Theodore Tsekeris
Centre of Planning and Economic Research (KEPE)
11 Amerikis, 106 72, Athens

Paraskevi Ntemoli
Technological Educational Institute of Halkida,
Department of Logistics, Thiva
Greece

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SIMULATION-BASED DESIGN OF LARGE-SCALE INTERMODAL SUPPLY CHAIN NETWORKS

SIMULACIJSKI PRIKAZ ŠIROKE MREŽE INTERMODALNOG LANCA DOBAVE

SUMMARY

This study describes the main components and practical deployment of a simulation-based model, using specific-purpose software, for the design and management of supply chain systems of heavy industries, such as that of automobile. A large-scale, intermodal logistics network is deployed to effectively distribute cars into many countries around Europe. The transport system includes a set of alternative transit routes and it encompasses a combination of modes, such as truck, rail wagon and ship. The overall procedure aims at finding out the most promising combinations of transport routes and modes, in terms of the total (storage and transport) cost, subject to a given set of (physical, capacity, delivery time and financial budget) constraints. The resulting network configuration produces a required level of revenues and profit, based on the car sales, within the given set of constraints.

Key words: *supply chain networks, maritime transport, intermodal distribution systems, simulation, automobile industry.*

SAŽETAK

Koristeći se software-om za specifične namjene, u radu su prikazane glavne sastavnice te raširenost u praksi simulacijskog modela za projektiranje i rukovanje sustavima lanca dobave teške industrije kao što je npr. industrija automobile. Razvijena je široka mreža intermodalne logistike kako bi se vozila uspješno distribuirala po mnogim europskim zemljama. Sustav prijevoza uključuje sklop alternativnih prijevoznih pravaca, uključujući kombinaciju različitih načina prijevoza kao što su kamion, željeznički vagon i brod. Cjelokupni postupak ima za cilj pronaći najbolju kombinaciju prijevoznih pravaca i načina prevoženja u odnosu na sveukupan trošak (skladištenje i prijevoz), a koji ovisi o određenom sustavu ograničenja (fizičkom, kapacitetu, vremenu isporuke i financijama). Tako nastala konfiguracijska mreža kompjutorskog sustava daje potrebnu razinu prihoda i dobiti u okviru zadanog sustava ograničenja a koja se temelji na prodaji automobile.

Ključne riječi: *mreže lanca dobave, pomorski prijevoz, sustavi intermodalne didtribucije, simulacija, industrija automobile.*

1. INTRODUCTION

Simulation models can allow investigating the responses of agents (manufacturers, infrastructure providers, operators, carriers, retailers) in logistics and transport systems, as well as in many other application domains [12], through formulating and testing alternative hypotheses about the current and future behavior of the system. Simulation constitutes the most important approach for the study of such complex problems with the increased number of parameters, ensuring lower costs and higher perception to the interaction among system components. It also provides a 'safe' approach, as it offers the opportunity of repeated runs of the system processes, taking into account all different aspects of its operation and environment. For instance, it supports the analysis and helps to formulate recommendations about the demand conditions and service rate of customers in a logistics firm and the cost structure of production and delivery at different time windows.

The design of realistically large supply chain networks with multiple modes and time windows constitutes a complex and non-convex optimization problem, whose existence and uniqueness conditions cannot be generally ensured but only for some restrictive cases. Hence, the implementation of methods from the fields of operational research and mathematical programming (e.g., see [3]), variational inequality (VI) and optimal control theoretic models cannot adequately and efficiently handle the high complexity and intense computational burden of these problems, which are typically formulated as game-theoretic problems (or multi-level programs).

Amongst those methods, [6] a multi-period capacitated supply chain network equilibrium model in which decision makers (manufacturers, retailers and consumers at demand markets) seek to determine their optimal plans, formulated as a VI problem, has been developed The VI approach was also followed in [11] to describe the supply chain network design problem with oligopolistic profit-maximizing firms and the method of projected dynamical systems was employed for its solution. Moreover, [7] an experimental economic approach has been used to show that the mode choice depends to a large extent on the shipment size resulting from the shipper-carrier interactions. Several studies (e.g., see [10]) have incorporated supply and demand uncertainty in logistics network operations as well as disruption mitigation strategies. In order to address uncertainty, [16] a number of risk evaluation models within supply chains has been implemented, including chance constrained programming, data envelopment analysis, and multi-objective programming models.

In the case of large heavy industries, like that of an automobile production firm, the simulation approach largely helps to circumvent problems related to computational burden and the efficiency of resulting plans and solutions. It allows analyzing the processes involved in the delivery and storage of raw materials, intermediate stages of production, storage of final products and delivery into different geographical locations and points in time. The development of such logistics network models can provide a useful insight into the behavior of different agents of the system, sensitivity and robustness of various system components, evaluation of future demand and assessment of financial viability and profitability, subject to changes in production, transport and sales market conditions.

2. SUPPLY CHAIN MANAGEMENT IN AUTOMOBILE INDUSTRIES

In the case of multi-national automobile industries, the planning and design of the supply chain network aims at expanding the firm's catchment or potential market area, improving its market share and profits and decreasing the cost of production, storage and transport [14], [2]. Automobile, as a durable consumer good, offers increased capabilities for standardization. Its consumption can be considered as significantly affected by local culture, compared to the non-durable goods. Large automobile industries typically follow "high market share strategies" in order to improve their dominant position. This is achieved through producing new car models, which are capable to penetrate in new markets and are relatively non-sensitive to competitive car model prices.

The production of an automobile industry is based on the usage of bulky and heavy raw materials. Subsequently, it requires facilities and plants which consume a considerable amount of land. The average delivery time of a car product does not usually exceed six weeks. Therefore, the emphasis is given to the minimization of distances between storage and processing units and delivery points in the supply chain network. For this purpose, there sometimes exists a number of logistics sub-systems, which are developed and operate according to different national and (sub-) regional criteria, taking into account geopolitical and economic conjectures. A primary objective in the (intermodal) network design is to select those (combinations of) transport modes and links/paths which can lead to the shortest feasible distances between the material providers, producers and wholesalers for specific car models. In this process, a special attention can be given to the inclusion of ports with adequate and efficient connections to land transport modes, particularly railways, in order to ensure a fast and reliable transshipment of cars between a ship and a rail wagon.

