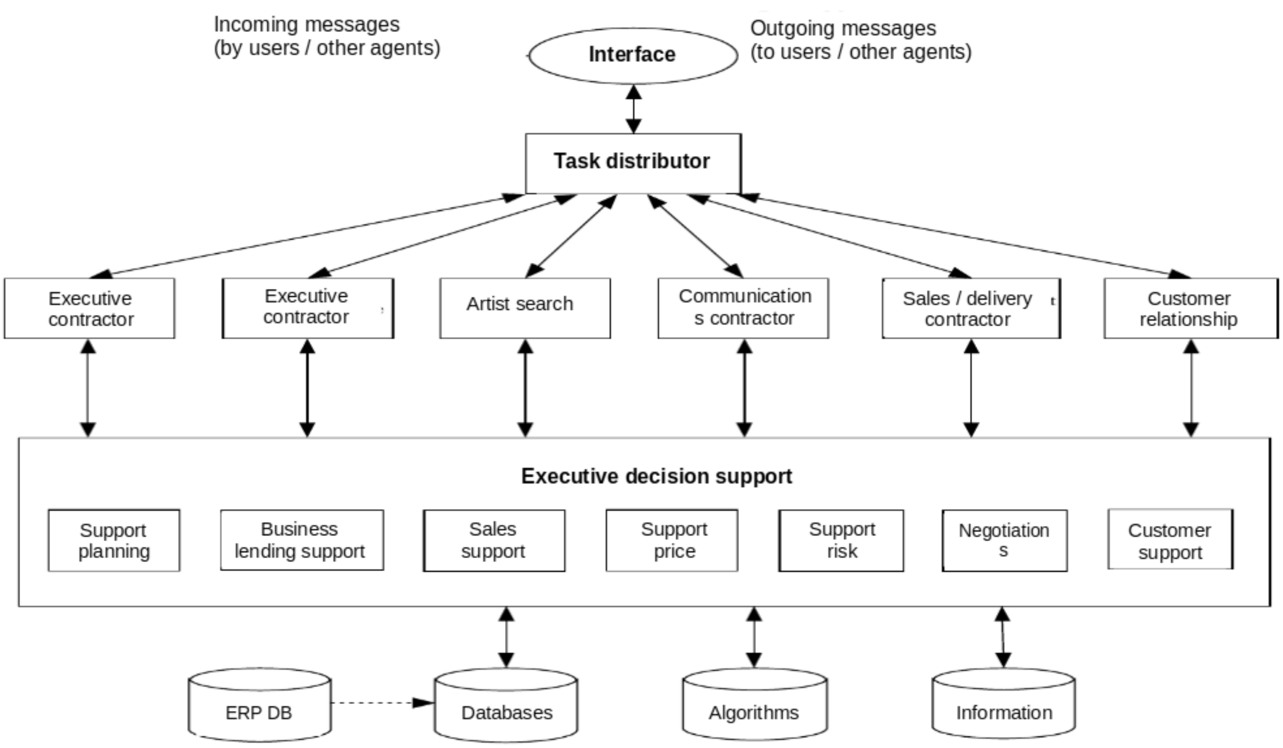

Fig. 1. Block diagram of a typical agent structure [4].

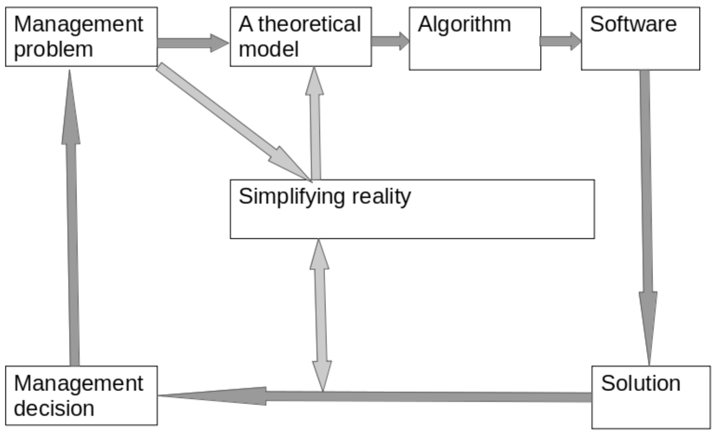

Fig. 2. Block diagram of model-based decision making in supply chain management.

