

## **A SIMULATION FRAMEWORK FOR ASSESSING THE PERFORMANCE OF COOPERATIVE TRANSPORTATION PLANNING ALGORITHMS**

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### **ABSTRACT**

In this paper, we suggest a framework that allows for the simulation-based performance assessment of algorithms for cooperative transportation planning. Therefore, we consider a coupling architecture that connects simulation models of the logistic system and the transportation planning algorithms. The center point of this architecture is a blackboard-type data layer between transportation planning system and the simulation engine. We provide detailed information on how the different subsystems communicate and how each system triggers events of the other systems. In a case study, we show how the suggested framework supports the required performance assessment.

### **1 INTRODUCTION**

Because of increasing crude oil prices novel approaches to solve transportation planning problems are quite important and attract many researchers from academia and industry. After developing new transportation planning schemes the performance of the corresponding algorithms have to be assessed.

Usually this is done by considering only a few static test instances (cf. Doerner et al. 2008 amongst others). However, we are interested in using performance measures that are the result of applying the transportation planning algorithms to the entire logistic system. Logistic systems are stochastic and dynamic whereas the transportation planning approaches are based on deterministic scheduling techniques. It is not clear what happens when applying deterministic transportation planning approaches to a stochastic and dynamic system. In order to close this gap we suggest to use discrete event simulation to emulate the logistic system. Simulation is able to capture the stochastic and dy-

namic nature of the logistic system. We have to embed the transportation planning approaches into a rolling horizon setting. Therefore, we have to solve a sequence of smaller transportation planning problems. Feedback from the logistic system can be taken into account for the construction of these transportation planning problems.

The approach of simulation-based performance assessment of transportation planning approaches is rarely discussed in literature. Ebben et al. (2005) use simulation to assess the performance of transportation planning approaches. However, there is no clear separation between the transportation planning approaches and the simulation engine. Simroth and Baumgart (2007) suggest a conceptual framework to assess the performance of dynamic transportation planning problems. However, no concrete implementation strategies for a simulation environment are described.

In this paper, we suggest a simulation framework that can be used to assess the performance of transportation planning approaches. Center point of our architecture is a generic blackboard-type data layer between transportation planning approaches and a simulation model that is used to emulate the logistic system. The simulation framework is an extension of a simulation framework suggested by the second present author (cf. Mönch et al. 2003 for details).

Our main goal consists in applying the framework to assess the performance of cooperative transportation planning approaches. This type of problems arise, for example, in the food industry where several food manufacturers are interested to share their vehicles to reduce fleet costs. We are interested to compare cooperate scenarios with non-cooperative scenarios. However, in both cases the logistic system is basically the same. Therefore, the usage of one simulation model makes sense. Furthermore, several centralized approaches have to be compared with decentralized approaches for the transportation planning problem.

The paper is organized as follows. In the next section, we discuss the domain researched in this paper. Then we derive several design criteria for the simulation framework. In Section 4, we describe the overall framework structure in some detail. We discuss the implementation of a prototype of the framework in Section 5. Finally, we provide a case study including the results of computational experiments for cooperative transportation planning.

## 2 DOMAIN DESCRIPTION

We are interested in solving transportation planning problems for the food industry. Several manufacturers with same customers but complementary food products collaborate by jointly using their vehicle fleets to reduce delivery costs (Pankratz and Steinlein 2008). The different products are delivered to first-class hotels. Therefore, small delivery quantities are typical and high on-time delivery performance is also an important goal.

There are different types of deliveries depending on the geographical location of the customers and the transportation capacities of each manufacturer. In the remainder of this paper a transportation order is a quantity of products that is sent to customers to fulfill customer orders. Transportation orders are assigned to vehicles. Each vehicle has to visit several customers to deliver its transportation orders. Each transportation order has a time window where it has to be delivered.

We differentiate three different cases for the organization of the corresponding deliveries:

1. In the simplest case, each manufacturer uses its own local vehicle to deliver products to customers that are closely located to the manufacturer. The location of a local vehicle is the location of the manufacturer. We call this delivery type delivery with own local vehicles.
2. Very often, some of the customers are far away. In this situation vehicles of a specialized shipping company are used to send the transportation orders to an intermediate distribution center where own vehicles of the manufacturer are used to deliver the transportation orders to the customers. This type of delivery is called delivery with own far away vehicles.
3. The third way consists of using the vehicle of a specialized shipping company to send the transportation order directly to the customers. This type of delivery is called delivery with couriers.