3. LOGISTICS STRATEGY OF A EUROPEAN AUTOMOBILE INDUSTRY

The specific European automobile industry whose logistics network is examined in this study aims at strengthening its dominant position in the international automobile market. It possesses a world-wide network of local facilities (above 150). In the European region, the production factory in Cologne supplies its car products to the consumption demand points in the following three ways:

(a) By ship, with an average transport time, e.g., 12 days from the port of Antwerp in Belgium to the port of Piraeus in Greece, or 5 days from the port of Valencia in Spain to the port of Piraeus. This bundle of transport choices also includes the transport of cars by boat through inland waterways in Central Europe.

(b) By truck, usually from intermediate destination points, such as the port of Piraeus, to hinterland destinations, like those in the Balkan regions (Sofia in Bulgaria, Tirana in Albania, Skopje in FYROM etc.).

(c) By train, usually from the production factory in Cologne to the port of Antwerp or some other port, and, then, from these ports to the points of storage and distribution.

The systematic usage of more than one modes of transport, i.e., combined transport (typically including ship and railway) can provide an efficient transport solution in the logistics network design. The stages of the overall supply chain normally involve road transport by truck or rail transport from the production unit to the nearest port, maritime transport to the country where an order has been made, transport to a warehouse or storage area, arrangement of administrative control processes, (e.g., pre-delivery inspection, custom clearance), and final delivery to the consumption demand points.

The use of outsourcing, i.e. third-party logistics (3PL) services, takes place in cooperation with the production units (assembly factories) and the carriers, warehouse operators and wholesalers in the distribution areas. This outsourcing can achieve remarkable reduction in the transport costs, higher accuracy in delivery times and increased performance of the network operation. The current simulation model represents all the stages of the supply chain of the automobile industry, from the delivery of raw materials (in Cologne) to the final disposal of cars to the demand points in the European cities (Oslo, London, Athens, Sofia, Tirana), through employing different transport modes and paths.

4. PRESENTATION OF AUTOMOBILE PRODUCT FLOWCHART

Production Process in the Cologne factory

Step 1: Arrival of raw materials in the production factory in Cologne.

Step 2: Processing of raw materials and production of car units.

Step 3: Storage of products in the warehouse facility of the production factory.

Product Management in the Antwerp Port

Step 4: Transport of car units from the factory warehouse to the port of Antwerp by rail wagons.

Step 5: Transport of car units from the port delivery area to the trade zone and separation into groups (batches) for the distribution to other European ports (Oslo, London and Piraeus).

Maritime Transport of Products

Step 6: Loading of car units (as batches) on board ships and shipment to the destination ports area (Oslo, London and Piraeus).

Product Management in the Piraeus Port

Step 7: Delivery and storage of car units into the ports of Oslo, London and Piraeus, and transport to the areas of departure to final destinations.

Final Delivery of Products

Step 8: Transport of car units from the port of Oslo by boat to the Norwegian distribution and wholesale centres.

Step 9: Transport of car units from the port of London by rail wagons to the English distribution and wholesale centres.

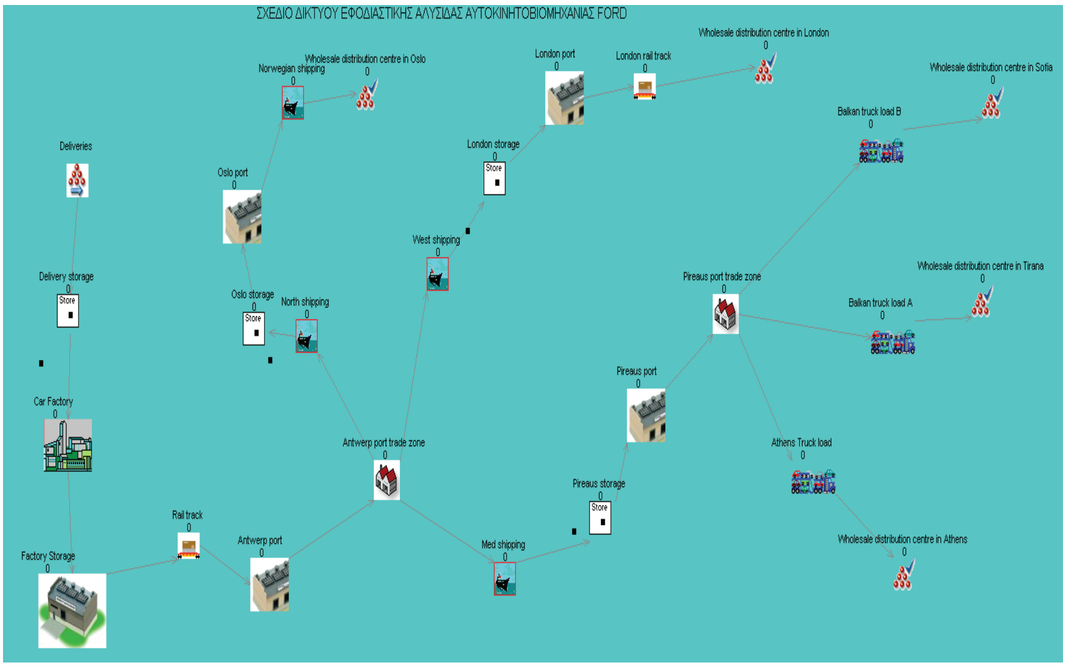
Step 10: Transport of car units from the departure areas of the port of Piraeus to the Greek distribution and wholesale centres.

Step 11: Transport of car units from the departure areas of the port of Piraeus to the Albanian distribution and wholesale centre at Tirana.

Step 12: Transport of car units from the departure areas of the port of Piraeus to the Bulgarian distribution and wholesale centre at Sofia.

