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A Supporting Decision Tool for the Integrated Planning of a Logistic Network

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1. Introduction

Design, management and control of a logistic distribution system are very critical issues in supply chain management (SCM). They involve a large number of interdependent decisions, such as the determination of the best location and capacity of a distribution center (DC), a production plant, a wholesaler etc., the allocation of customer demand to suppliers, e.g. regional DC (RDC), the adoption of a transportation mode, e.g. rail and truck, the vehicle routing adopting/not adopting a "groupage" strategy. This chapter presents an original and automatic supporting decisions platform for the integration of strategic (long-term), tactical (mid-term) and operational (short-term) decisions in the design, management and control of a logistic network including up to four operating levels: sources (production plants), central distribution centers (CDCs), RDCs, and customers (points of demand-Pods). A case study is illustrated and obtained results discussed in presence of different problem settings and operating hypotheses.

The main contribution of this chapter is the illustration of an automatic supporting decisions tool for the design, management, control and optimization of a logistic network.

The remainder of this chapter is organized as follows. Section 2 presents a review of the literature studies on the design and management of a supply chain. Section 3 illustrates the proposed conceptual framework for planning a supply chain: this framework has been adopted by LD-LogOptimizer. Section 4 presents a case study and illustrates the obtained results. Finally Section 5 presents conclusions and further research.

2. Supply chain planning

A supply chain (SC) is a network of suppliers (sources), production plants, warehouses, and distribution channel organized to acquire raw materials, convert them to finished products, and distribute products to customers. The flow of goods between a supplier and customer passes through several levels and stages, and each level consists of many facilities (Bidhandi and Yusuff, 2011).

A generic SC network is depicted in Figure 1. It is made of 4 levels (sources, CDCs, RDCs, Customers) and 3 stages (Sources-CDCs, CDCs-RDCs, RDCs-Customers). The generic stage involves two different kinds of entities, e.g. CDCs and RDCs, linked with a direct flow of

materials. In general by-pass flows are admissible, e.g. from the source level to customers, i.e. points of demand (Pods).
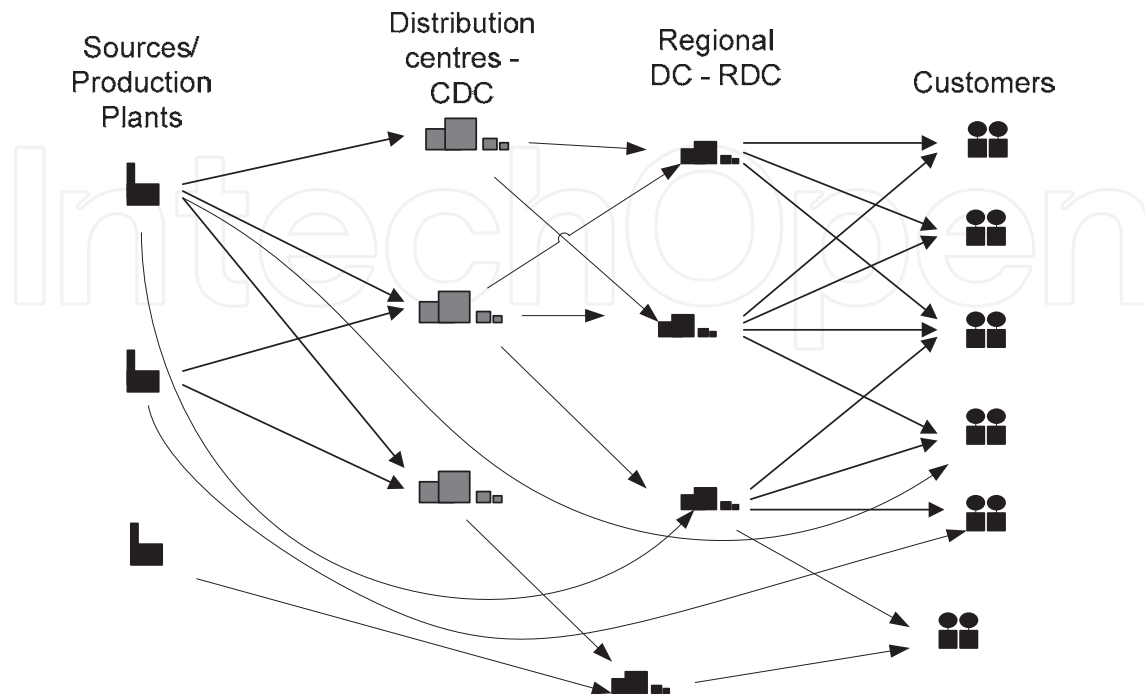

Fig. 1. A generic supply chain network

Supply chain management (SCM) is the integration of key business processes among a network of interdependent suppliers, manufacturers, distribution centers, and retailers in order to improve the flow of goods, service, and information from original suppliers to final customers, with the objective of reducing system-wide costs while maintaining required service levels (Simchi-Levi et al. 2000).

Stadtler (2005) presents a framework for the classification of SCM and advanced planning issues and targets: there are several commercial software packages available for advanced planning, the so-called advanced planning systems (APS), incorporating models and solution algorithms and tools widely discussed by the literature. In particular, Su and Yang (2010) discuss the importance of enterprise resource planning (ERP) systems for improving overall SC performance. ERP systems are essential enablers of SCM competences. Nevertheless there are not yet valuable integrated tools as supporting decisions makers for planning strategic, tactical and operational issues and activities of a wide and complex logistic network. In particular, ERP systems and APSs do not support decision making on the whole system (logistic network) optimization and design. The great complexity of such a problem forces the managers to accept *local optima* as sub optimizations renouncing to identify the best configuration of the whole network. The so-called best configuration usually corresponds to an admissible solution of minimum logistic cost and/or maximizes customer's service levels.

Planning a SC network involves making decisions to cope with long-term strategic planning, medium-term tactical planning and short-term operational planning as summarized in Figure 2.

Figure 3 reports main decisions for the strategic planning (e.g. supplier selection, production facilities location), the tactical planning (master production planning, DCs assignment, storage capacity determination) and the short time operational planning and scheduling

(scheduling, multi-facility MRP, vehicle routing) classified in terms of decision typology: *purchase & production* decisions, *distribution* decisions and *supply* decisions (Manzini and Bindi, 2009).
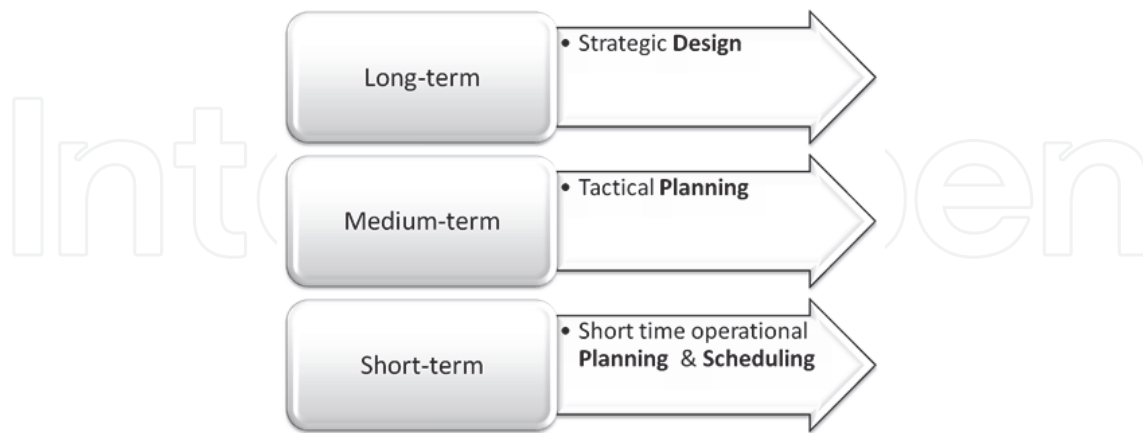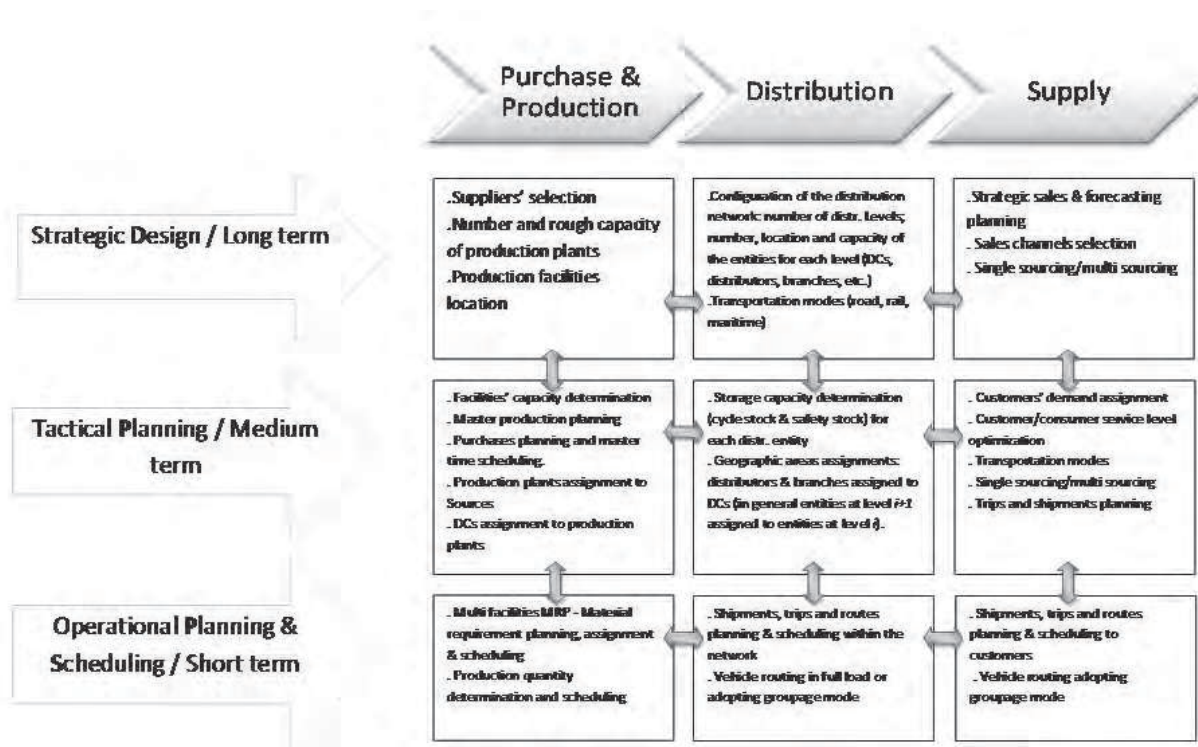