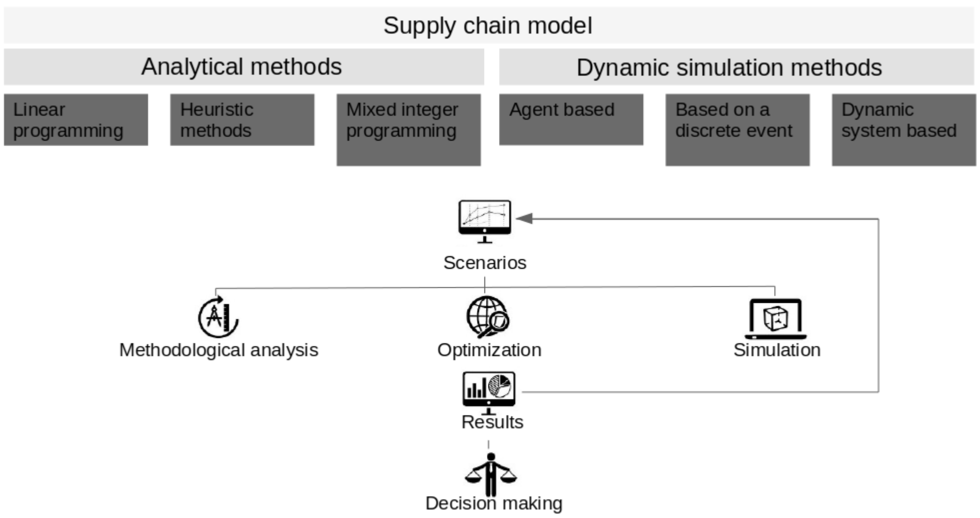

Fig. 3. Supply chain modelling options [4].

Basic principles of supply chain simulation and optimization in AnyLogistix

The supply chain can be analysed in two ways (Fig. 3), where analytical modelling uses optimization models to study supply, and simulation modelling, which uses a set of objects and rules that describe their dynamic behaviour and their interaction to introduce the supply chain.

Analytical modelling through optimization models for supply research have certain areas of application, advantages and disadvantages.

AnyLogistix uses both and helps to understand the differences and applications, so it is possible to solve tasks:

- Planning the location of facilities;
- Planning the capacity of the distribution centers;
- Inventory control policies and ordering

rules;

- Sourcing policies (single and multi-source);
- Transport policies;
- Packaging in transport, production and sales;
- Bullwhip Effect and Ripple Effect analysis in the supply chain.

In the case of analytical solutions with set key performance indicators, a plausible assessment of the quality of the management agent's decisions is achieved, and through software simulation, answers can be given to typical questions, such as:

- Where are the best locations for our warehouses, distribution centers and production facilities objects?
- What does an out-of-stock event cost?
- What is the best replenishment, supply and shipping policies?
- How stable is our supply chain?
- What happens if we change our inventory policy?
- What will happen if we increase the capacity of the distribution center?
- What will happen if demand changes?
- What will happen if we add a new product?
- What does an out-of-stock event cost?

Extending the scope of the analysis in the third stage, such as simulations that provide an overview of the effects of different combinations of inventory control, procurement, transportation and production policies (Fig. 4).

According to Ivanov et al. [4], "Simulation is imitating the behaviour of one system with another". Thus, the available processes in the supply chain are registered over time, and by changing the input parameters in the simulation, information is obtained about the effectiveness of a proposed model design obtained from an optimization model" [4]. Some critical data such as the number and location of facilities, inventory levels, and transportation and supply planning, etc., are required to run a simulation. In the analysis of the temporal processes embedded in the simulation, it may require information regarding process control, development forecasts and trends or decision support for choosing alternatives in an unexpected situation, operational risks, etc. The sensitivity to the number of iterations also sets the optimal result in the model from the point of view of process sustainability [5], realized by changing basic input parameters such as demand, stocks or costs. The combination of simulation and optimization depends on the purpose of the modeling and three main combinations are usually distinguished (Fig. 5): Optimization as a starting point and simulation as an advanced method of analysis, for example to refine solutions obtained analytically using dynamic process analysis; Simulation as a starting point and optimization as an advanced method of analysis, for example to obtain optimal parameter values in supply chain design when interacting between simulation and optimization models; Hybrid simulation-optimization techniques, such as simulation-based optimization, to iteratively improve supply chain performance.

Optimization is usually a combination of creating an efficient interrelationship between analytical and simulation models (Fig. 5).

Theoretical background and principles to support decision making in supply chain management using AnyLogistix

A supply chain is a network of organizations and processes in which manufacturers, distributors and retailers collaborate and coordinate, according to values, to acquire, convert raw materials and deliver these products to customers.

