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The Value of Cooperative Planning in Supply Chains - A Simulative Approach

Luis Martin
Freiberg University of Technology, luis.martin@bwi.ti-freiberg.de

Peter Buxmann
Freiberg University of Technology, buxmann@bwl.tu-freiberg.de

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Luis Martín Díaz
Freiberg University of Technology
Chair of Information Systems / Wirtschaftsinformatik
Lessingstr. 45
09596 Freiberg / Germany
Phone: ++49 3731 39 2674, Fax: ++49 3731 39 3117
luis.martin@bwl.tu-freiberg.de
URL: http://www.bwl.tu-freiberg.de/wi

Peter Buxmann
Freiberg University of Technology
Chair of Information Systems / Wirtschaftsinformatik
Lessingstr. 45
09596 Freiberg / Germany
Phone: ++49 3731 39 2674, Fax: ++49 3731 39 3117
buxmann@bwl.tu-freiberg.de
URL: http://www.bwl.tu-freiberg.de/wi

Abstract

In this paper we examine, how the benefits of Supply Chain Management, as announced by the literature and widely accepted, can simulatively be proven. We first present selected results of a survey conducted on the European automotive industry, which show an evident need for transparency, in terms of the quantification of the added-value of Supply Chain Management. For this purpose we introduce an XML-based prototype for modeling and simulating cooperative scenarios in supply chains, and illustrate its flexible architecture and the interaction between modeled scenarios and optimization routines through XML interfaces. In the context of this prototype we describe a simulation scenario in which the transportation activities in a supply chain are modeled and planned. We then run simulations in a cooperative and in a non-cooperative context and compare the results for the entire supply chain. This comparison can provide information about the benefits of cooperative logistics planning (i.e. Supply Chain Management), which for instance can be realized by implementing Supply Chain Management software for distribution planning purposes.

Keywords

Supply Chain Management, cooperative Planning, logistics, information technology, networking, inter-organizational business processes, simulation, java, XML.

1. Introduction

The origins of Supply Chain Management (SCM) can be traced back to 1958, when Forrester (1958) wrote: "Management is on the verge of a major breakthrough in understanding how industrial company success depends on the interaction between the flows of information, materials, money, manpower, and capital equipment". However, it should take 24 years for Oliver and Webber (1982) to create the term SCM. Since then, research and industry are focusing on its further development to an incomparable manner. In this paper we want to explore, how the benefits of SCM, as announced by the literature and widely accepted (Christopher 1998, Cooper, Lambert & Pagh 1997, Copacino 1997), can simulatively be proven. For this purpose we introduce a Java- and XML-based prototype for modeling and optimizing the supply chain, illustrate its flexible architecture and the interaction between modeled scenarios and optimization routines through XML interfaces.

In this paper we compare the results of a simulation run, in which each actor in the supply chain plans for her/himself, with the results of a simulation run within a SCM context, in which cooperative, integrated logistics planning is achieved. The scenario simulated represents the classic transportation problem in supply chains, where several distributors deliver goods to their customers and plan their routes and load allocation for an efficient transportation plan.

There is a lot of research work on the value of cooperation in terms of information sharing in supply chains. For instance, Cachon and Fisher (2000) show in a numerical study that, in the context of inventory management, a full information policy between the actors of a supply chain can lower the total costs by 2.2% on average compared to a traditional non-sharing information policy (Cachon & Fisher 2000, figure 1). They also show, that the far bigger benefits are acquired by other effects of implementing information technology: lead times reduction and smaller batch sizes. When cutting lead times in half, the supply chain reduces its total costs by 21% on average while, when cutting batch sizes in half, the costs are reduced by 22% on average (Cachon & Fisher 2000, table 1). Gavirneni, Kapuscinski and Tayur (1999) estimate the savings due to information flow, and analyze when information is most beneficial. They focus their attention on the relationship between information, capacity and inventory from the point of view of a supplier dealing with one customer (retailer), and compare a traditional non-information sharing policy with partial and complete information sharing policies. They show that, being information always benefitial, when the supplier has high capacity and the demand variance and Ä = $S - s$ are moderate, information is most benefitial. Further, Lee, So and Tang (2000) address the exchange of demand information between a manufacturer and a retailer, and show that the manufacturer can obtain inventory and cost reductions with information sharing, especially if the demand is highly correlated, highly variable, or when the lead times are long.

The planning with relevant information from other actors of the supply chain represents one of three alternative cooperation forms as described by Wyner and Malone (1996), being the decentralized planning with information exchange. What we want to show in the next sections is a simulation prototype that addresses the difference between the other planning alternatives: the cooperative (meaning actors in the supply chain plan together in a centralized way) and the non-cooperative planning policies (meaning there is no information sharing for planning purposes at all). The difference between these two planning forms, in terms of total costs of the supply chain, may be interpreted as the upper bound on the value of a system to support a centralized planning (e.g. a

SCM software solution). In a future work, we will address the simulation of the decentralized planning with information sharing.

In the following section we present selected results of an empirical study about the status quo of SCM in the European automotive industry. In the third section we introduce a simulation model for transportation planning. In the fourth section, we present a prototype called *SCOptimizer* for modeling and simulating cooperation in supply chains. Here, we show how the prototype is used to run non-cooperative as well as cooperative simulations and explain how the emerging differences can be interpreted. The paper ends with a summary of the implementation experiences and a short outlook on further research.[1]

2. Supply Chain Management in the European Automotive Industry

SCM describes the integration of business partners beyond the boundaries of the firm, by involving these partners in the different processes and activities that produce value in the form of products and services (Oliver & Webber 1982, Hulihahn 1985, Anderson, Britt & Favre 1997, Cooper, Lambert & Pagh 1997, Christopher 1998, Simchi-Levi, Kaminsky & Simchi-Levi 2000). The participants of the supply chain are suppliers, producers, logistics service providers, retailers and customers. The main idea is that cooperative planning generally leads to better performance than isolated planning. The better results can be achieved by coordination of procurement, transportation and inventory strategies as well as integrated planning of sales, production and distribution.