Fig. 2. Classification of planning decisions

Fig. 3. Issues and decisions (Manzini and Bindi, 2009)

2.1 Strategic planning

The strategic level deals with decisions that have a long-lasting effect on a company (Simchi-Levi et al. 2004) and supports the design and configuration of a logistic network. The terms "network design" and "SC network design" are usually synonymous of *strategic SC planning*. Melo et al. (2009) classify the literature on strategic planning in accordance with some typical SC decisions: capacity decisions, inventory decisions, procurement decisions,

production decisions, routing decisions, and the choice of transportation modes. Additional features of facility locations models in SCM environment are: financial aspects (e.g. international factors, incentives offered by governments, budget constraints for opening and closing facilities), risk management (uncertainty in customer demands and costs, reliability issues, risk pooling in inventory management), and other aspects, e.g. relocation, bill of material (BOM) integration, and multi period factors. To avoid sub-optimization, these decisions should be regarded in an integrated perspective (Melo et al. 2009).

As a consequence, the strategic planning usually deals with long-term decisions, *single period* modelling, and the so-called location allocation problem (LAP) (Manzini and Bindi, 2009). The strategic planning can be considered as the design of a "static network": the aim is the determination of the best configuration, i.e. the architecture, of the logistic system.

2.2 Tactical planning

The tactical planning deals with medium-term and short-term decisions by a *multi-period* modelling. This planning activity defines the best configuration of the multi-echelon inventory distribution fulfilment system. It generates also the list of deliveries/shipments between suppliers and customers at different stages of the distribution system. As a consequence the aim of the tactical planning is the determination of the best configuration and management of the fulfilment system. The tactical planning is similar to a multi-echelon and time-dependent capacity constraint material requirement planning (MRP) combined to a distribution requirement planning (DRP). This planning is multi-product (i.e. multi-commodity), multi-period and the duration of the planning horizon of time is generally a few months. Different transportation modes are available. Storage, handling and production capacities are modelled for each distribution/production center.

2.3 Operational planning

As a result of the application of a multi-period tactical planning to a distribution network, the logistic manager needs to daily supply products to a large set of customers/consumers, the so-called points of demand (Pods), by the adoption of a set of different transportation modes. The operational planning of a SC network deals with the short-term scheduling of vehicle missions & trips necessary to supply products to the demand points, in presence (or in absence) of the groupage strategy. This strategy consists in defining groups of Pods that can be visited by a vehicle in a single trip. Consequently, adopting the groupage strategy the customers/Pods are grouped in disjunctive pools and a single vehicle serves the members of each group simultaneously in a multi-stop (multi-visit) trip (route/mission). This is the well-known vehicle routing problem (VRP), which is a non-deterministic polynomial-time hard (NP-hard) combinatorial optimization and nonlinear programming problem seeking to service a number of customers with a fleet of vehicles (Baldacci and Mingozzi 2009, Dantzig and Ramser 1959). In particular CVRP is the so-called capacitated VRP, where a fixed fleet of delivery vehicles of uniform capacity must serve known customer demands from a common depot, e.g. a distribution center CD, at minimum transit cost (Güneri 2007).

In SC planning, given a point in time t, e.g. a day, and a defined depot (e.g. a production plant, a central distribution center CDC, a regional distribution center RDC), there are many Pods assigned to that facility as the result of a tactical planning: their demand values are allocated to that facility in t. For example in presence of a 3-stage and four levels SC made of production Plants (level 1), CDCs (level 2), RDCs (level 3), customer Pods (level 4), it can

be necessary to define the daily scheduling of deliveries from the central DCs to the regional DCs, and the daily scheduling from the RDCs to the customers in presence of fractionable and/or non fractionable (single-sourcing hypothesis) demand of products, and adopting and/or non adopting the groupage strategy.

The daily SC planning is a very complex problem and consists in defining the best groups of customers and the best geographical routings minimizing the global logistic costs in accordance to different kinds of constraints, e.g. time windows, load capacities, pickup and delivery sequencing, set-up, etc. Literature presents several models and methods to help the manager to find good solutions; but they are generally very complex and not effective given a real instance/application of the transportation problem characterized by a realistic dimension, e.g. hundreds of Pods and many depots.

3. A framework for an integrated planning

Figure 4 presents the conceptual framework of the proposed integrated planning process. The proposed automatic tool LD-LogOptimizer has adopted this framework. It is a multi-step supporting decisions framework for strategic, tactical and operational planning activities. This is the basis for the development of an automatic tool, named LD-LogOptimizer. LD-LogOptimizer is illustrated in this chapter and has been applied to a significant case study as discussed in last sections of this chapter. This tool deals with many input data and generates a lot of results and system performance as discussed below.
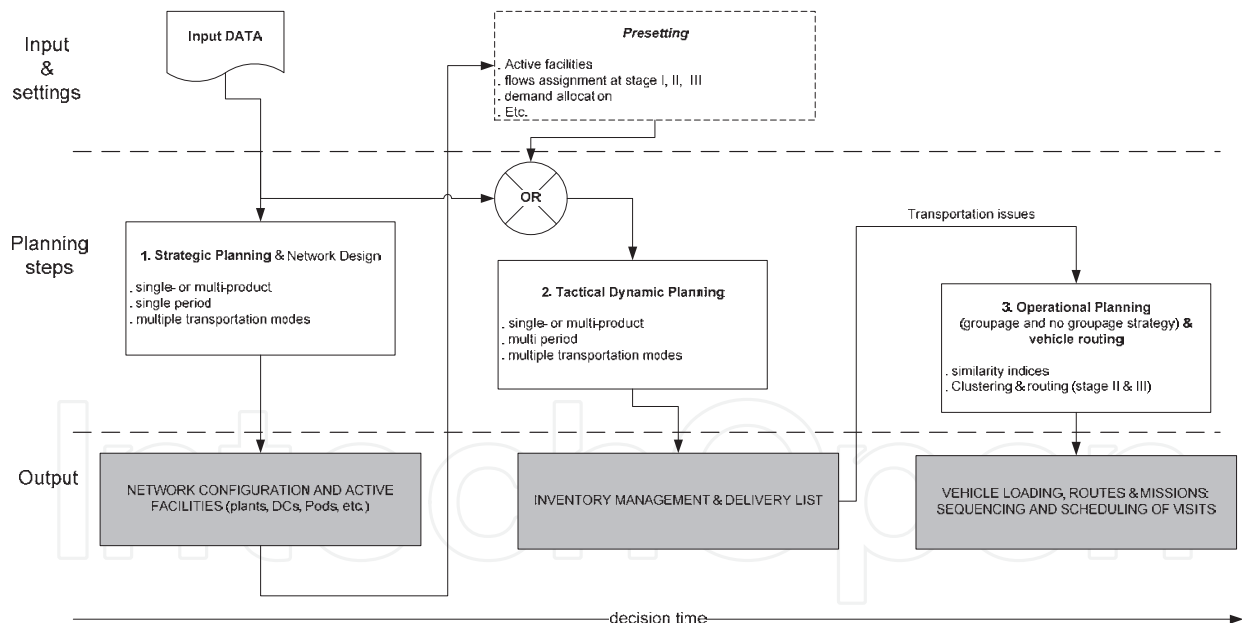

Fig. 4. Framework for an integrated planning of a distribution network

Figure 5 presents the input data to be collected for the implementation of the approach briefly illustrated in Figure 4. For the generic Pod: geographical location and demand quantity for each product and each point in time t, e.g. daily demand. For the generic RDC and CDC: location, fixed operating cost, variable operating (inventory and handling) costs, maximum admissible capacities (storage and handling). For the generic production plant: location, fixed operating cost, variable unit costs (also including the production unit cost), maximum admissible capacities (also including the production capacity), etc.
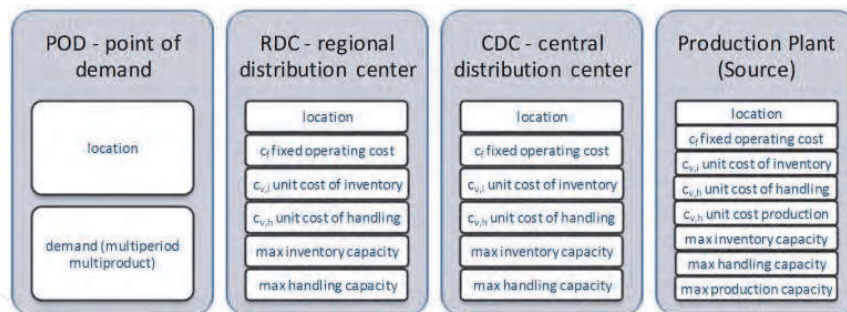
Fig. 5. Input data for the implementation, logic scheme

3.1 Strategic planning in LD-LogOptimizer

Figure 6 illustrates the strategic planning as modelled and implemented by the proposed automatic tool LD-LogOptimizer. In particular, given previously illustrated input data, a 3-stage (4-levels) single-period multi-product mixed integer linear programming (MILP) model for the location allocation problem (LAP) is defined. Euclidean distances are generally adopted to model the distances between two locations, e.g. a source and a RDC. A set of input data on variable and fixed costs and vehicles' settings has to be introduced because different transportation modes are available.