Manufacturers, intermediate distribution centers, and customers form a distribution network.

Note that of course the delivery with own local vehicles is the cheapest variant whereas the delivery with couriers is the most expensive one. The delivery with own far

away vehicles is between these two variants. The three different variants are shown in Figure 1.

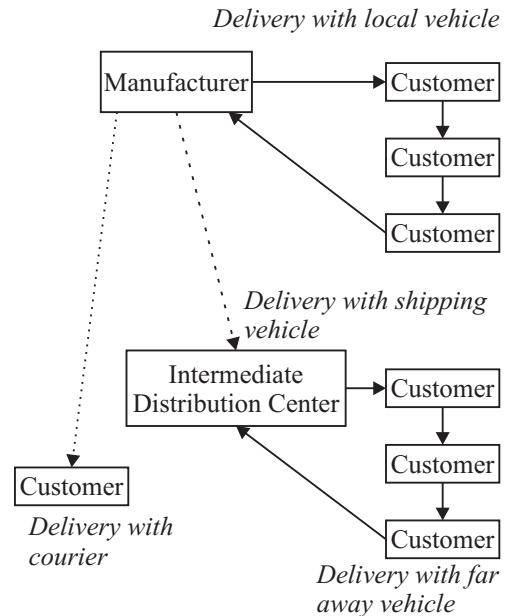


Figure 1: Distribution Variants

There are several ways to improve the efficiency of the transportation operations in the present situation. First of all it is possible to use the vehicles of the different manufacturers in each intermediate distribution center to deliver the transportation orders of all manufacturers to the corresponding customers.

The second possibility consists in sending first transportation orders of one manufacturer to another manufacturer and then using the local vehicles of the second manufacturer to deliver the products to the customers of the first manufacturer.

## 3 DESIGN CRITERIA FOR THE FRAMEWORK

In a real logistic system, a transportation planning system obtains its information via a message bus from operative information systems like Enterprise Resource Planning (ERP) Systems or position information directly from the drivers of the vehicles via GPS and computes transportation instructions based on these information. It stores the transportation information in a data base for evaluation purposes. Finally, the transportation planning system transmits the transportation instructions to the logistic system where the instructions are executed.

A set of transportation orders are assigned to a single vehicle. Customers that have to be visited are the result of these transportation orders. A sequence of these visits that is feasible with respect to due dates and work hours of the

driver is called a route. A tour is finally an assignment of transportation orders to a vehicle with a route. A transportation instruction consists of a set of tours.

Discrete event simulation can be used to emulate the logistic system. The simulation framework has to support the following tasks:

1. Mimic the behavior of the real logistic system that communicates with a transportation planning system,
2. Provide interoperability capabilities to plug in arbitrary transportation planning systems via a blackboard-type data layer. This includes especially the possibility to use both distributed and centralized transportation planning approaches.

The blackboard-type data layer is the center point of the suggested coupling architecture. It allows for a fast access to the data required for cooperative transportation planning because the objects of the blackboard reside in the memory of the computer.

Note that the suggested architecture is influenced to a certain degree by a similar performance assessment architecture for production scheduling approaches (cf. Mönch et al. 2003).

From a more technical point of view, we have to discuss interoperability issues for different software systems. The usage of text files for the coupling has to be avoided because of possible synchronization problems. Another possible approach consists in using inter process communication in the computer memory. A third approach is based on communication via network protocols. Because of the task to support also distributed transportation planning approaches the last approach is appropriate for our framework.

The framework can be used in the following situations:

1. assessing the quality of transportation plans with respect to certain performance measures related to the overall logistic system, for example, transportation costs, or on-time delivery performance,
2. investigation of appropriate planning horizons and time- and event-driven re-planning strategies,
3. investigation of the transportation planning software with respect to correctness.

#### 4 OVERALL FRAMEWORK STRUCTURE

In this section, we discuss the main components of the suggested architecture. Then we describe the required simulation environment. We provide some information on the design of the blackboard-type data layer in the last subsection.