For these purposes, SCM software solutions have been developed and are being increasingly implemented. Although the basic message of SCM is nowadays widely accepted, the quantification of the added value still remains a big question mark for most of the companies involved in logistics driven industrial sectors.

This statement is reinforced by the results of survey we have conducted recently. In the following, we present the key findings of our empirical study.

2.1 The Sample

The survey focuses on the European automotive industry. The details on 1000 companies were acquired through research on the Internet, company registers, the embassies of the various countries as well as the government offices responsible for trade and international relations. First, we approached the companies either via e-mail, phone or fax and asked them to name the responsible person for the logistics or SCM department/efforts. The companies were supplied with the hyperlink to our online-questionnaire or received the questionnaire via fax or mail. After two follow-up procedures by e-mail and phone, a total of 178 usable answers were obtained. This number equals a response rate of 17.8%.

[1] The topic presented in this paper is part of a research project called SkiLNet. We want to thank the German Research Foundation (DFG) for supporting this project with the grant BU1098/1-1.

Most of the participating companies are suppliers (tier 1 and/or 2) or manufacturers. Roughly 20% define their role to the automotive industry as distributors, and/or carrier/shipper; at the same time some of them are manufacturers or suppliers as well.

2.2 Selected Findings

The companies were asked if they have a SCM software solution implemented or not, respectively if the implementation is still lasting or at least planned. The results are displayed in Figure 1:

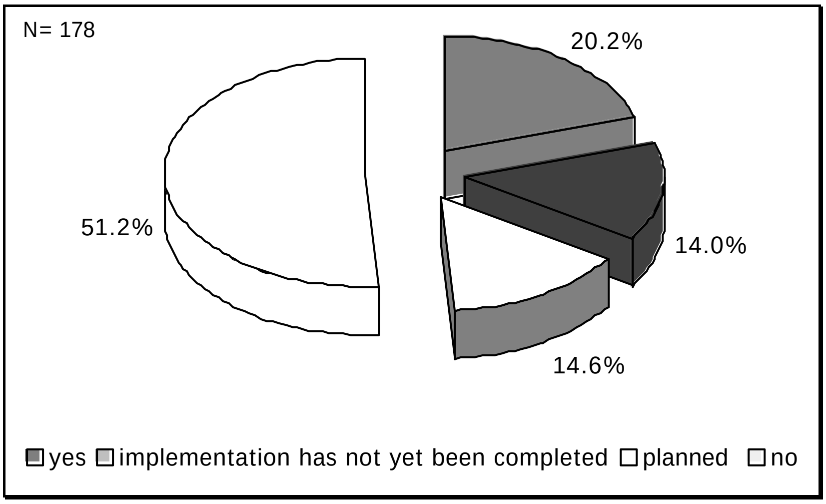

Figure 1. Do you have a Supply Chain Management software solution?

Only 20.2% of the companies are using SCM software solutions at the time. But 14% are currently running an implementation project, while 14.6% plan to implement a software solution but the project did not start yet.

When asked those companies, who do not yet implement SCM software (being 117 firms), about the reasons for the non-application of SCM software, 62.4% revealed not to be able to quantify the benefit of using such a software solution (see Figure 2).

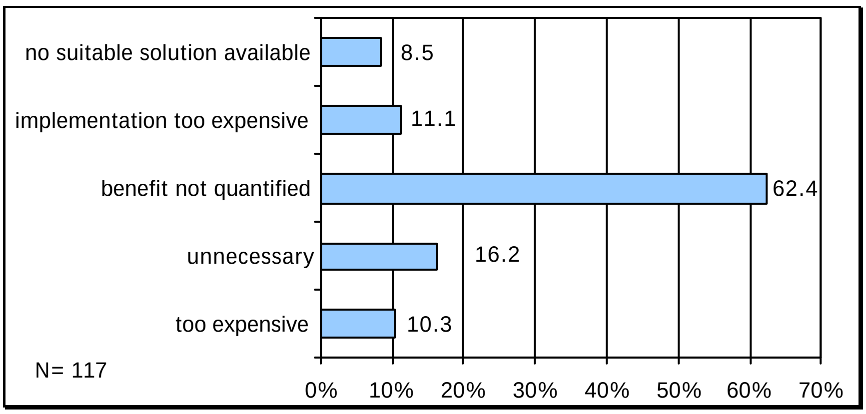

Figure 2. Reasons for non-application of SCM software

In addition to that, we found that the biggest part (52.5%) of the companies implementing or planning to implement SCM software actually use or plan to use their SCM software solution on an inter-organizational level. To lighten up why 47.5% of those companies are not using their SCM software solution for integrated inter-organizational planning, we asked the respondents to indicate what they consider as the biggest challenges of an inter-organizational usage of SCM software. This question allowed multiple answers and was posed to those companies, which either do apply SCM software or are currently implementing it (being 61 firms). The results are displayed in Figure 3.[2]