5. ASSUMPTIONS AND DESCRIPTION OF SIMULATION PROCEDURE

As mentioned previously, the automobile industry aims at the fast, reliable and safe distribution of car units from the production factory to wholesale centres, taking into account a range of business strategies and operational constrains. Specifically, the firm makes the design of the supply chain network on the basis of monthly demand records originating from customers' orders, by employing historical data on sales. Besides, it discriminates the cost of transport by alternative modes, in order to minimize the storage needs and queuing times at warehouses and intermediate seaport and railway stations. Hence, in the case of changes in the demand conditions (sales forecasts), the user of the simulation model can readily change the selected transport corridors and interconnected paths through choosing different combinations of modes. Similar changes can be made in the case of unavailability and technical/mechanical problems in vehicles and wagons, link (highway, railway, short-sea freeway) or node (rail station, seaport freight centre) closures due to adverse weather conditions, strikes, terrorist acts, accidents or other types of incidents. Each alternative solution is evaluated on the basis of the expected benefits and costs of the resulting network performance.



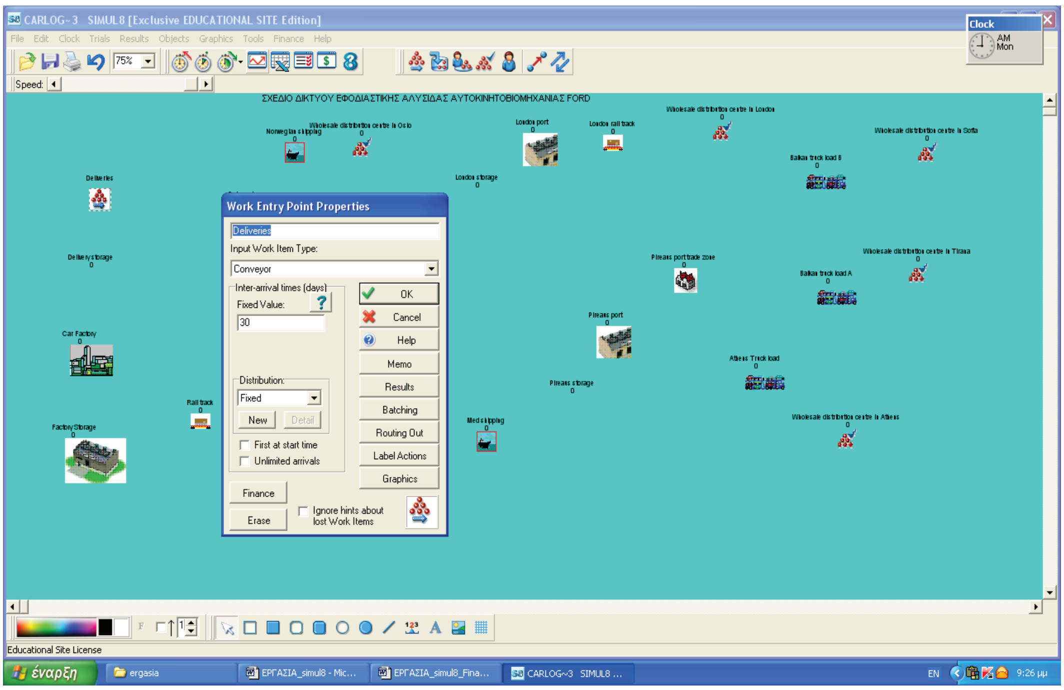
Schema 1. Overall configuration of the supply chain network
***Shema 1** Sveobuhvatni razmještaj mreže lanca dobave*

Schema 1 depicts the overall configuration of the supply chain network of the automobile industry in the Simul8 software environment [5]. The schema indicates the various stages of the processing and distribution of the car units from the production factory at Cologne to the final delivery points. The products are standardized, having a fixed production cost and purchase value. Thus, the revenues are expressed as a function of the transport cost components. The cost of transport by each mode is scaled and expressed in Euros (€). The "clock" of the simulation system is defined in terms of day units and it runs over a total annual period, using a pre-warming period of two weeks.

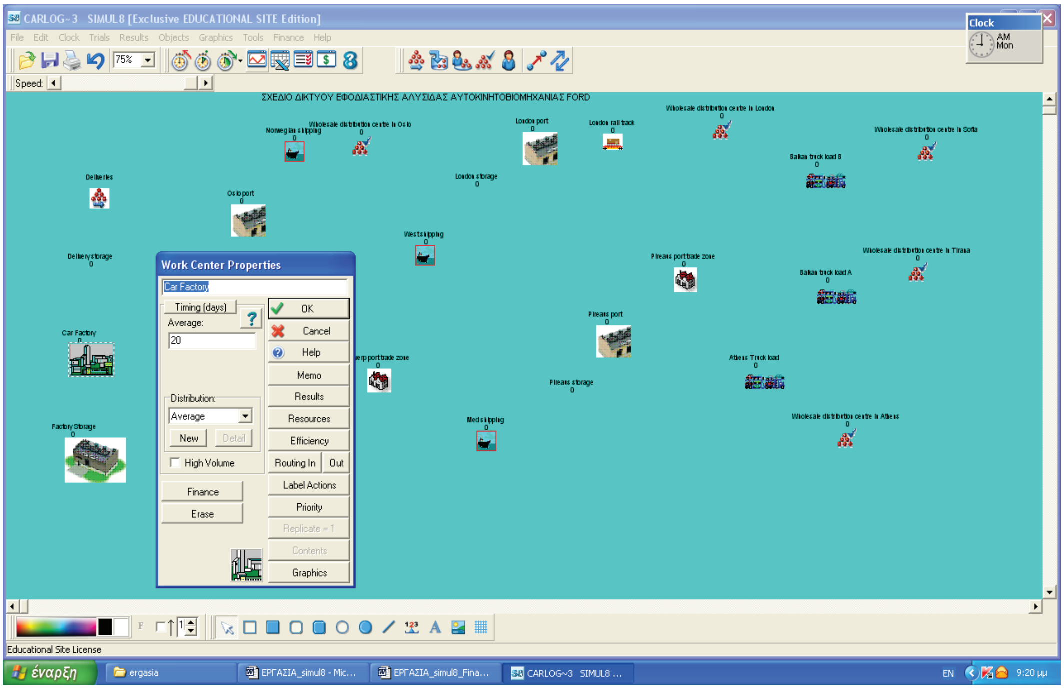
A first problem in realizing the simulation procedure refers to the arrival rates of raw materials to the production factory. This rate is constrained to be larger than the rate of processing the car units in the production factory. For this reason, the required time of delivery of raw materials is defined as equal to 30 days from the day of order, while the time of the car unit processing is defined as equal to 20 days. Between the operational unit of the delivery of raw materials and the processing unit (production factory), a delivery storage unit with very large capacity has been placed, in order to avoid the likelihood of the formation of large queues. These types of delivery storage units, which do not constitute "Work Items", are also introduced in other delivery points (nodes) of the supply chain network, such as the ports of Oslo, London and Piraeus.