The model can be solved as-is (see "strategic model 3S" in Figure 6) or reducing the number of levels from four to three (i.e. the number of stages to two) by the generation of two distinct sub-problems: the assignment of Pods demand to RDCs by the execution of a heuristic rule and the assignment of materials flows to the higher levels of the network (from RDCs to the sources passing from the CDCs). The in-depth illustration of the heuristics is not the aim of this chapter. The simplification introduced by the heuristic approach to problem solving significantly reduces the computational complexity of the decision problem: the as-is "strategic model 3S" is substituted by the so-called heuristic rule at the first stage combined with the "strategic model 2S" at the second and third stages. The as-is problem modelling is for the optimal solution of the LAP; the simplified reduces the computational time but accept feasible solution very closed to the unknown optimal one. The strategic planning as reported in Figure 6 generates a large number of output results.

3.2 Tactical planning in LD-LogOptimizer

The tactical planning implemented by LD-LogOptimizer is illustrated in Figure 7. The dynamic multi-period, multi-product, multi-transportation mode, 3-stage LAP can be solved as a result of the application of the so-called "pre-setting" process (see Figure 7), i.e. by the activation of facilities and/or flows and/or transportation modes adopted at the strategic decisional step, or as an optimization problem without assuming any hypothesis/decision generated at the previous step. In absence of pre-setting the model is called "tactical model 3S" (see Figure 7). Examples of output data, mainly time based, for the tactical planning are: inventory levels at production/distribution facilities, material flows, picking/delivery lists of products at the generic Pod for a point in time t, transportation mode adopted for a specific product from a supplier level to a point of demand level in t, costs, etc.

3.3 Operational planning in LD-LogOptimizer

Figure 8 illustrates the adopted operational planning for a 3-stage, multi-period, multi-product, multi- (transportation) -mode. It is a cluster-first and route-second procedure based
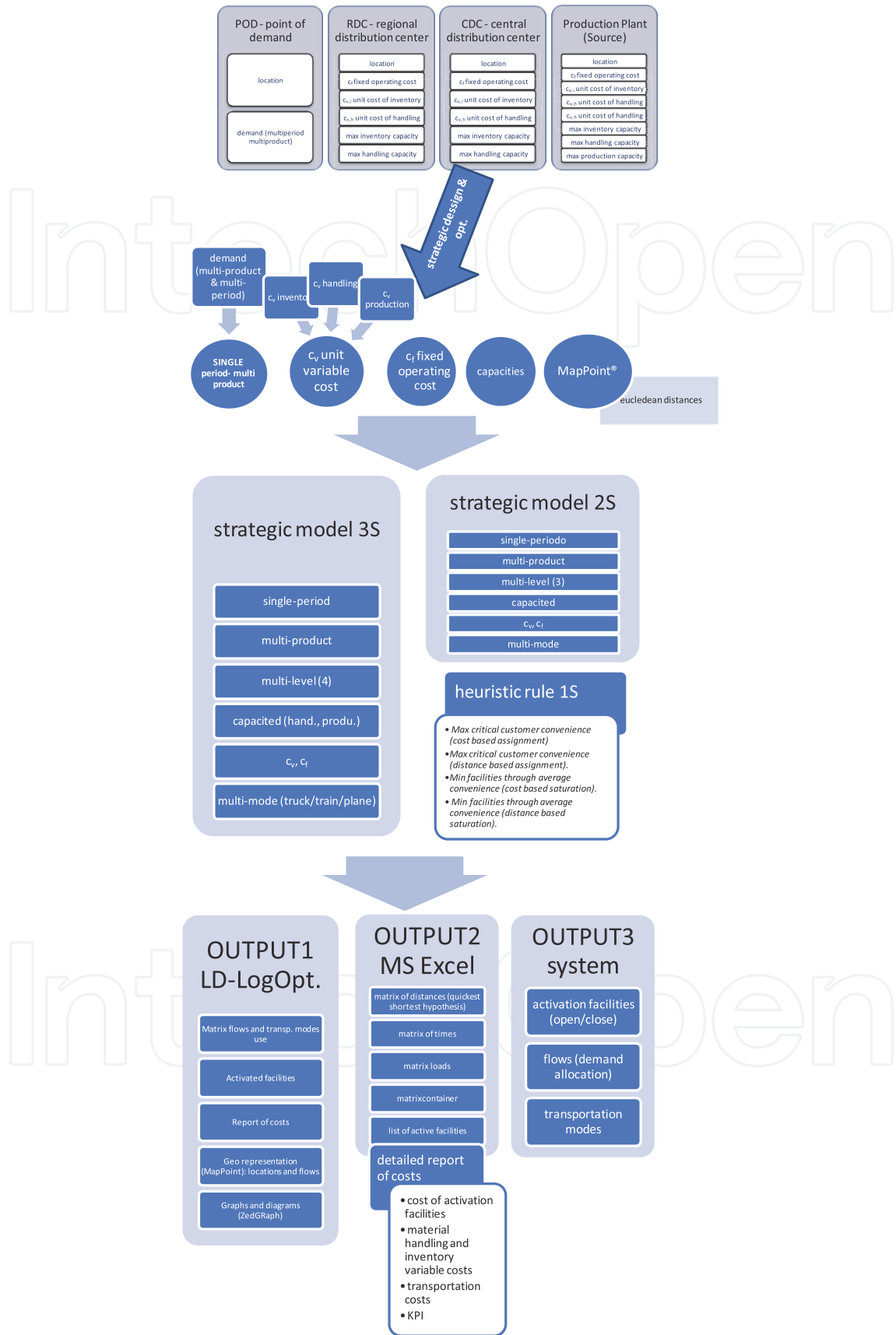
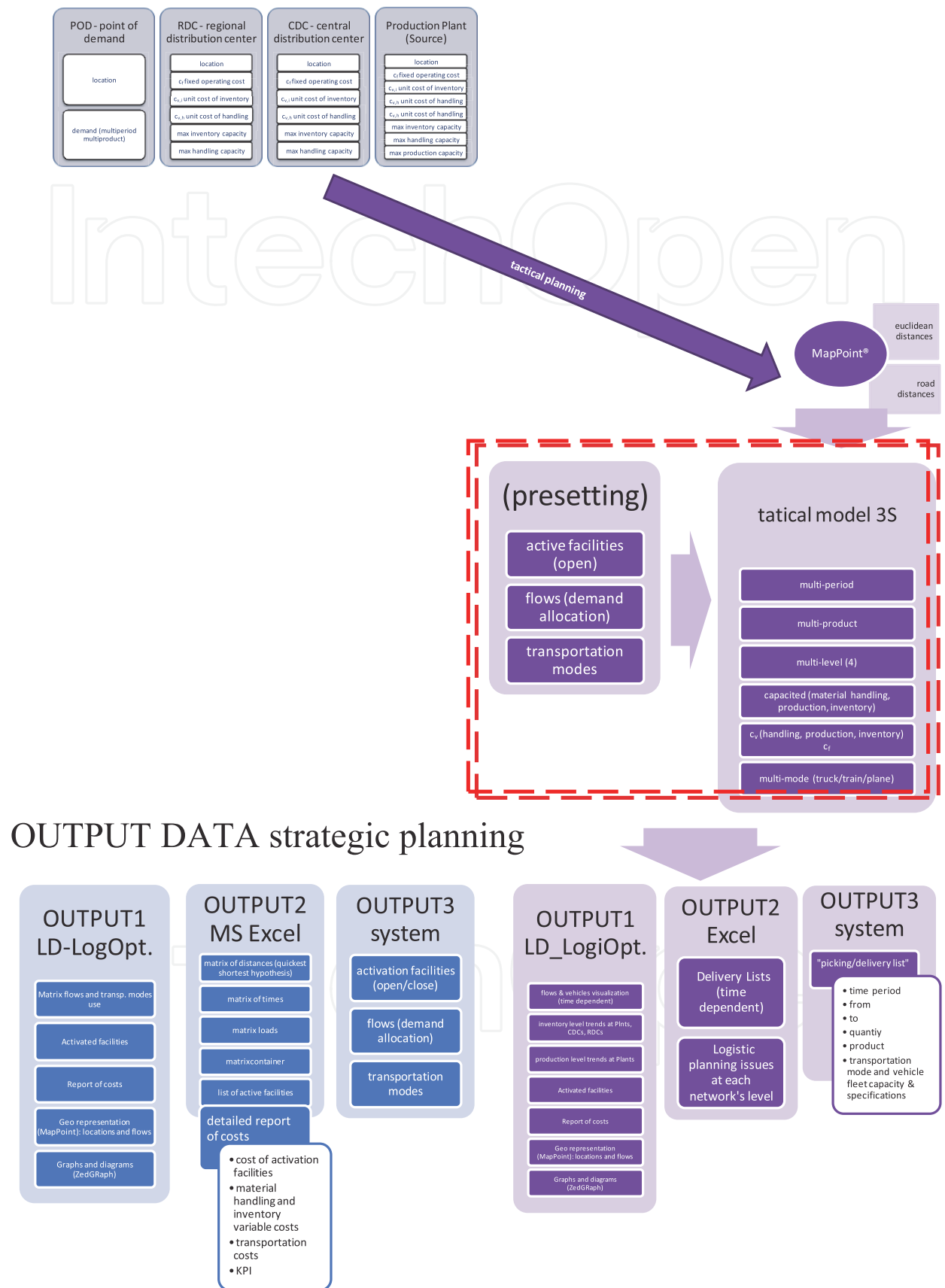Fig. 6. Strategic planning, LD-LogOptimizer
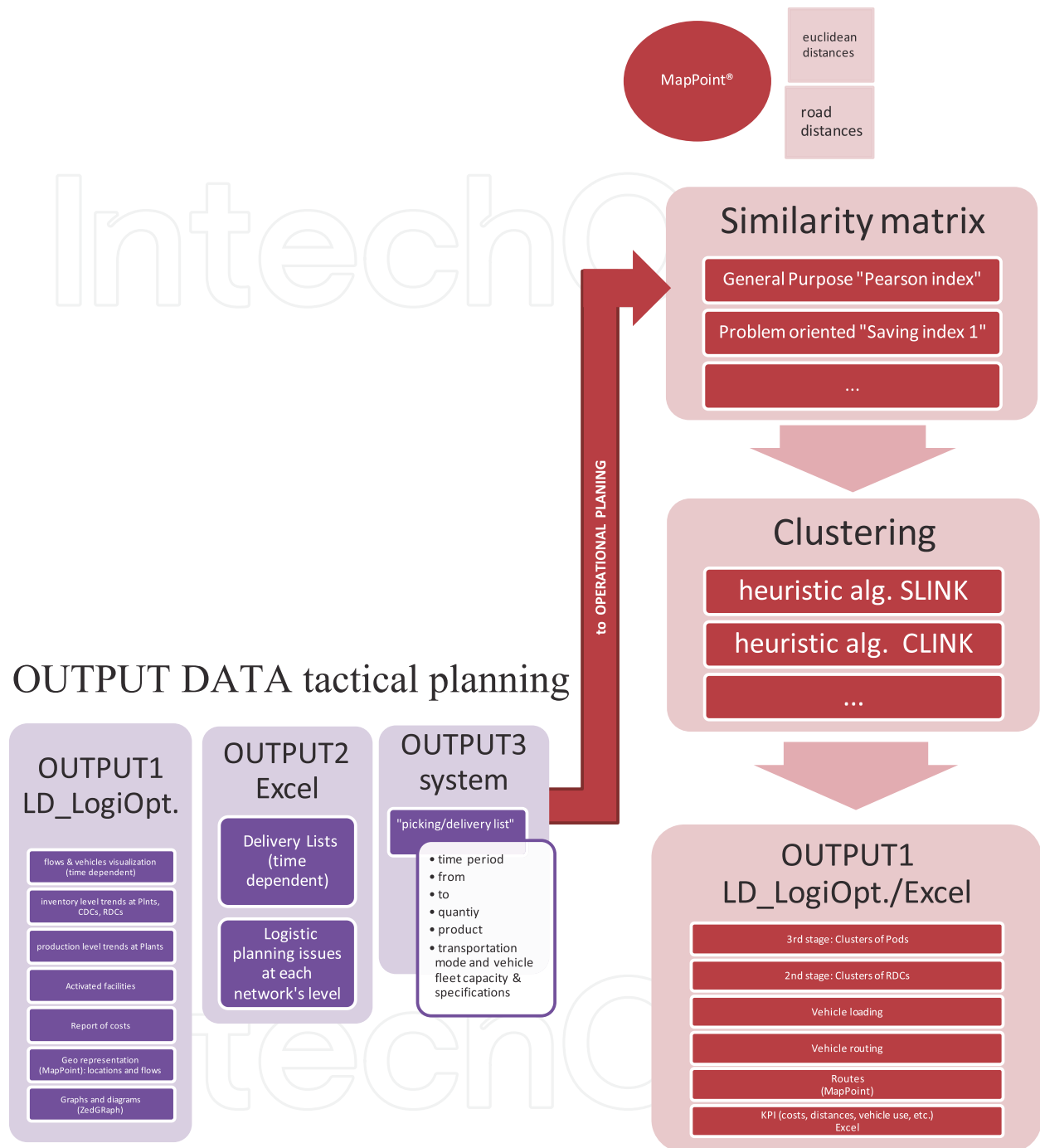
Fig. 7. Tactical planning, LD-LogOptimizer