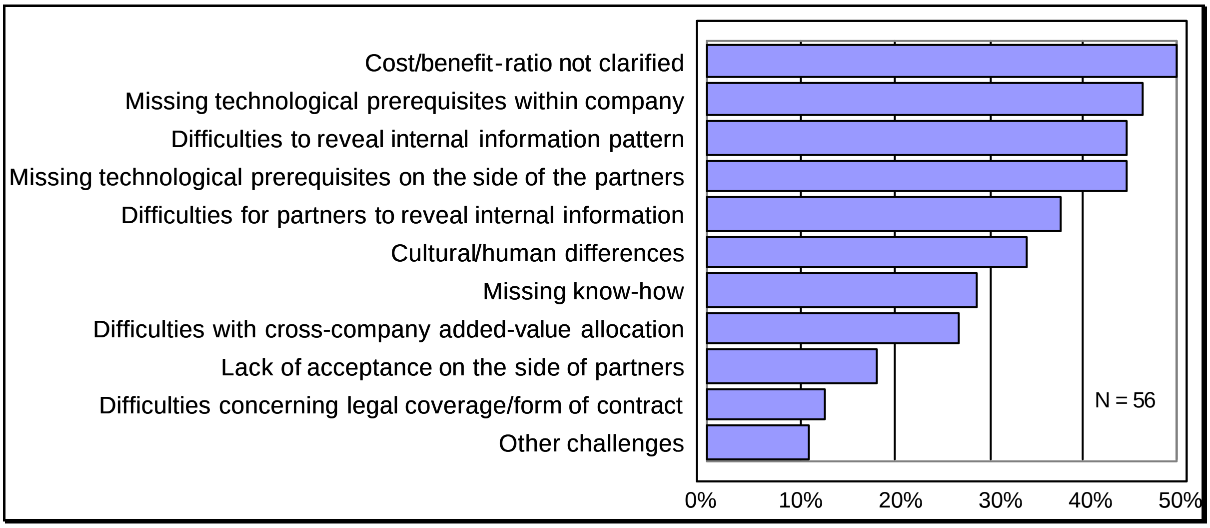

Figure 3. Challenges of an inter-organizational usage of SCM software

As one can see, 50% of the questioned companies consider the not clarified cost/benefit-ratio as one of the biggest challenges. This reveals an evident need for transparency in terms of the added-value of software-based SCM. For that purpose, we developed a prototype that allows simulating cooperative and non-cooperative planning of logistics activities in supply chains.

3. The Simulation Model

In this section, we take a look at the requirements that the model has to meet in order to be able to simulate different planning scenarios in a supply chain. We also describe, in the context of transportation planning, what a cooperative and a non-cooperative planning scenario can look like.

3.1 Requirements

A simulation model that aims to clarify the added-value of cooperative planning in supply chains has to fulfill the following requirements: The planner must be able to model scenarios, in which both all types of supply chain actors and their relations can be described. It has to be possible to represent segments of a supply chain, on the basis of which different planning and optimization alternatives

[2] Five of the 61 companies, which were requested to answer this question, did not provide any information and were therefore not taken into consideration for the analysis. We understand the missing answers as both *missing at random* and *observed at random* (Rubin 1976, Little & Rubin 1987, pp. 39ff).

(e.g. transportation and location planning) can be simulated. For this purpose the modeling of scenarios has to remain independent from the planning model and optimization or the heuristic methods used for the simulation. In addition, it has to be possible to apply the same optimization and heuristic methods in a cooperative as well as in a non-cooperative context in order to guarantee comparability.

3.2 Cooperative vs. Non-Cooperative Planning

Logistics planning activities in regard to SCM can generally be divided into the following categories: Sales and demand planning, location planning, purchasing and inventory planning, production planning, distribution and reflux planning.

Thereby, an important example of the potential advantages of cooperative behaviour in supply chains can be found in the literature in the context of purchasing and inventory planning as the so-called *bullwhip effect* (Lee & Padmanabhan 1997, Metters 1997, Chen, Drezner, Ryan & Simchi-Levi 2000).

Another planning activity that can be simulated in order to identify potential cooperative advantages is transportation planning. It takes place as part of many of the logistics activities in supply chains. A usual example for the need of transportation plans can be found in the context of distribution planning (Bramel & Simchi-Levi 1997). In this case, distributors deliver goods to customers, in order to satisfy their demand for those goods in a given time period.

In a non-cooperative context each distributor can plan the delivery for example after the model known as Capacitated Vehicle Routing-Problem (CVRP) (Dantzig & Ramser 1959, Balinski & Quandt 1964). The goal of this delivery problem is to minimize the total costs of transportation, which is equivalent to the minimization of the number of routes (i.e. the number of required vehicles) and the total covered distance.

If we take a look at a simulation scenario with three distributing warehouses, each of which supplies four customers, the non-cooperative delivery planning would mean that each warehouse solves a CVRP that only considers those customers, with whom this distributor has direct business relationships. Other customers delivered by other distributors of the same supply chain would not be taken into account. The result could look like Figure 4:

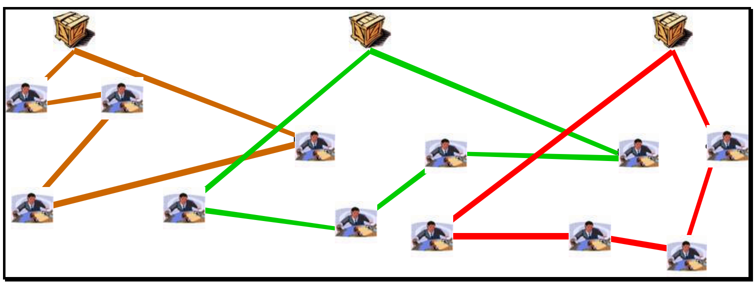

Figure 4. Non-cooperative transportation planning

Figure 4 shows that the warehouses deliver customers that are located nearer to another warehouse. This means that the total covered distance could be minimized if the nearest warehouse would supply those customers. A cooperative planning therefore implies a “customer exchange” between the cooperating warehouses. Every customer would be reassigned to the nearest warehouse and according to that the delivery routes would be planned. This kind of model is called Multi Depot Vehicle Routing-Problem (MDVRP) (Golden, Magnanti & Nguyen 1977, Laporte, Nobert & Taillefert 1988).