Schema 2 depicts the definition of the parameters in the delivery unit (conveyor) of raw materials and Schema 3 shows the definition of parameters in the automobile production unit. The produced car units are transported and stored in a storage area (warehouse) next to the production factory in Cologne, assuming a storage cost of 1€ per unit per day. The same storage cost is assumed for all other warehouses in the supply chain network as well as for the same capacity (i.e. very large, essentially infinite). The car units are then transported as batches by rail wagons to the port of Antwerp and afterwards to the trade zone of that port. This trade zone is defined so that it allows the batched separation and distribution of car units into the points of departure for the delivery (port) destinations. The cost of transport by rail wagons is assumed to be 35 € per car unit.

The travel time by boat is defined here in a stochastic way (probabilistically), assuming a random distribution of possible delay time, in order to take into account some realistic restrictions and practical problems in implementing the trip schedule [1], [4]. These problems can be related to ship departures from the ori-



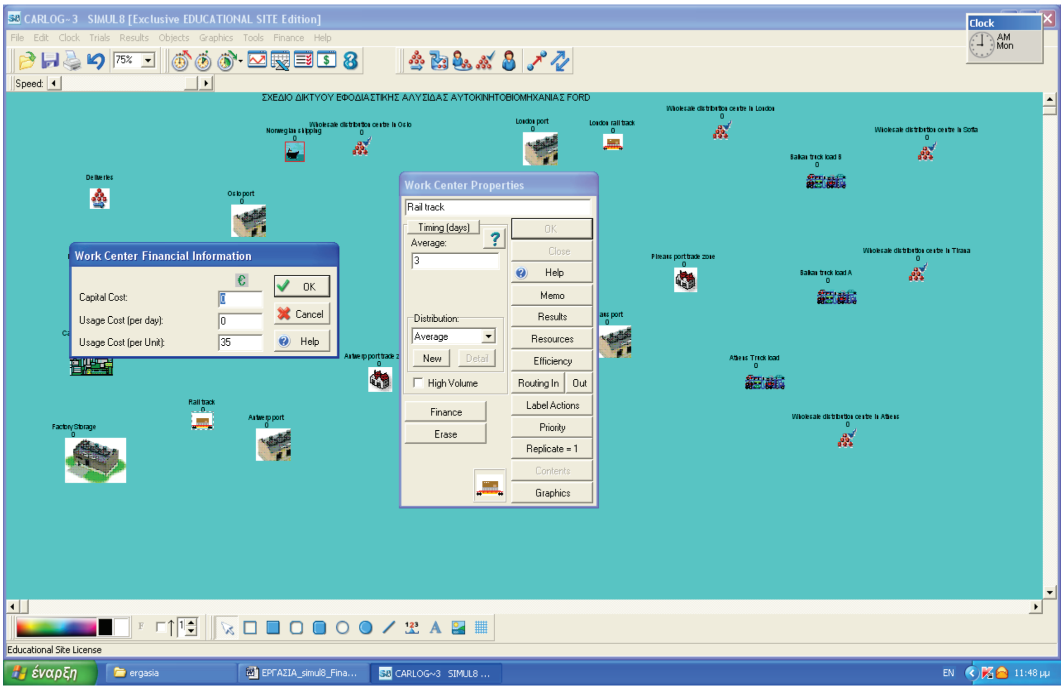
Schema 2. Definition of the parameters in the raw material delivery unit
Shema 2 *Određivanje parametara jedinice dostave sirovine*



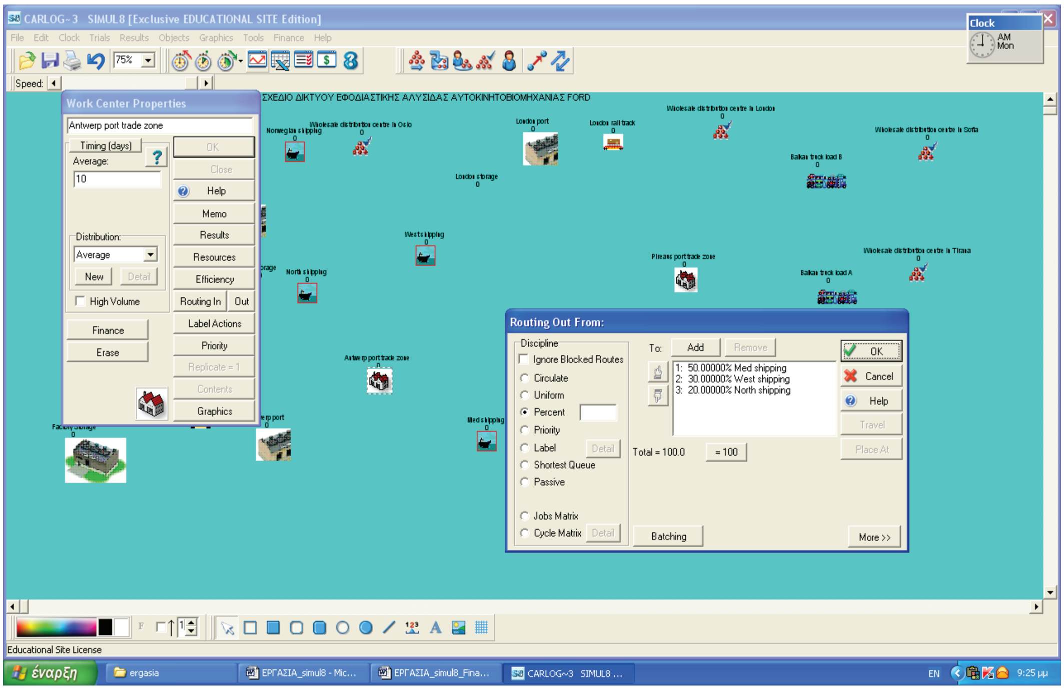
Schema 3. Definition of the parameters in the production unit
***Shema 3** Određivanje parametara jedinice proizvodnje*