Fig. 8. Operational Planning, LD-LogOptimizer

on the introduction of original similarity indices for clustering of demand points (e.g. Pods at the first stage RDCs-Pods or RDCs at the second stage CDCs-RDCs) and sequencing/routing of visits (e.g. Pods) within each cluster of demand points assigned to a supplier (e.g. an RDC). Examples of output data generated by the tool are: configuration of clusters, vehicle loading and saturation, vehicle routing, routes, costs, distances, etc.

Figure 9 shows the conceptual framework adopted by LD-LogOptimizer as the integration of strategic, tactical and operational planning activities.
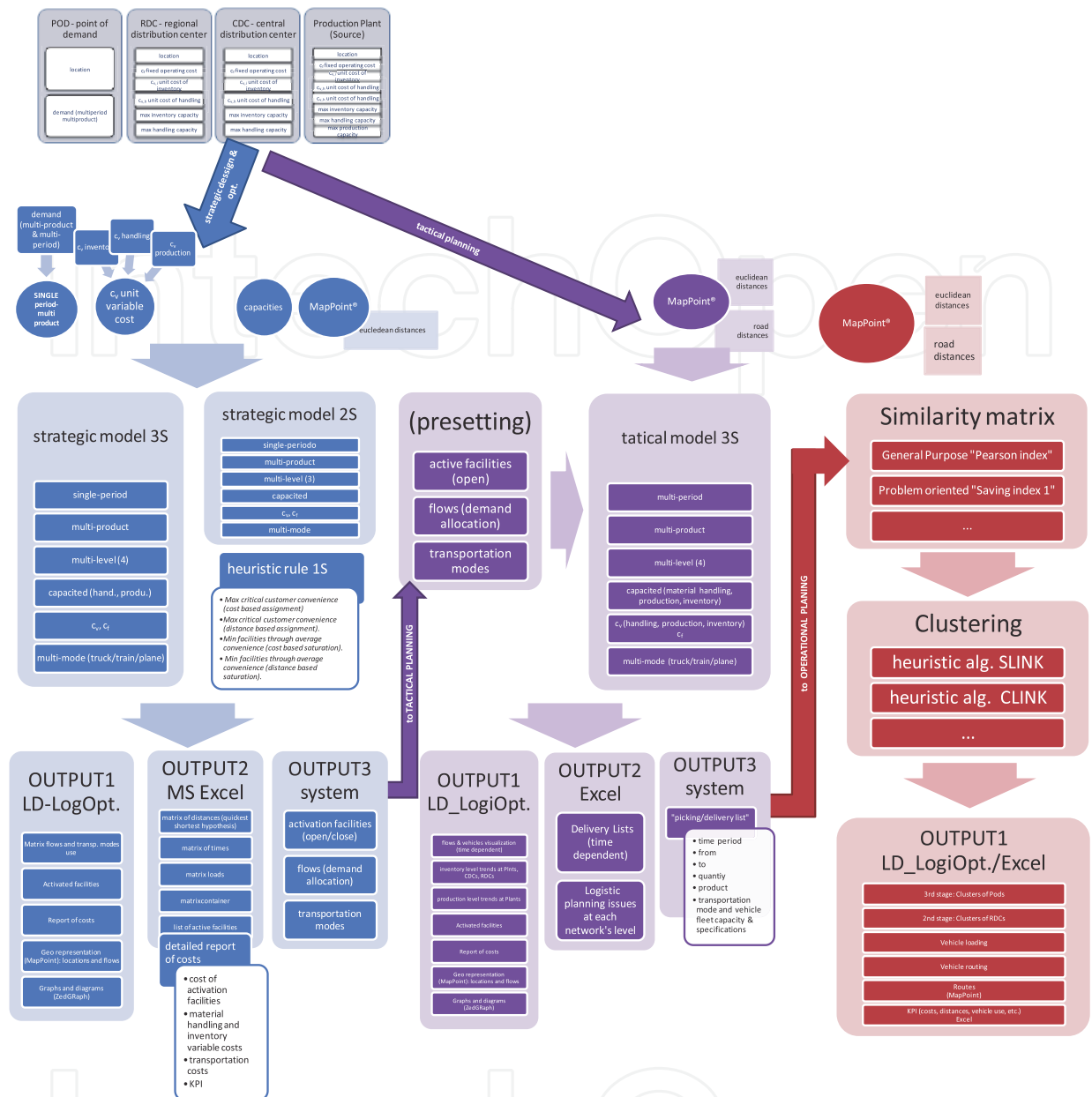
Fig. 9. LD-LogOptimizer tool for the integrated planning

4. A case study

This case study refers to a 3-stage US distribution system operating in USA and made of:

- 3 production plants located in Sacramento (California), Philadelphia (Pennsylvania) and Topeka (Kansans);
- 3 CDCs located in Baltimore (Maryland), Kansas City (Missouri) and Reno (Nevada);
- 12 RDCs whose location, capacities and costs are reported in Table 1;
- 120 Pods all located in USA;
- the number of time units for the planning period is 20 corresponding to days (20 days are about one month);
- 3 transportation modes are available: truck, train and plane.