One way of consecutively solving the assignment and the routing problem is applying the Voronoi heuristics first and then solving the CVRP for each warehouse (Voronoi, 1908; Klein, 1989; for other solution procedures see for example Chao et al., 1993). This method divides the planning area R^2 in so called Voronoi-regions by using the following function:

$$V(DC_i) = \bigcap_{k:k \neq i} \{x \in R^2 : d(x, DC_i) < d(x, DC_k)\} \tag{1}$$

The variable x represents the location of a customer that has to be supplied. This customer is assigned to the distribution center DC_i that is nearest to it in terms of the distance d. The result of applying this formula is a set of regions V supplied by a single distribution center DC_i. Assuming that the distance is the primary cost driver and all warehouses have enough handling and transportation capacities available, this reassignment should reduce the overall tour costs. The resulting delivery plan could look like Figure 5:

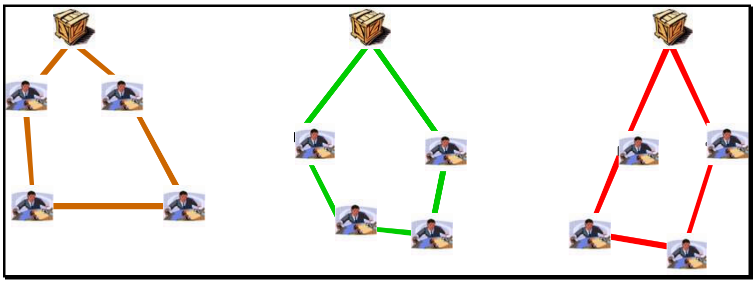

Figure 5. Cooperative transportation planning

While Figure 4 shows the non-cooperative context, where each warehouse plans the stake of the trucks, load allocation, delivery order and delivery route for its customers independently, Figure 5 displays the results of cooperative planning. Under the assumption that the distance-dependent variable costs have the highest proportional weight, cooperative planning will result in overall lower transportation costs for the supply chain.

We want to take a look now at how this potential added-value of cooperative planning can be determined through our simulation prototype. For this purpose, we describe the architecture of the prototype in the next section and explain the modeling of scenarios and their optimization.

4. *SCOptimizer* – A Prototype for Simulation of Logistics Planning

The *SCOptimizer* is part of an application system called SIMPLEX (Supply Chain Management Platform Enabled by XML). While the other modules of SIMPLEX support the operational aspects of SCM, like the exchange of business documents between the partners in supply chains and the transformation between different XML business vocabularies, the *SCOptimizer* is intended to cover the planning side of SCM. First, we want to introduce the architecture of the *SCOptimizer*.

4.1 The Architecture of the *SCOptimizer*

The *SCOptimizer* is mainly based upon open standards, open source software, and freeware. It is written in Java and uses XML for the description of interfaces and the modeling of simulation scenarios, which makes the prototype platform independent. The following figure shows the architecture of the *SCOptimizer*:

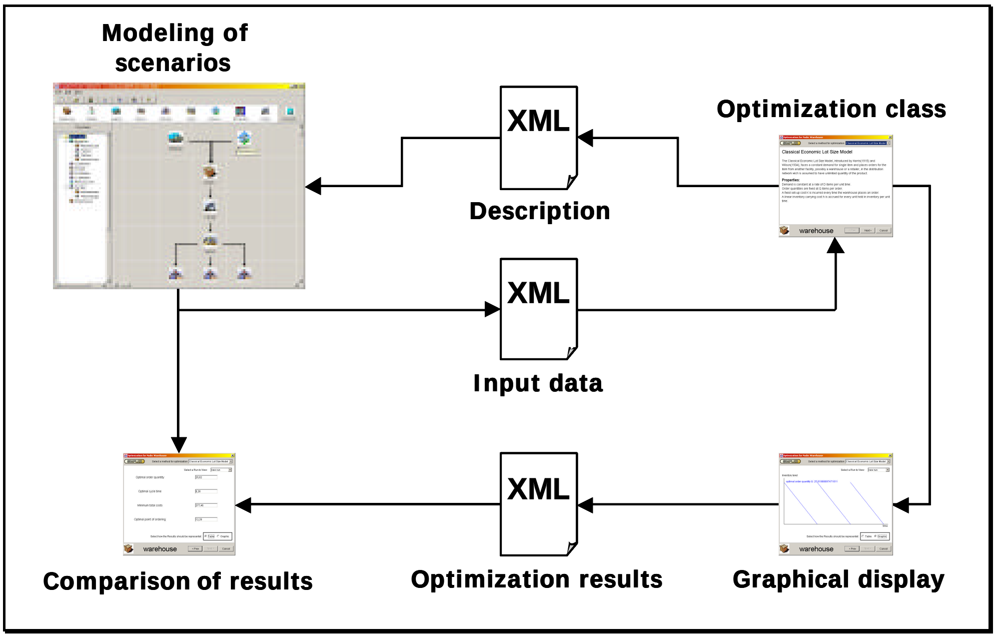

Figure 6. The architecture of the SCOptimizer

The idea of decoupling the modeling of scenarios (meaning the description of actors and their relation to each other; see Figure 8) from the particular use of optimization methods and planning models is realized in our prototype using XML interfaces. XML acts as the mediator between a particular scenario ("Modeling of scenarios" in Figure 6) and the available planning methods ("Optimization class" in Figure 6). After modeling a scenario, the planner selects the planning task she or he wants to perform (see section 3.2). At this stage, the *SCOptimizer* looks for all available task-specific planning models and dynamically displays a list of them for the user to select the appropriate model and method for the simulation. Each planning model and method is described in an XML file ("Description" in Figure 6), which is stored in the file system (we are currently testing the XML data base Xindice 1.0 for better access performance; see http://xml.apache.org/xindice). This description is read at runtime by the prototype and is used to dynamically create the input masks and to instantiate the optimization class (see Figure 7).

```xml
<?xml version="1.0" encoding="UTF-8"?>
<Optimization>
    <MethodDescription>
        Clarke and Wright - Savings algorithm. A classic algorithm from 1964 (Clarke and Wright)
        to solve Vehicle Routing Problems with capacity restrictions. There is no restriction in the
        number of vehicles and there is only one depot. The algorithm starts creating routes from
        the depot to every node and back. At each step, the two routes that realize the largest
        costs savings are merged.
    </MethodDescription>
    <optiondlg>
        <improve>true</improve>
        <depot>true </depot>
        <carPool>true</carPool>
        <cost>true </cost>
        <tour>true</tour>
    </optiondlg>
    <neededInput>
        <InputParam name="Costs" title="Transport Costs">
            <description>Costs per distance-unit for transporting one product item.</description>
            <Tab name="TransportCosts">
                <data name="Transport Costs">
                    <field name="SourceName" type="ComboSelect" length="5">
                        <listSource>all</listSource>
                    </field>
                    <field name="DestinationName" type="ComboSelect" length="5">
                        <listSource>all</listSource>
                    </field>
                    <field name="Input" type="IntegerType" length="5"/>
                </data>
                <table name="NodeTable">
                    <rows>SourceName</rows>
                    <columns>DestinationName</columns>
                </table>
            </Tab>
        </InputParam>
        <InputParam name="Distances" title="Distances">
        ...
        </InputParam>
        ...
    </neededInput>
</Optimization>
```