Supply chain management is an inter-departmental and inter-firm system for integrating and coordinating material, information and financial flows to use resources in the chain in the most rational way along the value chain, from raw material to actual suppliers and customers [4]. Strategic decision elements include both the size and location of manufacturing facilities or distribution centers, as well as the structure

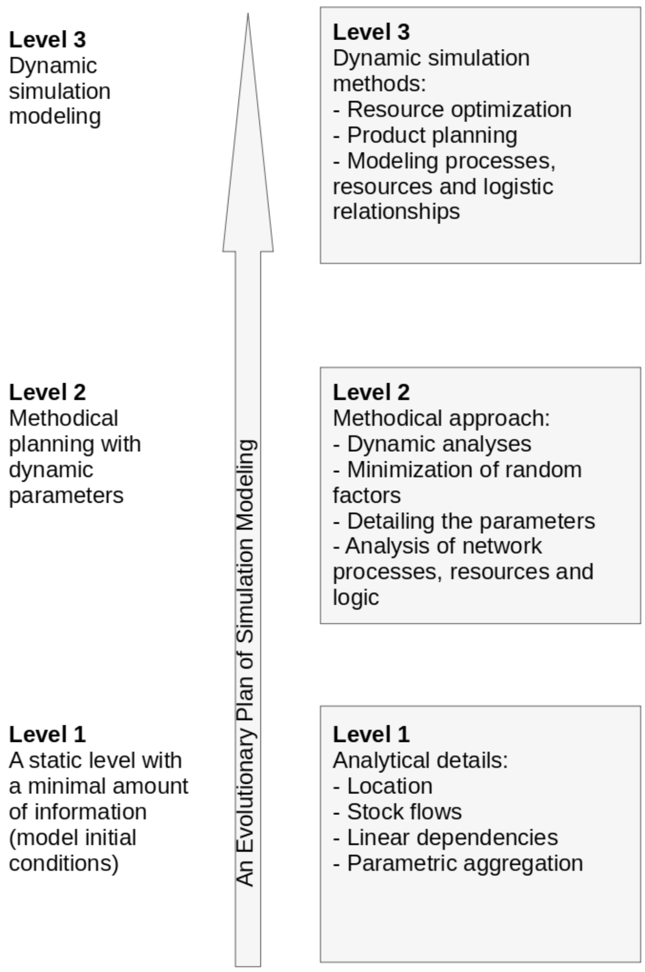

Fig. 4. Supply chain planning and problem analysis.

of service networks and supply chain design. Tactical issues include production, transportation, and inventory planning. Operational issues relate to production planning and control, inventory control, and vehicle routing.

The theoretical basis according to Ivanov at. al. is considered as a global chain of supply and management oriented to decision-making and their normalization to a parametric value [6]. The objective is to determine the best location for a distribution center with a view to optimization while minimizing total transportation costs. Such an analysis, also known as center of gravity analysis, is a common method for determining optimal locations for new facilities [7].

A high level of abstraction is required to implement this model with a minimum number of details used, considering data such as customer locations, customer demand, number and location of distribution centers and/or service distances are used as inputs to the analysis. The output of the program analysis is an optimal location for a production or warehouse base [4]. This optimal point is called “central to the model” [7]. As explained, these so-called “model central points” determine the location at which the cost of all