gin port because of adverse weather conditions, port closure due to strikes, natural disasters or manmade actions, etc. The average cost (in time units) of the maritime transport from Antwerp to Oslo is defined as 10 days, from Antwerp to London as 7 days, and from Antwerp to Piraeus as 20 days.

The cost of maritime transport is defined on the basis of the shipping distance and the relative cost with regard to the railroad. Specifically, the cost of transport to the port of Oslo is defined as 56 € per car unit, to the port of London as 44 € per car unit, and to the port of Piraeus as 80 € per car unit. The cost of transport

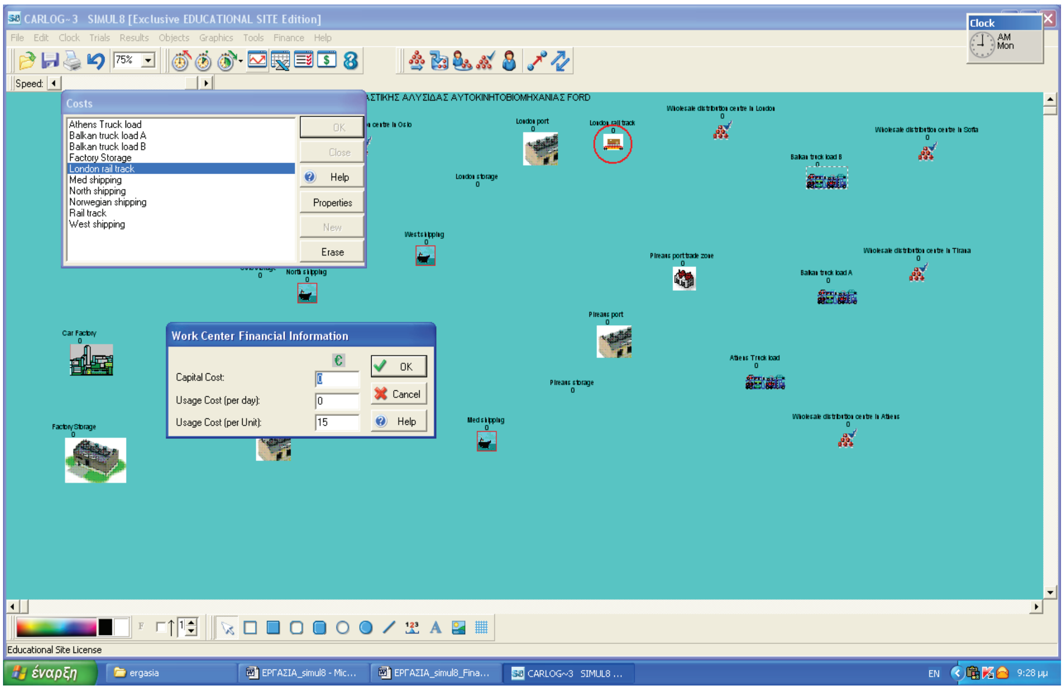


Schema 4. Definition of the parameters for the rail transport of products to the Antwerp port
***Shema 4** Određivanje parametara prijevoza proizvoda do luke Antwerp-en*



Schema 5. Definition of the parameters in the Antwerp port and the distribution of products in the trade zone per destination

***Shema 5** Određivanje parametara unuttar luke Antwerp-en i raspodjela proizvoda po odredištu unutar trgovačke zone*



Schema 6. Definition of the parameters for the rail transport of products from the port of London

***Shema 6** Određivanje parametara za prijevoz proizvoda željeznicom iz Londonske luke*

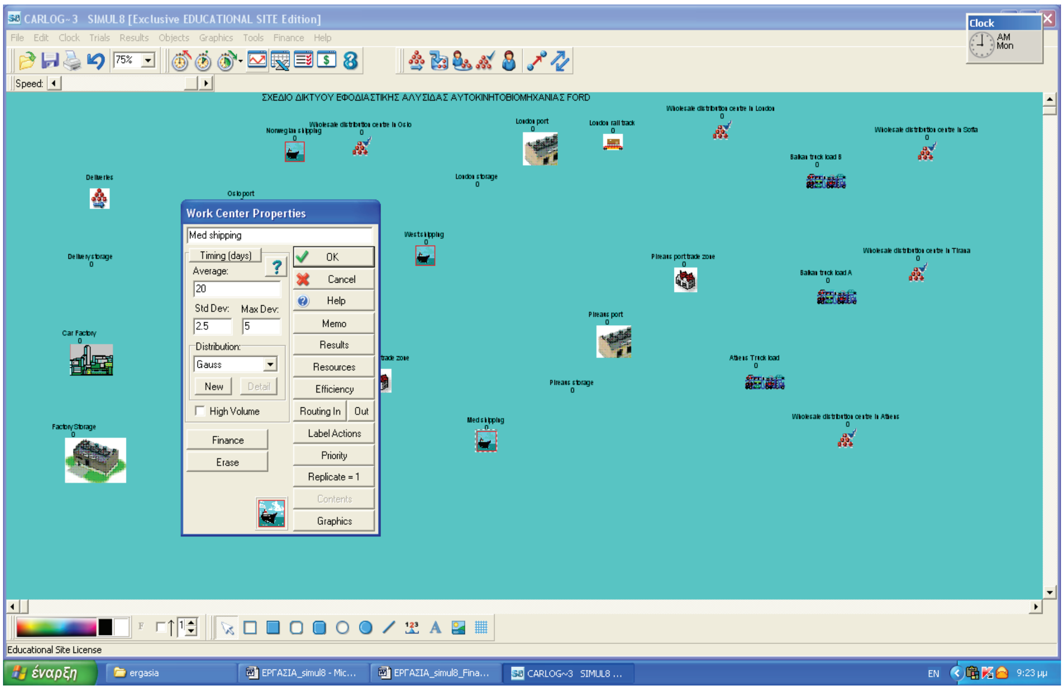
by ship from the port of Oslo to the Norwegian distribution centre is defined as 8 € per car unit and from the port of London by rail to the English distribution centre as 15 € per car unit. Schema 4 indicatively presents the definition of the parameters for the rail transport of cars from Cologne to the Antwerp port.