Figure 7. Excerpt from an XML description for an optimization class

This description allows the *SCOptimizer* to create the appropriate input masks at runtime, where the user can enter the data required for the planning model and the optimization method (see also Figure 10). This data is also stored in an XML file ("Input data" in Figure 6), which is then parsed by the optimization class. The class applies the optimization or heuristic method and stores the result in another XML file ("Optimization results" in Figure 6). The patterns for optimization classes in the context of our prototype demand a graphical display of the results ("Graphical display" in Figure 6). The graphical display as well as the XML results can be used for a comparison between cooperative and non-cooperative planning ("Comparison of results" in Figure 6).

All needed and created XML documents comply with strictly defined structure and vocabulary. This avoids hard-coding the offered planning models and optimization methods in the simulation prototype. These models and methods are accessed at runtime and thus can be added to and removed from the prototype without additional programming effort. The optimization classes of course have to provide the appropriate XML interface.

4.2 The Simulation of Transportation Planning with the *SCOptimizer*

After describing the architecture of the *SCOptimizer* we now want to perform a simulation in order to identify the added-value of cooperative planning in the context of a distribution scenario. Here, we will compare the total costs of both a cooperative and a non-cooperative transportation planning.

The first step of a simulation is the modeling of the distribution scenario. For this purpose, the *SCOptimizer* provides a modeling mask, where the supply chain (or segments of it) can be described graphically.

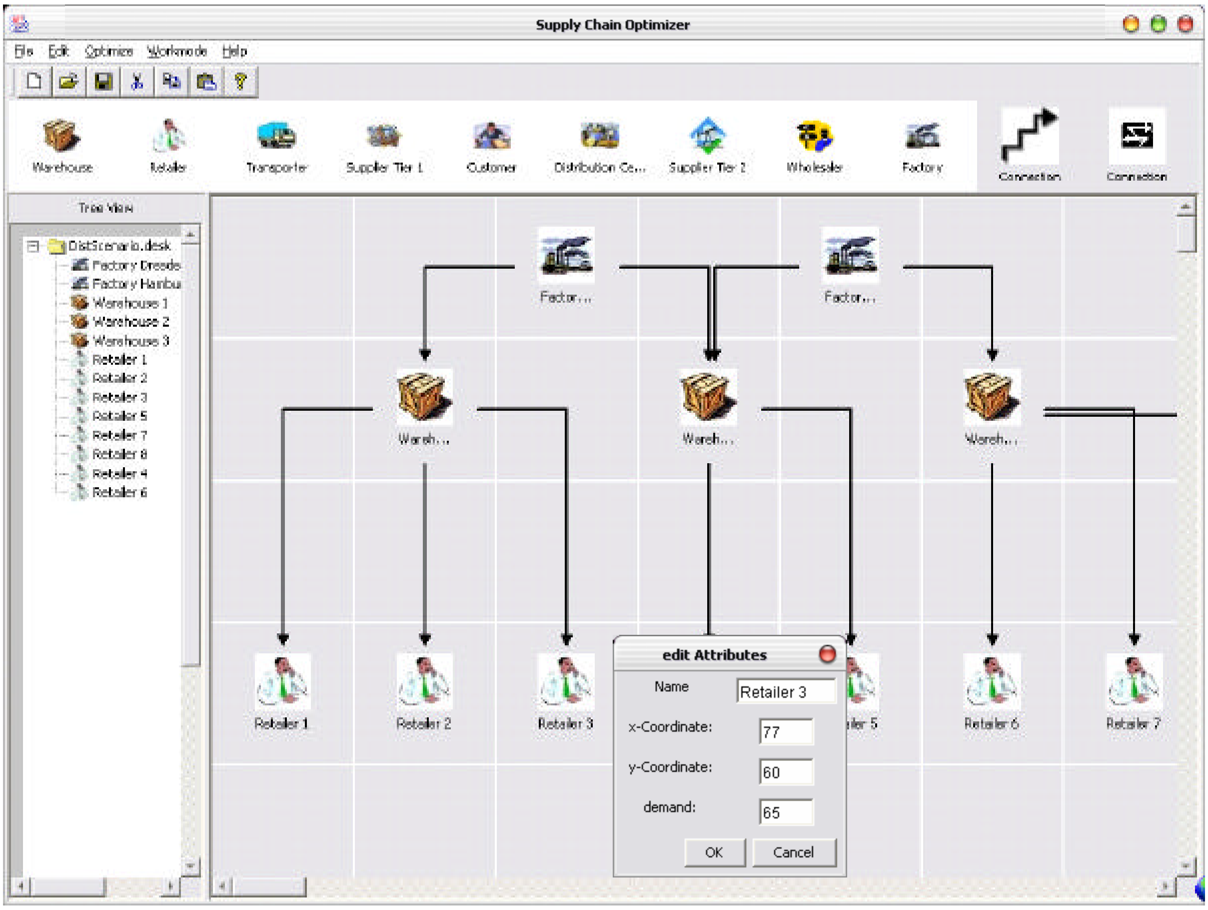

Figure 8. The modeling user interface of the SCOptimizer

Figure 8 shows the mask, in which the distribution scenario has been modeled. This is a single-product scenario as described in section 3.2. It contains two factories, which supply three warehouses with the product. These warehouses in turn supply their own customers with the product. The scenario does not describe routes but shows logical relationships. This means that, for instance, the first warehouse supplies retailer 1 through 3 with the product.