Id	Address	Zip	City	Country	Activation cost [€]	Handling variable cost [€/load]	Handling capacity [load]	Storage variable cost [€/load]	Storage capacity [load]
RDC1	425 Toland St	94124	San Francisco, California	USA	11129000	0.09	1950000	0.05	115000
RDC2	2768 Winona Ave	91504	Burbank, California	USA	11129000	0.09	1950000	0.05	115000
RDC3	768 Taylor Station Rd	43230	Columbus, Ohio	USA	11129000	0.09	1950000	0.05	115000
RDC4	1890 Elm Tree Dr	37210	Nashville, Tennessee	USA	11129000	0.09	1950000	0.05	115000
RDC5	393 Telluride St	80011	Aurora, Colorado	USA	11129000	0.09	1950000	0.05	115000
RDC6	509 Carroll St	11215	Brooklyn, New York	USA	11129000	0.09	1950000	0.05	115000
RDC7	7211 S Lockwood Ave	60638	Chicago, Illinois	USA	11129000	0.09	1950000	0.05	115000
RDC8	3640 Atlanta Industrial Dr NW	30331	Atlanta, Georgia	USA	11129000	0.09	1950000	0.05	115000
RDC9	618 W West St	21230	Baltimore, Maryland	USA	11129000	0.09	1950000	0.05	115000
RDC10	3915 SW Moody Ave	97239	Portland, Oregon	USA	11129000	0.09	1950000	0.05	115000
RDC11	2412 Commercial St	72206	Little Rock, Arkansas	USA	11129000	0.09	1950000	0.05	115000
RDC12	5518 Export Blvd	31408	Savannah, Georgia	USA	11129000	0.09	1950000	0.05	115000

Table 1. Regional distribution centers - RDC

4.1 Strategic planning, case study

Figure 10 shows the main form of the strategic planning in LD-LogOptimizer. It is made of different sections for input and output data. A quick report guides the user to the full comprehension of the tool activities. Figure 11 presents the input data including the geographical map. In particular, on the map yellow flags represent the production plants (sources), white flags the RDCs, light blue flags the CDCs, green flags the Pods.

Figure 12 shows the results of the application of the strategic planning: the activated nodes of the network and the activated material flows are visible. For example, RDC1 and RDC6 are closed at the third stage of the system; Pod98 is supplied by RDC3 that supplies also other points of demand, e.g. Pod99, Pod101, Pod106. The total logistic cost and different contributions are reported in the quick report.

6 of 12 available RDCs are closed; 1 of 3 available CDCs is activated (open); 1 of 3 available plants is open. Closed plants are represented in black colour, in blue closed CDCs and in red closed RDCs. Figure 12 show also the flows of material for a specific product at the first stage.

Figure 13 presents the results of the strategic planning showing also the flows at the third stage (RDCs-Pods). Similarly Figure 14 shows the flows activated by product P2.

Figure 15 reports the graph of the distribution of costs within the system as the result of the strategic planning in LD-LogOptimizer: about 21% of the total cost is due to transportation activities; about 34% to fixed costs (e.g. to open/activate facilities as CDCs and RDCs); about 45% of the total cost is variable (e.g. handling cost).

Table 2 presents the obtained results in terms of KPI. The activated facilities are: 6 of 12 RDCs, 1 of 3 CDCs, 1 of 3 production plants. The total cost refers to the whole planning period of one year. It is a very expensive cost because it includes all fixed cost contributions necessary to build the network, i.e. to open/active logistic facilities, and to move materials from suppliers to demand points.

4.2 Tactical planning, case study

Tactical planning is a time-dependent planning. Consequently, for each product and the generic point in time t a set of facilities and materials flows are activated in order to ship products from sources (production plants) to Pods passing through CDC and RDC facilities, in accordance with capacity constraints, lead time, variable and fixed unit costs, etc.
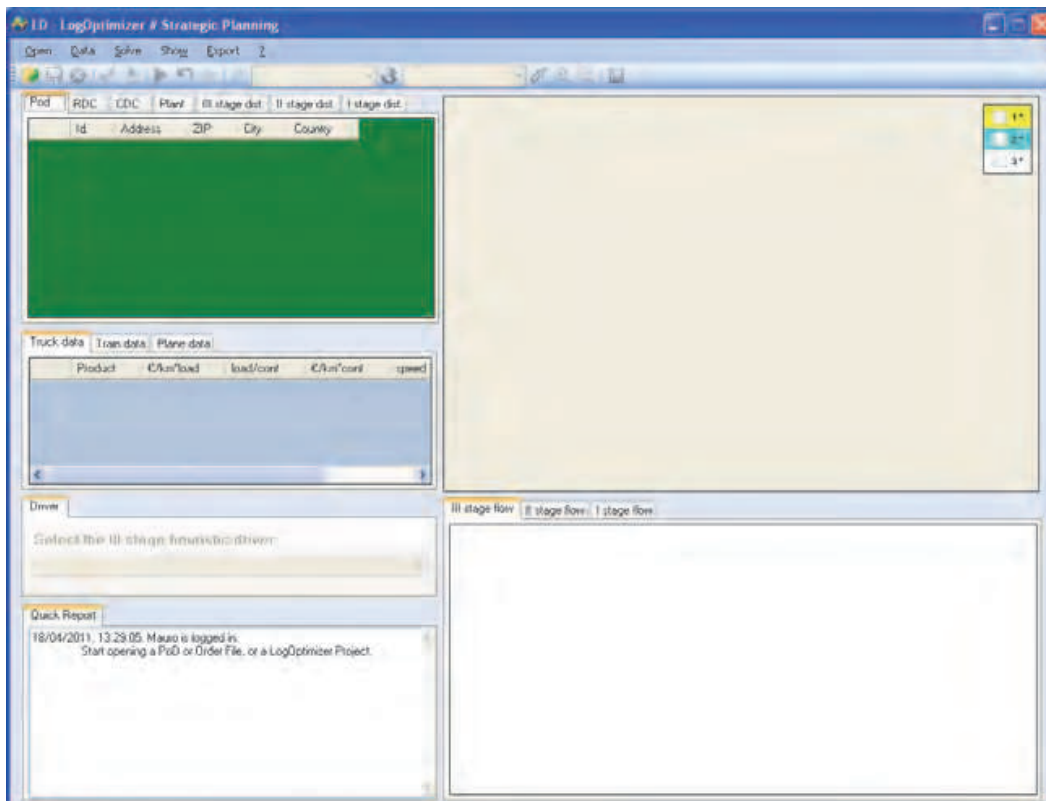
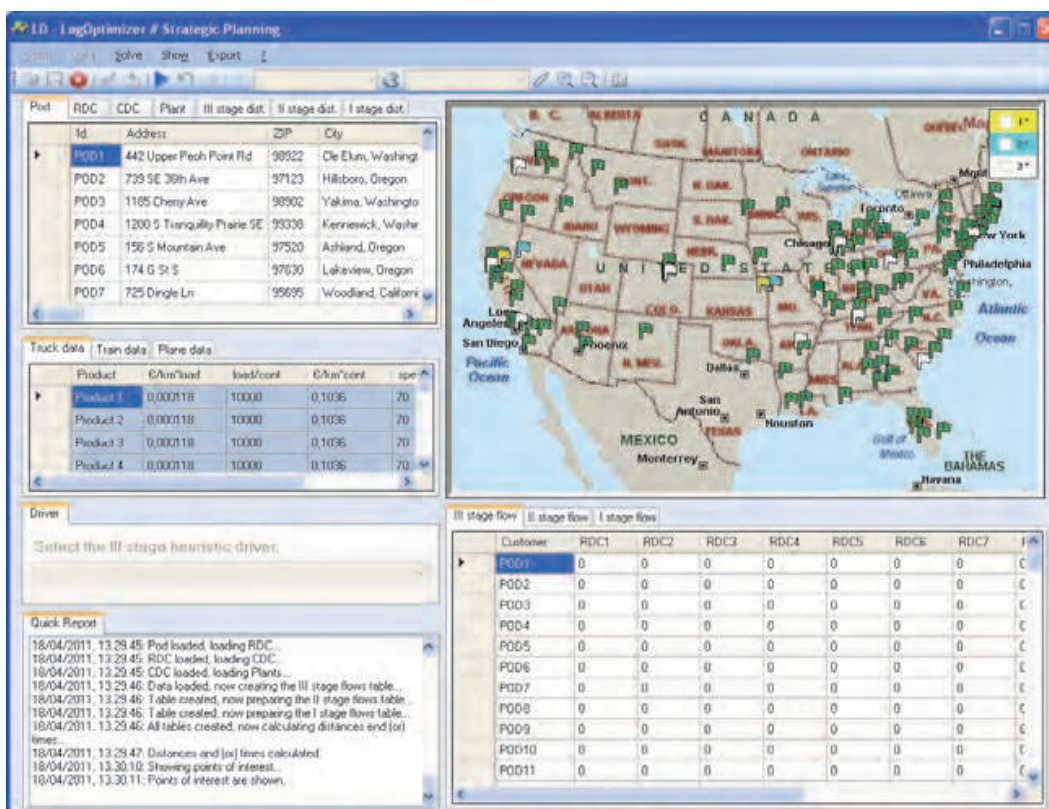Fig. 10. Strategic planning, LD-LogOptimizer, main form