Schema 5 provides an illustration of the definition of parameters in the Antwerp port and the distribution of products in the trade zone per destination. The fixed proportions of departing car units (as batches) from the Antwerp port to each destination port are set as follows:

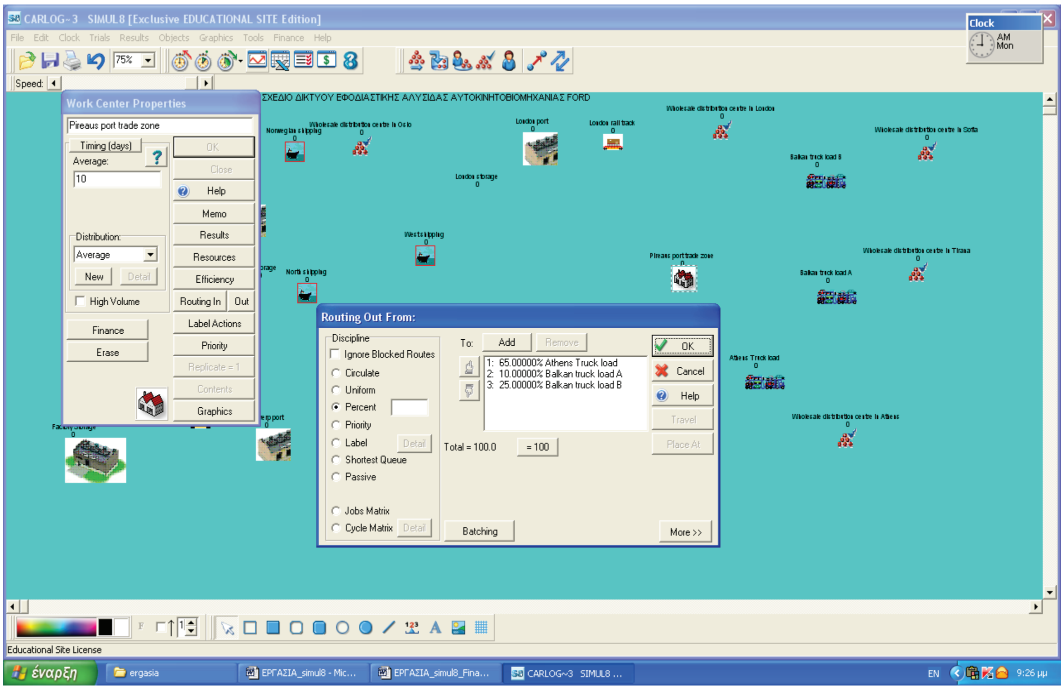
- Oslo 20%,
- London 30%,
- Piraeus 50%.

Schema 6 demonstrates the definition of the parameters for the rail transport of the products (car units) from the port of London to the corresponding distribution centre. Besides, Schema 7 shows the definition of the parameters for the maritime transport of products to the port of Piraeus.

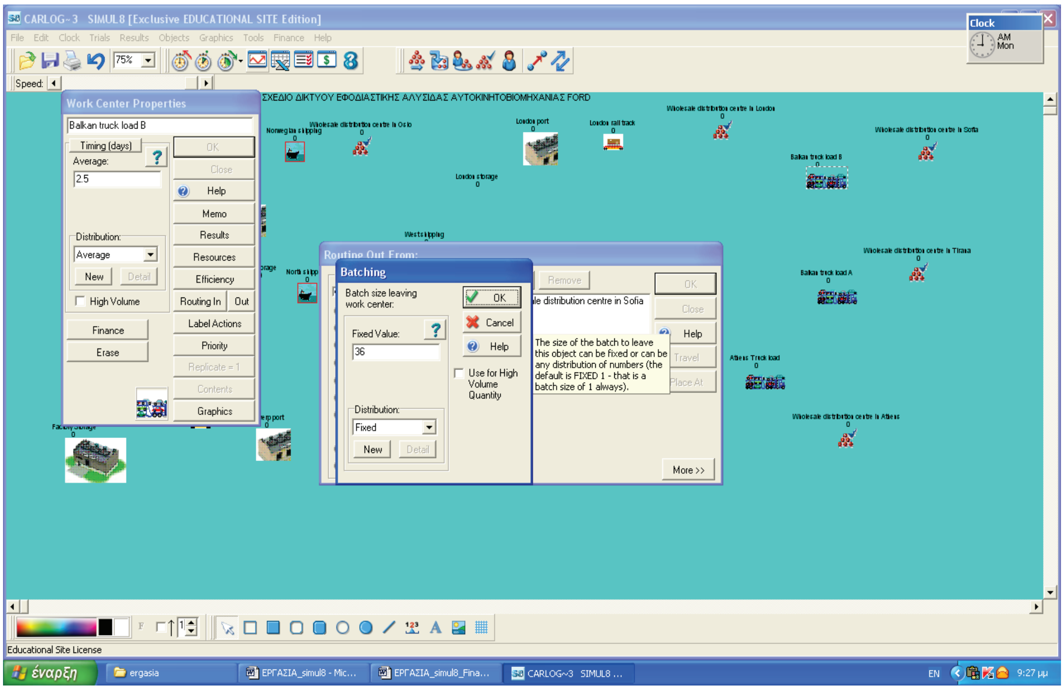
Schema 8 presents the definition of the parameters in the port of Piraeus and the distribution of car units in the trade zone per desti-



Schema 7. Definition of the parameters for the maritime transport of products to the port of Piraeus
Shema 7 *Određivanje parametara za prijevoz proizvoda brodom do luke Pirej*



Schema 8. Definition of the parameters in the port of Piraeus and the distribution of products in the trade zone per destination
Shema 8 *Određivanje parametara unutar luke Pirej i raspodjela proizvoda po odredištu unutar trgovačke zone*



Schema 9. Definition of the parameters for the road transport of products from the port of Piraeus to Sofia
Shema 9 *Određivanje parametara za cestovni prijevoz proizvoda iz luke Pirej do Sofije*

nation. The fixed proportions of the departing car units (as batches) from the Piraeus port to each land destination are set as follows:

- Athens 65%,
- Sofia 25%,
- Tirana 10%.