The second step of the simulation is the choice of a specific planning model and optimization or heuristic method. In the case of our distribution scenario there is a set of classes available that apply traditional methods in order to perform the transportation planning: Savings method (Clark & Wright

1964), Sweep-Algorithm (Gillet & Miller 1974), and Branch and Bound (Little, Murty, Sweeney & Karel 1963, Smith, Srinivasan & Thompson 1977).

Figure 9 shows the mask for choosing between available distribution planning methods. This mask is created at runtime and applies the description data contained in the XML files of those available classes.

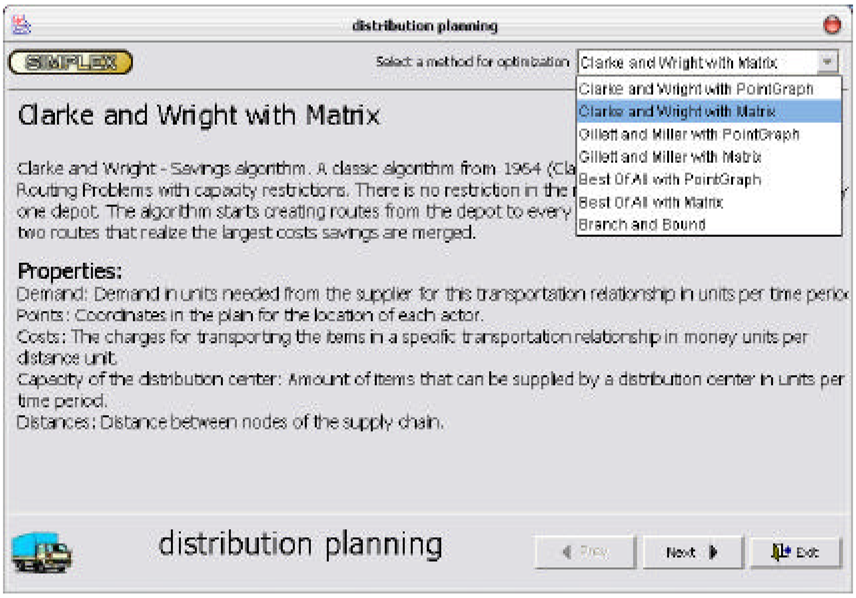

Figure 9. Selecting a planning method for distribution planning

The methods with point graph apply a single cost rate for every transportation relationship, while the methods with matrix apply specific costs for every relationship in the modeled scenario.

After choosing the method, the prototype parses its XML description and creates the input masks for the user to enter required information. Figure 10 shows the input mask for the savings method of Clarke and Wright with matrix.

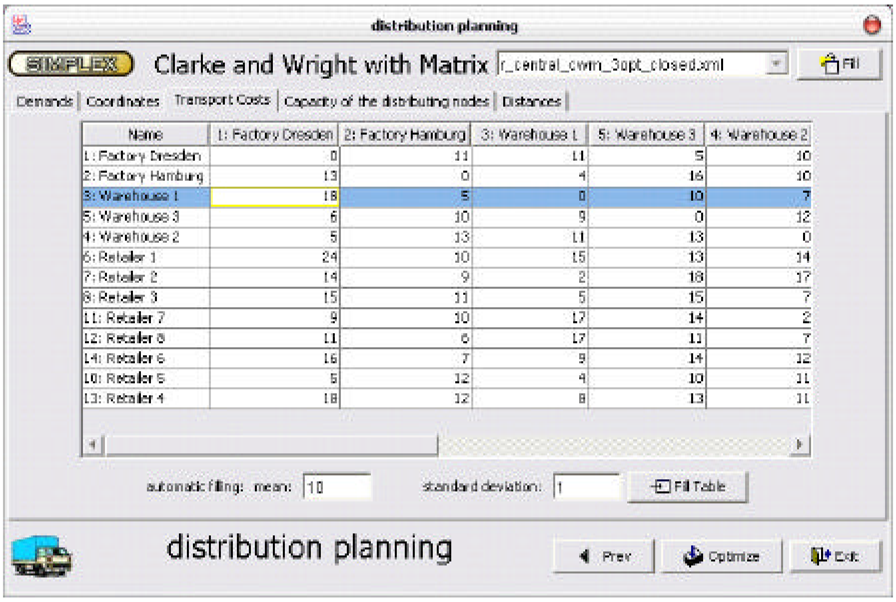

Figure 10. Input mask for the savings method of Clarke and Wright (1964) with matrix

Figure 10 shows the transportation costs per distance unit between the involved partners of the supply chain. After entering the required information, the user has to determine the following parameters:

- Improvement algorithm: Available are a 2-opt and a 3-opt algorithm.
- Tour characteristics: The choice is between closed or outbound tours.
- Tour dependent costs: The user has to determine the fixed costs of a vehicle and the maximum costs for a tour.
- Vehicle type: The user has to choose the type of vehicle that will be used for distribution to and from the distribution nodes (in our scenario we will focus on the three warehouses). The characteristics of the available vehicles are also stored in an XML file, for again avoiding programming effort when adding or removing vehicle types to the optimization methods.

In addition to that, the user has to determine if the planning takes place in a cooperative or a non-cooperative context. For this purpose the prototype provides a mask for choosing the cooperating actors in the supply chain (see Figure 11).