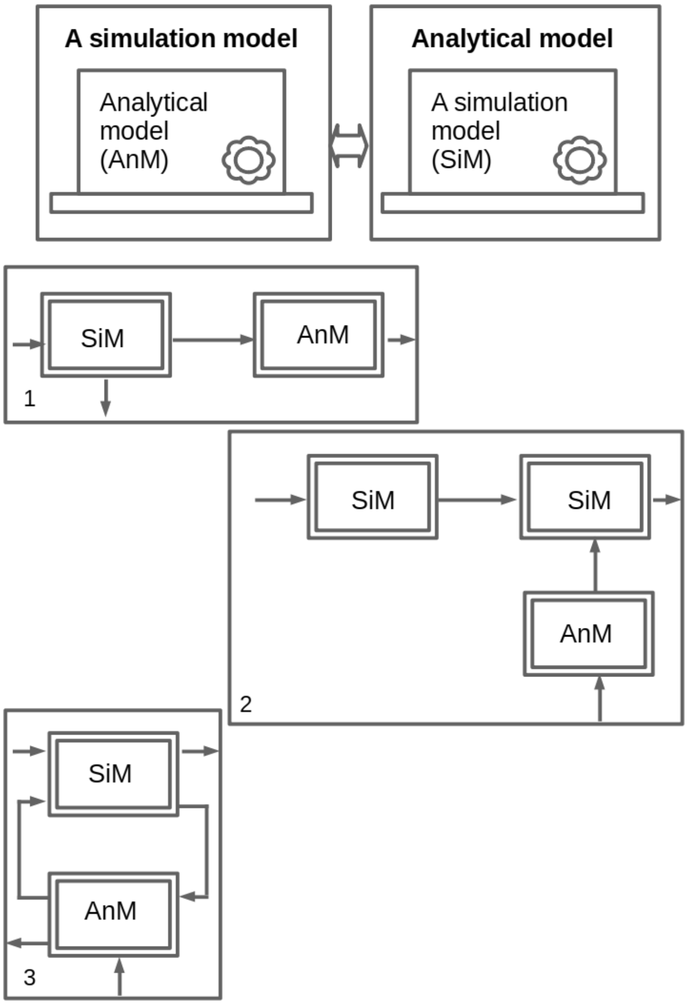

Fig. 5. Block diagram of a combination of the interaction options between the simulation and optimization models (options 1, 2 and 3).

inbound and outbound transport is minimized [8, 9].

Thus, (x;y) are the coordinates of each localized user, which are constant. The coordinates $(p_x;p_y)$ are variables and their values are set as the solution of the simulation model. We also assume that our transport costs are linearly dependent on distance and transport volume (ie demand). That is, the total transportation costs will depend on the coordinates $(p_x;p_y)$ to the aggregated customer locations $(x_i;y_i)$.

With this in mind, we need to determine the distances $d((p_x;p_y);(x_i;y_i))$ between the location of the i-customer and the warehouse to calculate the transportation costs by minimizing the function $Z(p_x;p_y)$, also called the object function .

$$Z\left(p_x;p_y\right)=\sum_{i=1}^{N} d\left((p_x,p_y);(x_i,y_i)\right)\cdot D\left(x_i,y_i\right)\rightarrow \min \quad (1)$$

This minimization is obtained by finding the first derivative along the x and y coordinates, respectively:

$$\frac{dZ}{dp_x}=\frac{Np_x}{\sqrt{\left(x_i-p_x\right)^2+\left(y_i-p_y\right)^2}}-\sum_{i=1}^{N}\frac{x_i}{\sqrt{\left(x_i-p_x\right)^2+\left(y_i-p_y\right)^2}} \quad (2)$$

$$\frac{dZ}{dp_y} = \frac{Np_y}{\sqrt{(x_i - p_x)^2 + (y_i - p_y)^2}} - \sum_{i=1}^{N} \frac{y_i}{\sqrt{(x_i - p_x)^2 + (y_i - p_y)^2}} \quad (3)$$

Thus, the object function (1) is defined as central to the model in location analysis. Thus we will be able to calculate the optimal coordinates of the distribution center:

$$p_x = \frac{\Sigma_{j=1}^{N} \frac{D(x_j; y_j) \cdot x_j}{\sqrt{(p_x - x_j)^2 + (p_y - y_j)^2}}}{\Sigma_{j=1}^{N} \frac{D(x_j; y_j)}{\sqrt{(p_x - x_j)^2 + (p_y - y_j)^2}}} \quad (4)$$

Thus, in the presence of the initial information necessary to implement the model for minimizing the transport costs of delivery. This basic information is:

- Who are the users and what are their locations;
- What are the products and their measurement units for quantitative characterization;
- What are the products sought by customers;
- What about the costs per kilometer for transport;
- What about the distances in the delivery network.

Through such a realistic case study, it can be modelled using AnyLogistix [10] by following the following steps:

1. Create a scenario and define the structure and parameters of the supply chain.
2. Define consumer demand, transportation and supply chain for supplies.
3. Parameterization of locations and policies.
4. Analysis and determination of the best locations for one or several warehouses.
5. Establish a baseline and gather supply chain performance statistics.
6. Simulate the supply chain design with the new warehouse locations and determine the impact.

CONCLUSIONS

This paper presents a theoretical model of the supply chain analysed in the Any Logistix environment in the context of a hybrid use of simulation and analytical modelling as a method to create an agent-based simulation model. The principal flowcharts of the main elements and processes of a typical agent-based model are set out. An analysis of the interaction of the assigned agents was made, as well as the general options for modelling the logistics processes in the context of minimizing transport costs. The general approach for constructing a model optimization problem in the AnyLogistix environment is demonstrated.

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