Finally, Schema 9 indicatively depicts the definition of the parameters for the road transport (by trucks) of car units (as batches) from the Piraeus port to Sofia in Bulgaria.

6. SIMULATION RESULTS

The results of the simulation model can refer to a range of measures of a statistical value. Such measures include, for instance, the average queuing time at the delivery storage units, capacity or resource utilization rate of specific "Work Items", such as the production factory, warehouses, seaports, etc. After specifying the structure and constituent elements of the simulation model, a number of trial runs (e.g., 10) can be executed in order to evaluate its statistical and computing performance. Schema 10 demonstrates the outcome obtained from the operation of the supply chain network at each delivery location. The animated motion of "Working Units" as either individual car units (products) or batches, or individual modes of transport carrying the products, allows the virtual evaluation of the operating status and performance of the whole system. Based on the assumed fixed proportions of car stocks distributed to each location, the results indicate the delivery of 4290 cars to Oslo, 2140 cars to London, 6324 cars to Athens, 900 cars to Sofia and 600 cars to Tirana, during the total simulation period.

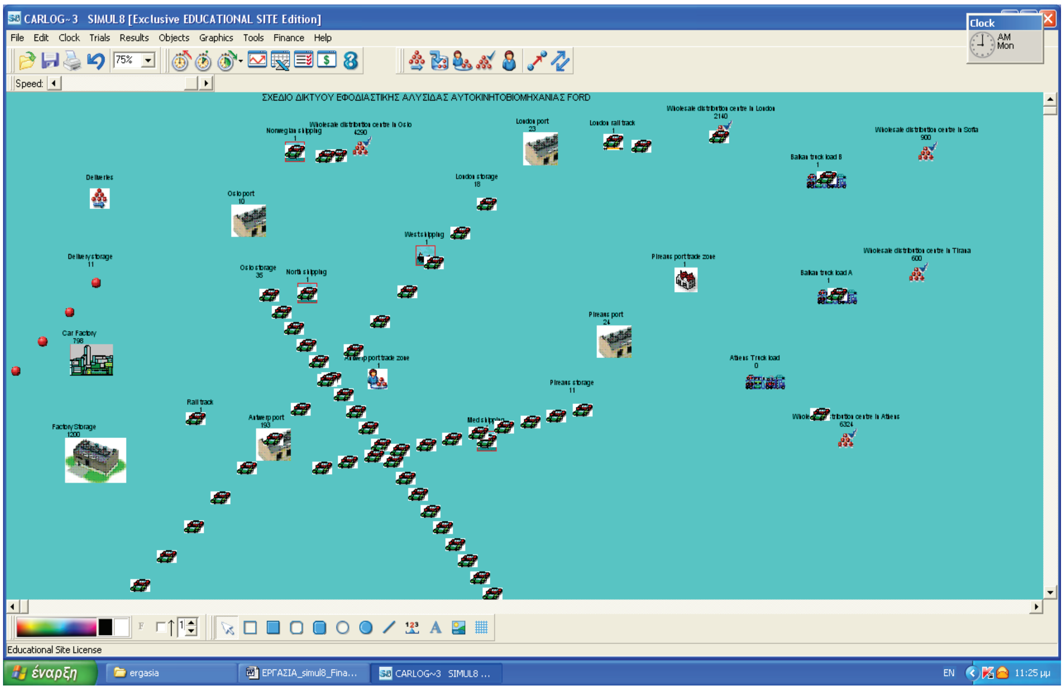
After the completion of the simulation runs and operational performance results, the supply chain system is also evaluated in terms of the expected revenues, costs and profit. Schema 11 presents the results of the economic assessment of the logistics network.

Table 1 summarizes the input and output data used in the model for the given period of simulation.

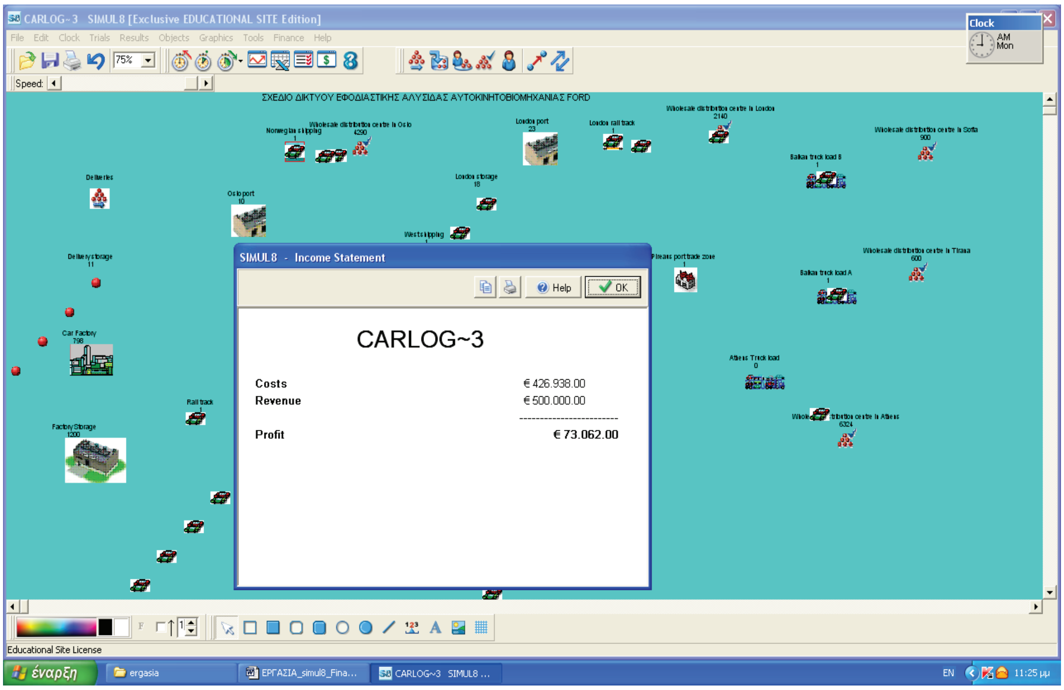
The resulting profit based on car sales, which amounts to 73 000 €, reveals that the logistics network design under development can be highly satisfactory, in financial terms, for the automobile industry, taking into account all the required constraints.