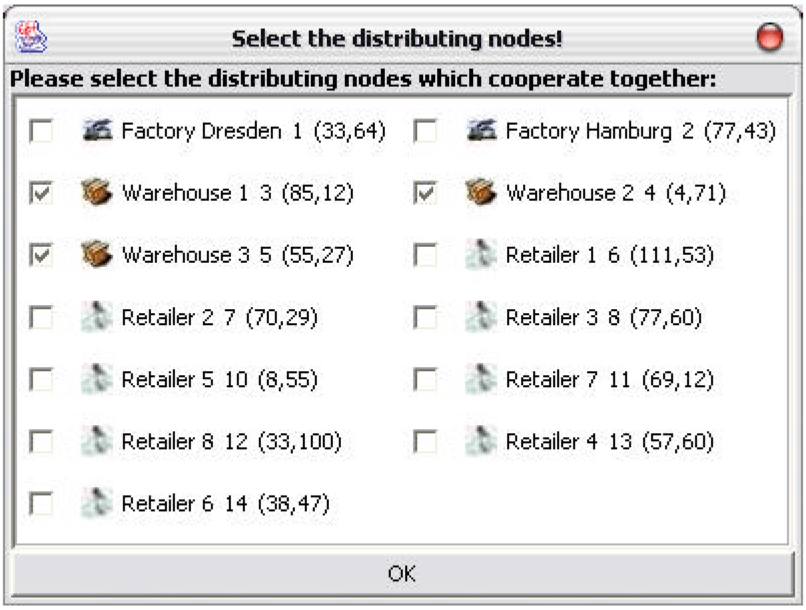

Figure 11. Mask for choosing cooperating actors in the supply chain

Figure 11 shows the settings for a simulation, where all three warehouses cooperate in the context of the distribution planning. This means that every supplied retailer will be assigned to the nearest warehouse. This is done by the optimization class by applying the Voronoi heuristics (see section “Cooperative vs. Non-Cooperative Planning”).

If the planner wants to simulate the non-cooperative context, he will choose just one warehouse in the mask shown in Figure 11. In this case there will be no reassignment of customers, only the chosen optimization or heuristic method will be applied. In our scenario, the non-cooperative simulation has to be done once for each distributing warehouse.

After running the simulation, the results can be displayed in a coordinate plane as shown in Figure 12 and Figure 13.