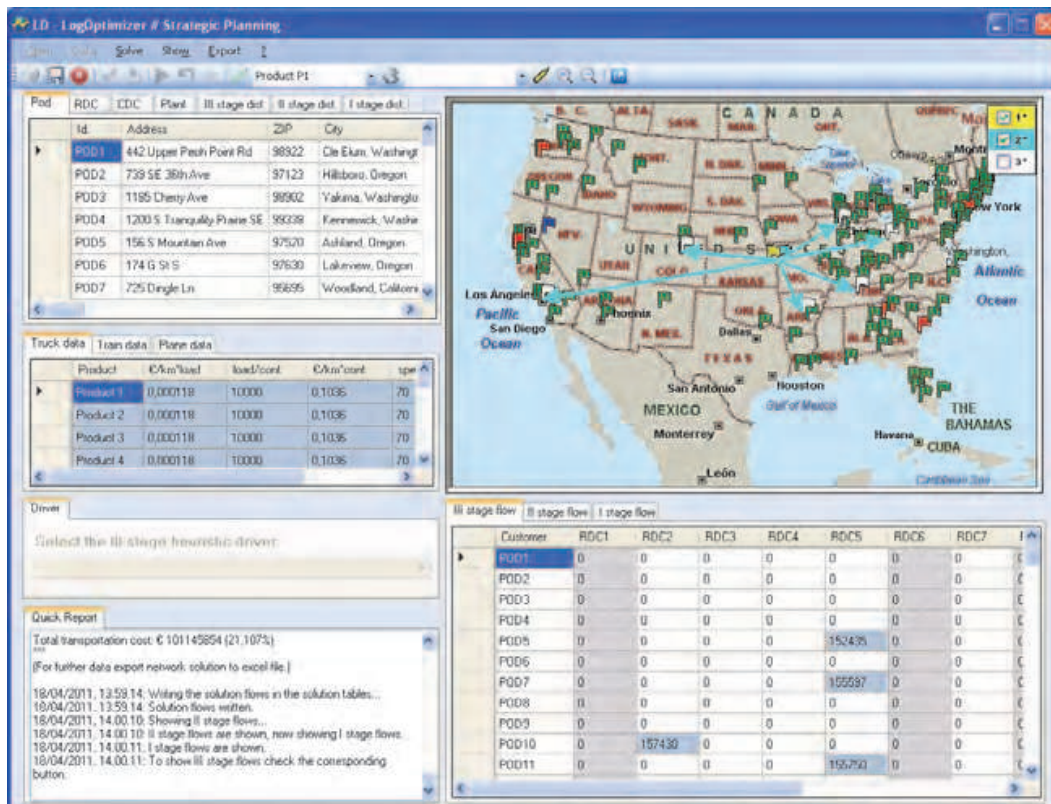

Fig. 11. Input data for the strategic planning

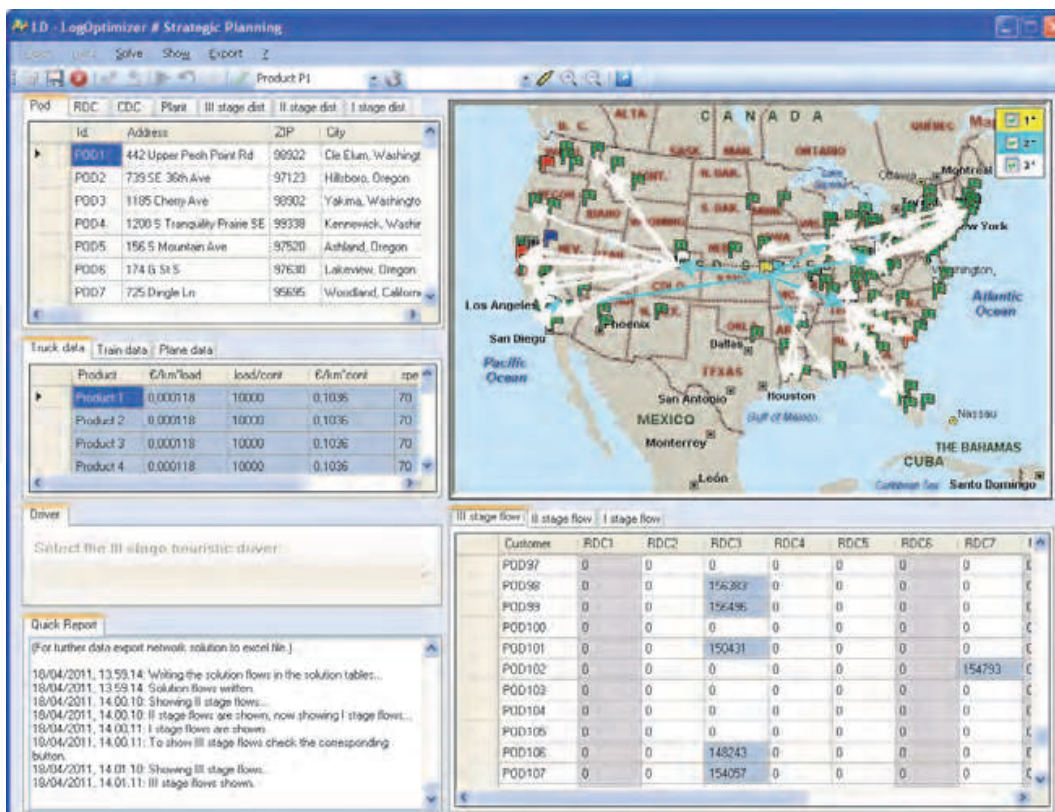Fig. 12. Results, strategic planning

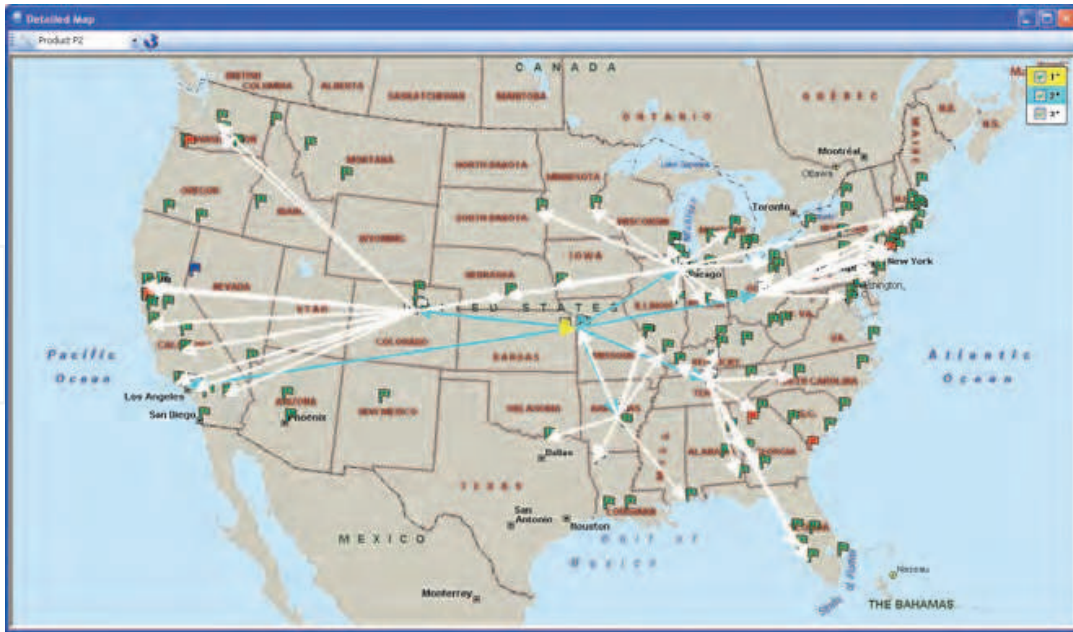Fig. 13. Product 1, strategic planning. Flows at the first stage.

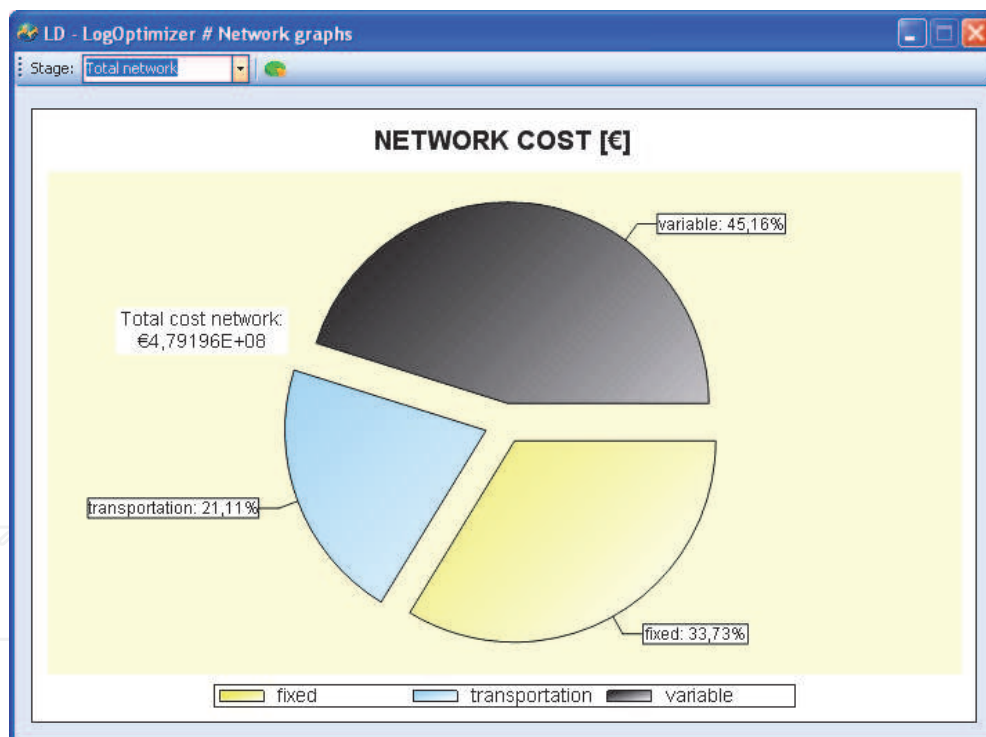Fig. 14. Product 2, materials flows. Strategic planning.

Fig. 15. Strategic planning, network cost.