Table 1 Input and output data used in the simulation model
Tablica 1. *Ulazni i izlazni podaci korišteni kod modela simulacije*

Variables *varijable* / **Region** *regija*	**Inputs (in time and/or monetary units)** *Ulazi (po jedinici vremena i /ili po novčanoj jedinici)*				**Outputs (car units and Euros)** *Izlazi (jedinice automobile i EUR-a)*	
	Material Delivery *Dostava materijala*	Car Production *Proizvodnja automobila*	Storage Capacity (cost) *Kapacitet skladišta (cijena)*	Transport time (cost) *Vrijeme prijevoza (cijena)*	Car Deliveries *Isporuke automobila*	Revenue (Profit) *Prihod (dobit)*
Cologne *Koln*	30 days *30 dana*	20days/unit *20 dana/ jedinica*	Infinite (1€/day/unit) *Neograničeno (1EUR/na dan/ po jedinici proizvoda)*			
Antwerp *Antwerpen*			Infinite (1€/day/unit) *Neograničeno (1EUR/na dan/ po jedinici proizvoda)*	35€/unit *35 EUR/po jedinici proizvoda*		
Oslo			Infinite (1€/day/unit) Neograničeno *(1EUR/na dan/ po jedinici proizvoda)*	10days (64€/unit) *10 dana (64EUR/po jedinici proizvoda)*	4290 units *4290 jedinica Proizvoda*	
London			Infinite (1€/day/unit) *Neograničeno (1EUR/na dan/ po jedinici proizvoda)*	7days (59€/unit) 7 dana *(59 EUR/ po jedinici proizvoda)*	2140 units *2140 jedinica proizvoda*	
Piraeus Pirej			Infinite (1€/day/unit) *Neograničeno (1EUR/na dan/ po jedinici proizvoda)*	20days (80€/unit) 20 dana *(80EUR po jedinici proizvoda)*		
Athens Atena					6324 units *6324 jedinica proizvoda*	
Sofia				2 ½ days (150€/unit) 2 ½ dana *(150EUR/po jedinici proizvoda)*	900 units *900 jedinica proizvoda*	
Tirana				2 ½ days (150€/unit) 2 ½ dana *(150EUR/ po jedinici proizvoda)*	600 units *600 jedinica proizvoda*	
Total ***Sveukupno***						500000€ (73000€)



Schema 10. Results of the logistics network operation at the delivery points
***Shema 10** Rezultati djelovanja mreže logistike na mjestima dostave*



Schema 11. Results of the financial assessment of the logistics network
***Shema 11** Rezultati financijske procjene mreže logistike*

7. CONCLUSION

In the dynamic environment of globalized markets and intense competition among firms, the design of efficient and reliable large-scale supply chain networks plays a crucial role in the production and distribution processes involved in the operation of heavy industries, like that of automobiles. This paper aims at describing the development and implementation of a simulation-based intermodal network design model for the European-wide logistics activities of the automobile industry. The model, which has been built in the Simul8 environment, can represent the flows of products (car units) from the production factory in Germany to the final delivery locations around Europe. The simulation results allowed to analyze and evaluate different stages and components of the overall supply chain, including the delivery of raw materials, automobile production, storage, transport and distribution to the final consumers. In order to minimize the transport cost and increase the revenue and profit, a suitable combination of transport modes and network paths has been selected from the factory of origin to the final distribution centres. The resulting network configuration ensures the satisfaction of a number of physical, operational and financial requirements, while it considers the stochastic nature of the system supply components. Therefore, it can be well applied into the design and evaluation of numerous other problems in the operations management and compare alternative business development plans as well as transport network strategies. Such strategies can include the introduction of new regulatory measures, pricing regimes and infrastructure investments.

Future research directions involve the modeling of the dynamic behavioral processes in the route choice of shippers, while uncertainty may also be introduced into the production rate, shipment orders, and prices with regard to volume-price contracts. The strategic selection of the location of intermodal transport facilities at the European-wide scale can additionally be considered in the overall network design problem, by employing either simulation or multiple-assignment hub-network design techniques [15]. A number of other objectives can be simultaneously examined in the present network design problem, such as the protection of the environment and the improvement of the economy at the local or regional level [8].

The complexity of the problem can be increased, especially in the case where alternative authorities do not act synergistically and there are shipping companies competing for profit maximization. Then, optimal strategies can be sought and deployed at both the long-range and the tactical planning horizon, possibly yielding conflicts and/or merging among them and the emergence of oligopolistic market conditions. On the other hand, optimal cooperation or coalition strategies can be developed between chain partners (carriers, shipping companies, retailers etc.), according to the resulting pay-off (or profit) of each company [13], [9]. Finally, the current study could benefit from computational advances in the agent-based software, through the use of autonomous Intelligent Agents or Agent-Based Simulation (ABS), which have been used to address similar complex decentralized optimization problems. This software can be coupled with powerful Genetic Algorithms (Gas), which have been successfully implemented into the optimization of highly complex single and multi-objective problems.

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