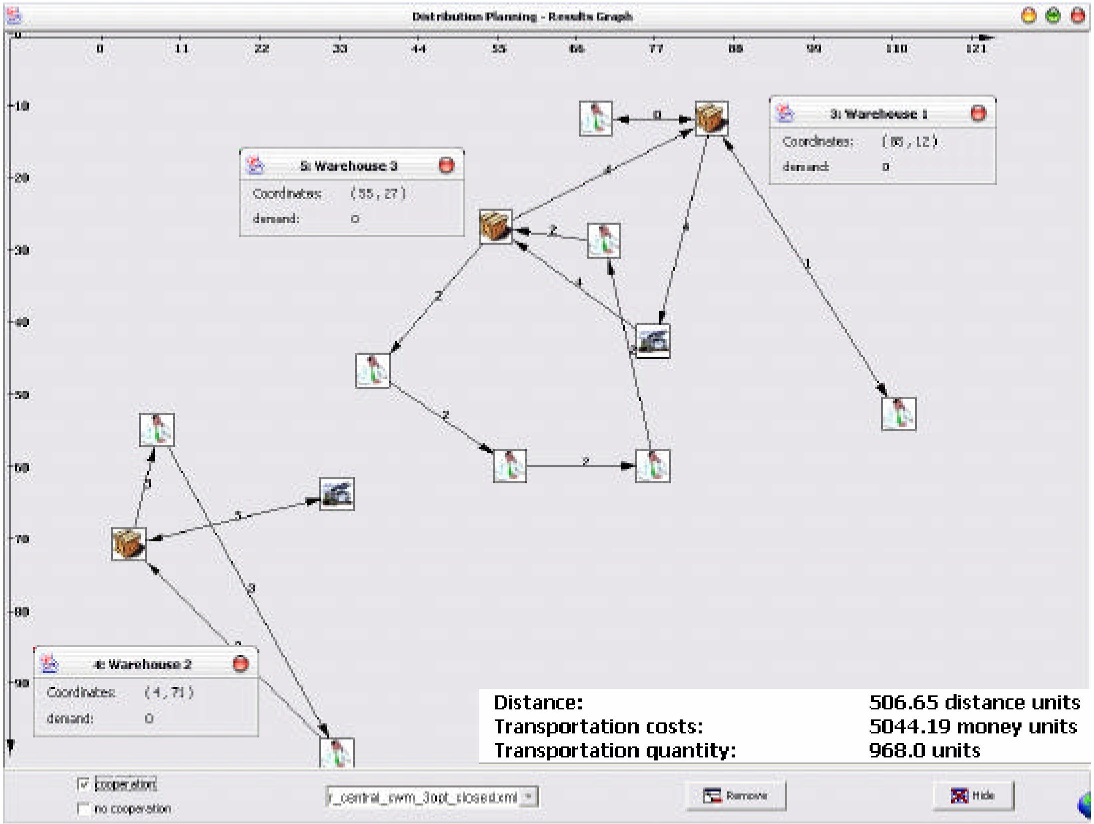

Figure 12. Graphical display of the cooperative distribution planning

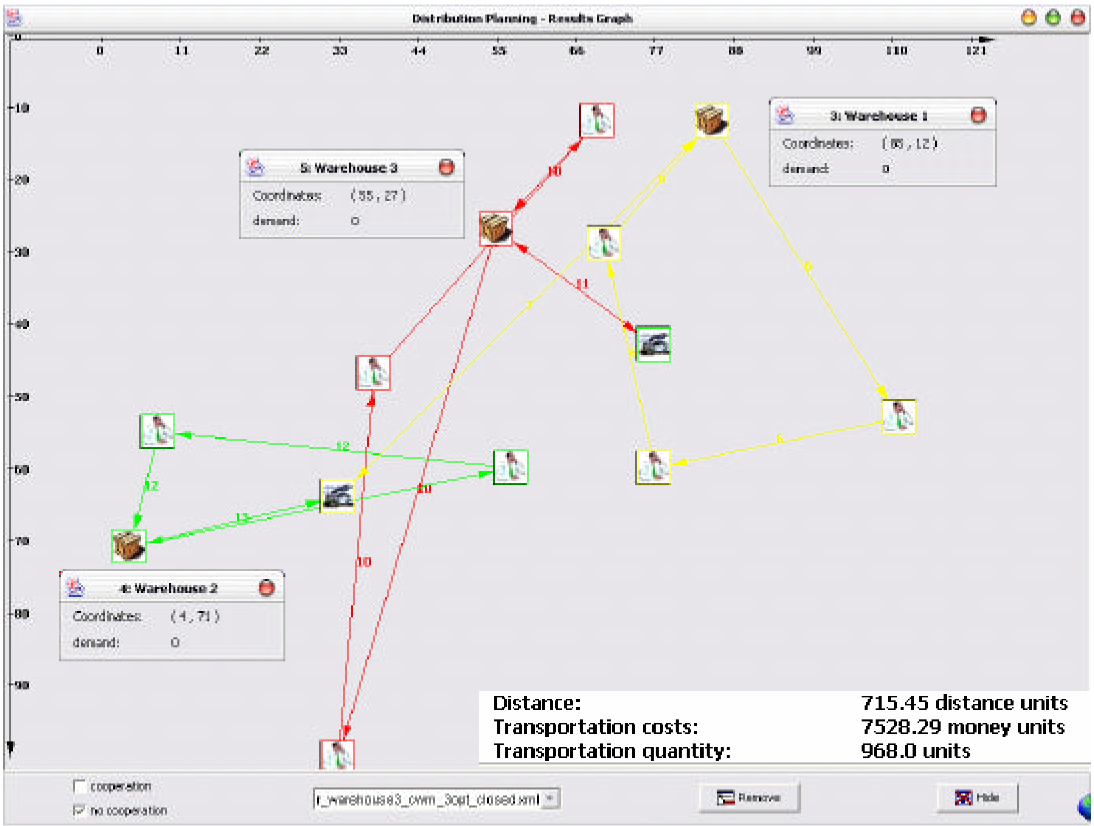

Figure 13. Graphical display of the non-cooperative distribution planning

Every calculated route is labeled with an identification number, which is unique and allows further analysis.

In the graphical display of the simulation results it becomes clear that the reassignment of retailers to the warehouses results in shorter tours. In addition, the factories now supply the nearest warehouses, which also reduces the total covered distance.

4.3 Interpretation of the Simulation Results

As mentioned before, the results of the simulation runs are stored in XML files. These can be parsed for comparison purposes, in order to analyze for example how much better is the cooperative result.

In our scenario the cooperative simulation generates a transportation plan with overall costs of 5,044.19. The non-cooperative context originates total costs of 7,528.29 (these costs are the sum of the costs of all transportation plans in the supply chain). This means that cooperation in such a scenario for distribution purposes would be convenient for the supply chain as a whole. This does not always mean that every cooperating institution performs better than without cooperation. This fact is one of the first problems that arise once the simulation level is left and a realization of cooperative planning in the industry is attempted (Hoffmann 1998, LaLonde 1998).

The 2,484.10 costs units that are saved in the cooperative context can be interpreted as the added-value of SCM software usage for planning the transportation in a scenario that uses the method described in the simulation. This means that the implementation of such software and the additional coordination and transaction costs should not exceed this amount. Otherwise the cooperative planning would not be of worthwhile.

5. Conclusion and Outlook

In this paper, we presented a prototype for simulating both cooperative and non-cooperative planning of logistics activities in supply chains. The goal was to compare the cost situation in the cooperative and non-cooperative context for the same supply chain scenario in order to provide clarity about the added-value of concerted logistics planning, i.e. of SCM. We also showed that there is an observable lack of clarity about the added-value of software based SCM in the European automotive industry.

As shown in this paper, the modeling and simulation of flexible planning of logistics activities is possible. Java and XML provide appropriate techniques for creating platform independent applications with open interfaces.

But there are further issues that we did not contemplate in our simulation model, which set other challenges to the cooperative planning in supply chains. We only considered costs within the optimization and heuristic methods; we did not take into account the detailed controlling in order to determine the actual overall costs implied with practicing SCM (Zäpfel & Piekarz 1996, LaLonde & Terrance 1996, Hendricks & Singhal 2001). We also did not go deeper into game theoretical aspects, in order to set the right incentives to make actors cooperate in the supply chain (Baker, Jensen & Murphy 1988). Furthermore, neither the coopetition aspect (Brandenburger & Nalebuff, 1996) nor the issue of how to share the common revenues of SCM activities were addressed (Jeuland & Shugan 1983, Tsay, Nahmias & Agrawal 1999, Cachon & Lariviere 2000).

Similar considerations apply to the legal context of the integration in supply chains. The definition of long-term international contracts represents a challenge that is often insuperable.

At this stage of development, the *SCOptimizer* supports the simulation of cooperative and non-cooperative distribution planning as well as non-cooperative inventory planning. In a next step we will implement the decentralized planning with information sharing as described by Wyner and Malone (1996). We are also currently working on the implementation of further planning models and methods for both purchase and location planning. More sophisticated planning methods for all planning areas will follow as well as additional algorithms, which are actually implemented in commercial SCM software like the Advanced Planner and Optimizer (APO) from the SAP AG. In a further step, the implementation of blackboard architectures for parallel optimization (Erman, Hayes-Roth, Lesser & Reddy 1980, Nii 1986, Corkill 1991, Carver & Lesser 1994) and the integration of optimization classes over the Web using Web Services (Apshankar, Sadhwani, Samtani, Siddiqui, Clark, Fletcher, Hanson, Irani, Waterhouse & Zhang 2002, Chappell & Jewell 2002) will be addressed.[3]

[3] We thank the referees for their comments and suggestions that have improved the presentation of this paper.

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