Figure 16 presents the result of the execution of LD-LogOptimizer on the case study object of the analysis and for the tactical planning. In particular, results in figure refer to the product named P1. The list of deliveries for the active RDCs to the Pods in the point in time T1 is also reported: this is the input for the operational planning illustrated in next subsection. Flows of product P1 between active facilities in T1 are shown.

Figure 17 shows the material flows of another product, P2, for the period of time T1.

KPI Strategic Planning	Value
Points of demand	120
RDC	12
CDC	3
Plants	3
RDC activated	6
CDC activated	1
Plants activated	1
TOTAL COST [€]	479196000
RDC cost [€]	98235760
CDC cost [€]	37760600
Plant cost [€]	242053800
3° stage trasportation cost [€]	42149040
2° stage trasportation cost [€]	53662470
1° stage trasportation cost [€]	5334346
Average n° of points of demand served by a regional distribution center	10.24
Average n° of regional distribution centers that serve a point of demand	0.51
Average n° of regional distribution centers served by a central distribution center	5.97
Average n° of central distribution centers that serve a regional distribution center	0.99
Average n° of central distribution centers served by a plant	1
Average n° of plants that serve a central distribution center	1
Average 3° stage distance [km]	835.03
Average 2° stage distance [km]	1175.36
Average 1° stage distance [km]	103.78

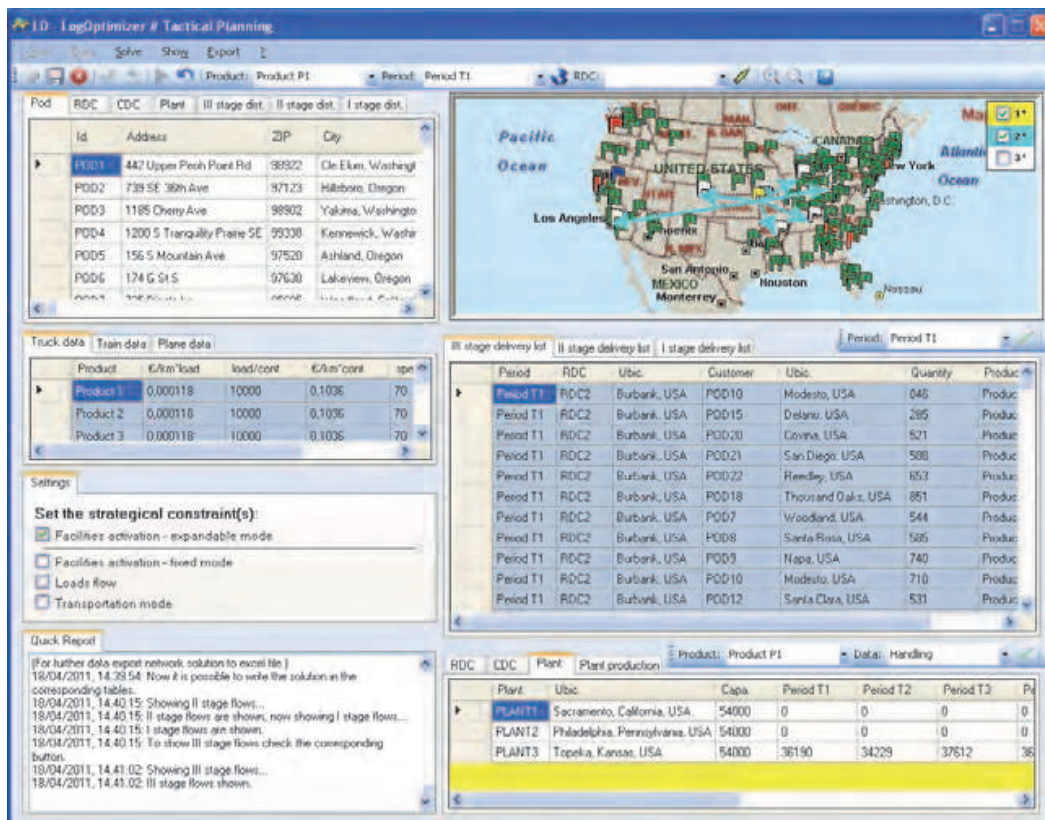Table 2. Strategic planning, KPI
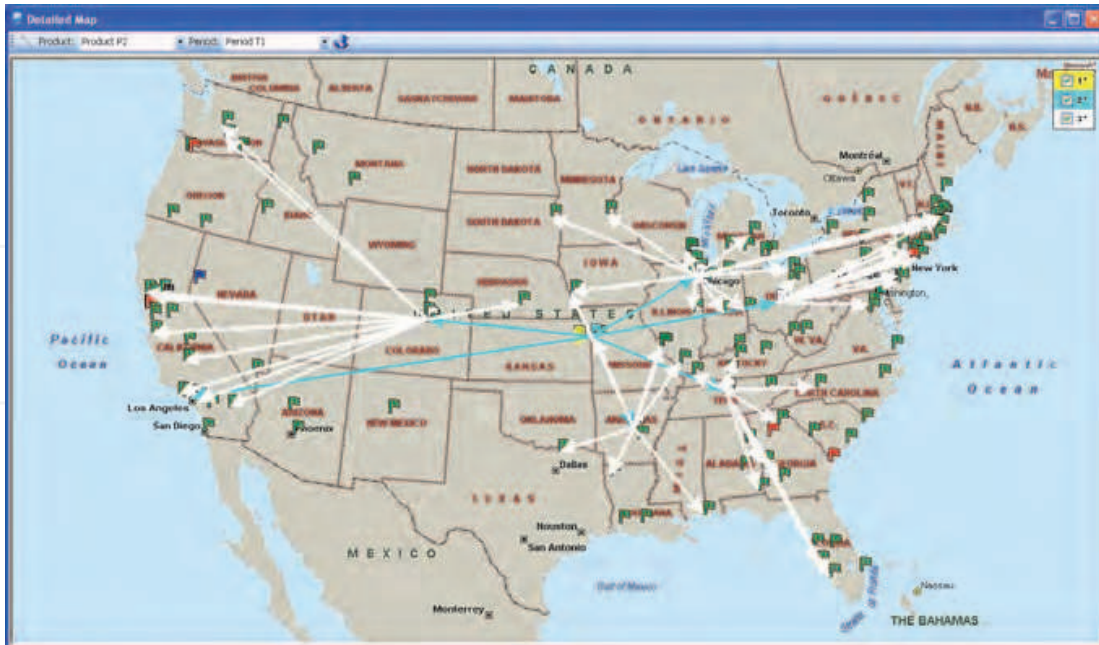

Fig. 16. Tactical planning, case study

Fig. 17. Tactical planning (P2 in T1)

Table 3 presents the obtained results in terms of KPI for the tactical planning. In particular, the expected costs significantly differ from the strategic planning costs because they refer to the planning period made of 20 units of time. The activated facilities are: 6 of 12 RDCs, 1 of 3 CDCs, 1 of 3 production plants. An RDC serves about 10-11 Pods.

KPI Tactial Planning	Value
Points of demand	120
RDC	12
CDC	3
Plants	3
RDC activated	6
CDC activated	1
Plants activated	1
TOTAL COST [€]	19584910
RDC cost [€]	3542925
CDC cost [€]	1197645
Plant cost [€]	9232994
3° stage trasportation cost [€]	3171216
2° stage trasportation cost [€]	2227638
1° stage trasportation cost [€]	212496
Average n° of points of demand served by a regional distribution center	10.26
Average n° of regional distribution centers that serve a point of demand	0.51
Average n° of regional distribution centers served by a central distribution center	5.96
Average n° of central distribution centers that serve a regional distribution center	0.99
Average n° of central distribution centers served by a plant	1
Average n° of plants that serve a central distribution center	1
Average 3° stage distance [km]	834.07
Average 2° stage distance [km]	1174.56
Average 1° stage distance [km]	103.78

Table 3. Tactical planning, KPI

4.3 Operational planning, case study

The operational planning can be applied to plan and schedule the vehicle routing at the each stage of the network and in particular from RDCs to Pods and from CDCs to RDCs. The first of this stage usually involves trucks as transportation modes; while CDCs-RDCs shipments can be executed also adopting one of the other available modes (e.g plane and train).

Figure 18 presents a result obtained by the execution of the operational planning on the case study. A list of clusters is reported and for each cluster it is possible to generate the optimal route as the minimum Hamiltonian circuit visiting all the members grouped in a cluster.

The route ID 173 is shown. It is made of the following sequence of visits: RDC4, Pod106, Pod110, Pod111, Pod109, Pod108, Pod107, RDC4. Another detailed route is exemplified in Figure 19. The groupage strategy can reduces the cost of travelling of about 55% if compared with direct delivery, i.e. direct shipment from a generic supplier to a point of demand.

Figure 20 exemplifies another route (named ID 109) departing from Chicago and generated by the operational planning.
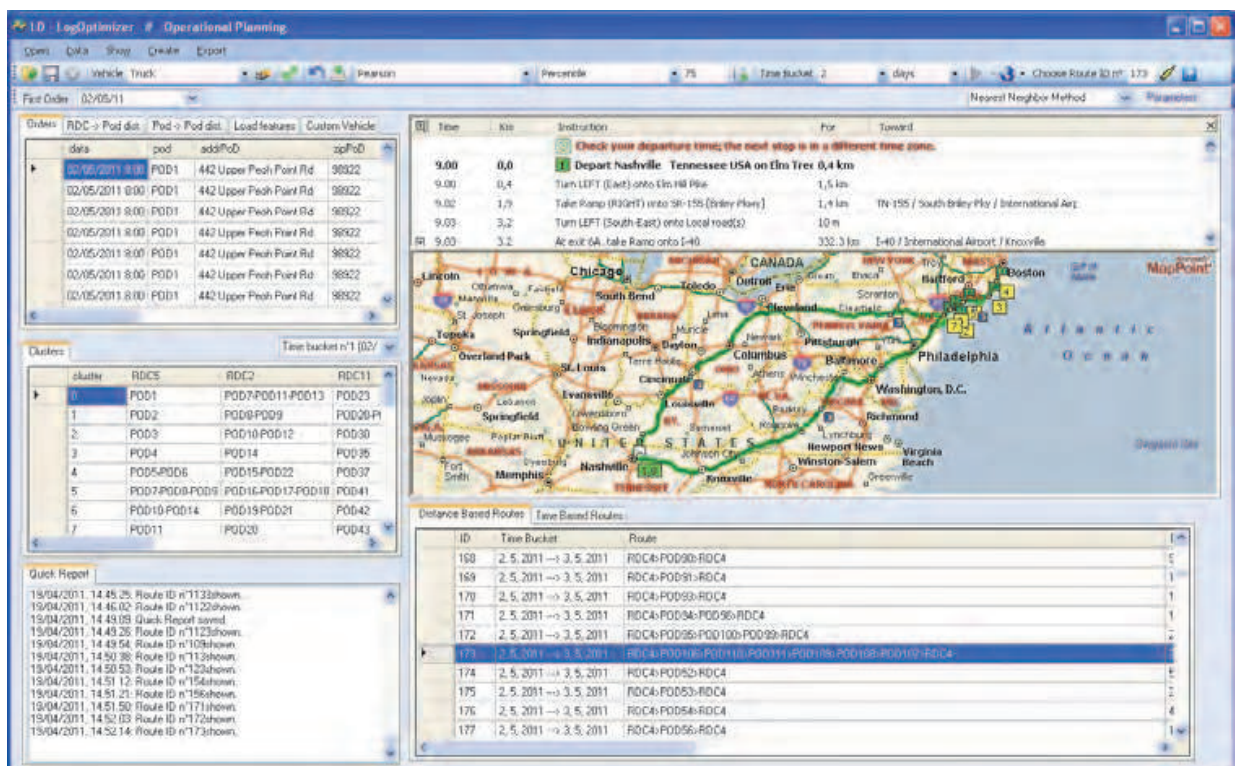

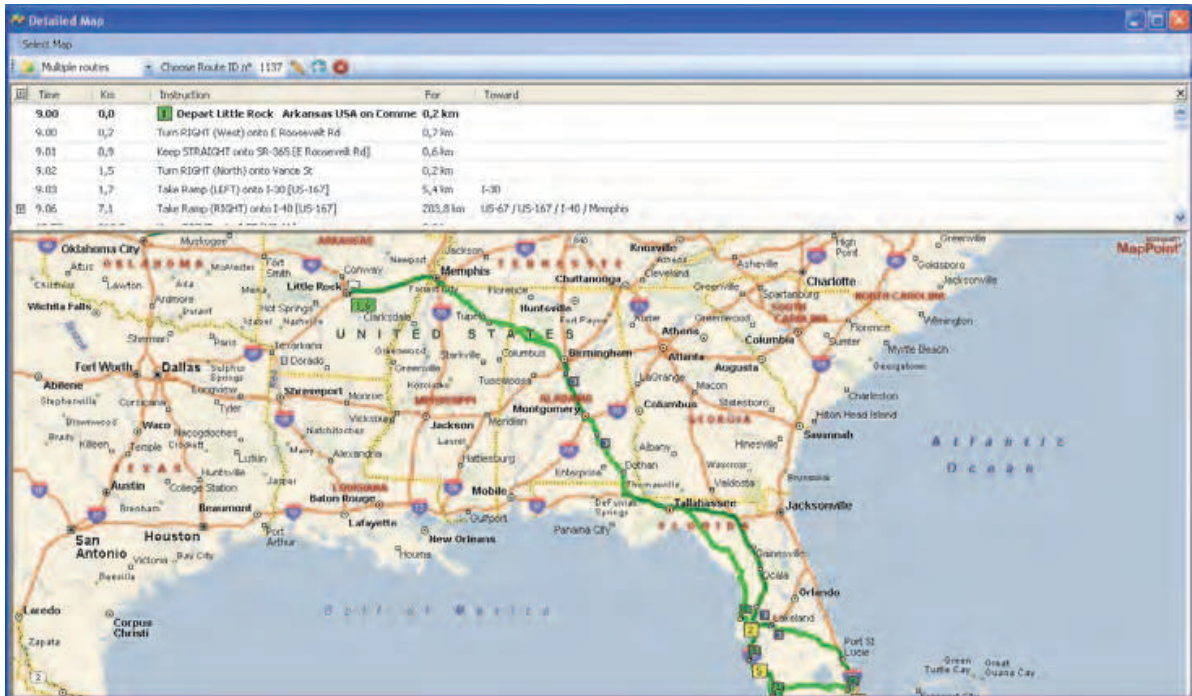Fig. 18. Operational planning, route ID 173
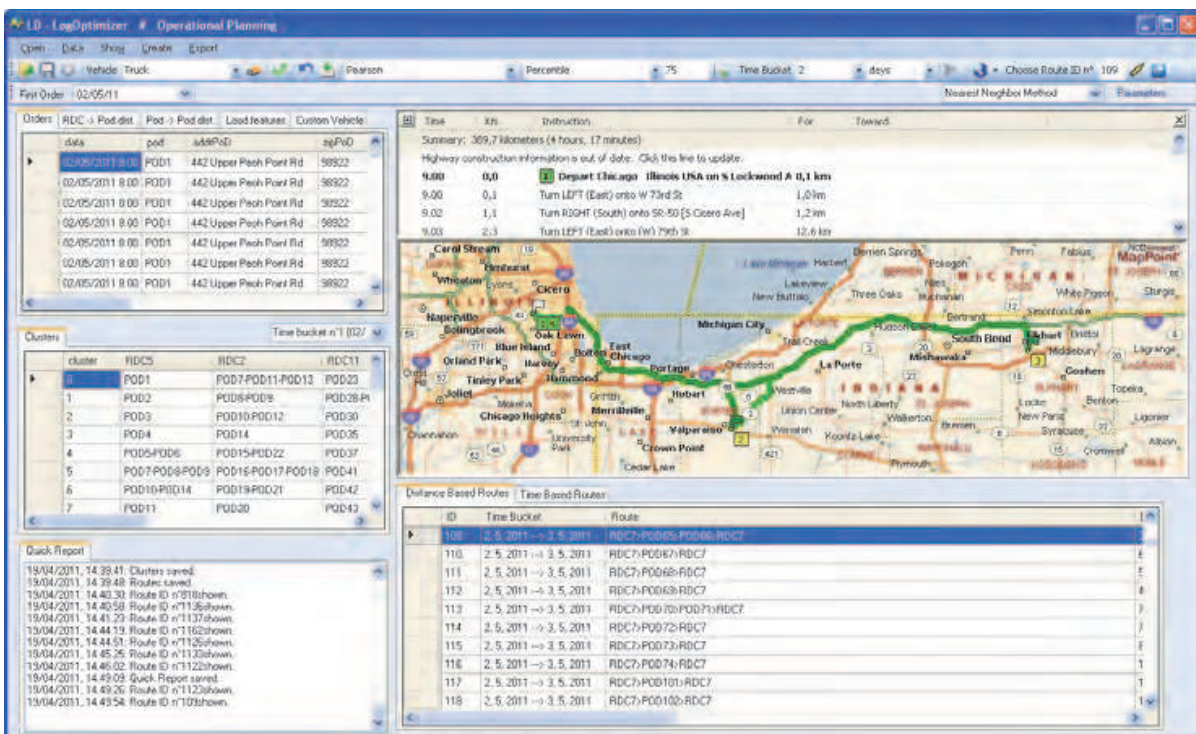
Fig. 19. Operational planning, Route ID 1137

Fig. 20. Operational planning, an example

4. Conclusions and further research

This chapter illustrates an original framework for the design and planning a production-distribution logistic network by the integration of the strategic planning, the tactical planning and the operational planning. This framework has been implemented by a supporting decisions platform, a software tool, named LD-LogOptimizer. The discussed case study demonstrates the effectiveness of the proposed models and automatic supporting decisions tool. The tool supports the manager in configuring the system by the determination of the number, location and capacity of the generic facility, e.g. a distribution center and a production plant. Further research is expected on the development of new models, new effective solving methods and procedures/algorithms, experimental multi-scenario what-if analyses conducted on significant case studies. New applications and benchmarking are also expected. Finally, the development of reverse logistic flows and issues and the integration in LD-LogOptimizer tool are expected. The new platform will support managers in the design, optimization and management of direct and return flows in a multi-level logistic network, minimizing the global logistic cost and/or maximising the customers' service level by the joint optimization of strategic, tactical and operational issues, including vehicle loading and routing. Models and tools for electronic data interchange between the planner, as a controller (the server), and vehicles (the clients) executing the transportation missions are expected. The generic vehicle can also communicate its location during the routing and visit of a set of Pods adopting the groupage strategy: the server can update the planned routes and eventually modify them accordingly.

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Supply Chain Management - New Perspectives

Edited by Prof. Sanda Renko

Over the past few decades the rapid spread of information and knowledge, the increasing expectations of customers and stakeholders, intensified competition, and searching for superior performance and low costs at the same time have made supply chain a critical management area. Since supply chain is the network of organizations that are involved in moving materials, documents and information through on their journey from initial suppliers to final customers, it encompasses a number of key flows: physical flow of materials, flows of information, and tangible and intangible resources which enable supply chain members to operate effectively. This book gives an up-to-date view of supply chain, emphasizing current trends and developments in the area of supply chain management.

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