#### 4.1 Main Components of the Architecture

The framework consists of six parts that are connected:

1. a transportation planning system that assigns transportation orders to vehicles of a certain manufacturer or a shipping company,
2. a simulation component that reflects the behavior of the real-world and simulates the logistic system,
3. a blackboard-type data layer that is between the transportation planning system and the simulation model,
4. a performance assessment component to calculate the values of performance measures for the logistic system,
5. a generator for transportation orders,
6. an initialization component that reads the model data from XML files and transmits them to the blackboard type data layer before start of the simulation.

The main components of the framework are shown in Figure 2.

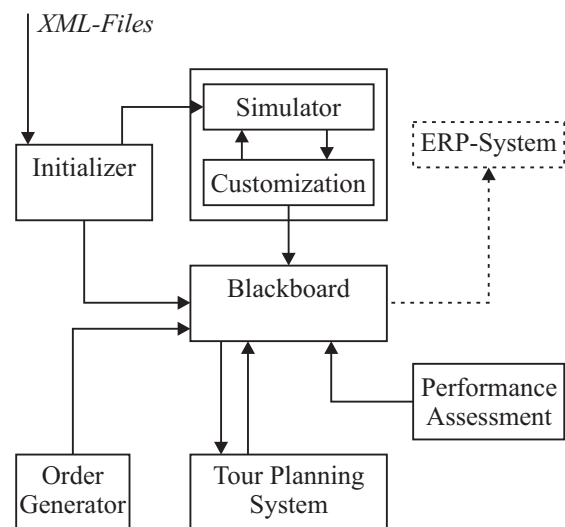


Figure 2: Components and their Communication

The suggested architecture mimics the situation found in a real-world logistic system. The simulation engine generates data that is sent to the blackboard that stores this information. A set of functions is used to replace the message bus and GPS in a real-world logistic system. These functions allow for a clear separation of data that resides inside the simulation model and data that is transferred to the blackboard-type data layer.

Our architecture has the advantage that we can easily split the transportation planning system and the simulation model. The transportation planning system needs only data

that is contained in the blackboard-type data layer to make transportation planning decisions. No internal data of the simulation model is going to be used for this type of decisions. The resulting transportation plans are stored in the blackboard. They can be used as reference data sets for re-planning activities.

## 4.2 Simulation Environment

The simulation environment is used to emulate the behavior of the real-world logistic system. Therefore, we have to select a simulation software that allows for model process characteristics of logistic systems.

We also need an event-based communication between transportation planning system and simulation model because we have to implement decisions of the transportation planning system into the simulation. This is done in the following way. When a vehicle has to make a decision then the corresponding transportation plan is requested from the transportation planning system. Vehicle decisions can be classified into tour assignment decisions for transportation orders and routing decisions.

The transportation planning system can be activated in an event-driven manner. When certain situations in the logistic system require a new transportation plan then the transportation planning system can determine such a plan. On the other hand, a time-driven activation of the transportation planning system is also supported. This feature is important for rolling horizon transportation planning approaches.

The simulation engine has to be the leading system that triggers the activation of the remaining components of the suggested architecture.

## 4.3 Design of the Blackboard-type Data Layer

The blackboard-type data layer is used to store information required by the transportation planning system to make transportation planning decisions. Its interface provides methods to manipulate the stored data and an input-output-interface.

A logistic system consists of several business objects. We differentiate between static and dynamic data. Static data is given by:

- a set of manufacturer,
- a set of customers for each manufacturer,
- a set of intermediate distribution centers that are run by shipping companies.

Dynamic data is provided by the following business objects:

- a set of transportation orders,
- a set of local vehicles for each manufacturer,

- a set of far away vehicles for each manufacturer,
- a set of vehicles for the shipping companies.

The black-board type data-layer is used in four different situations:

1. Initialization of the objects in the blackboard-type data layer at the beginning of the emulation. They are initialized with a distribution network that is defined by XML documents,
2. Update of the objects within the blackboard-type data layer in an event-driven manner during the emulation,
3. Reading of blackboard information by the transportation planning system to make transportation planning decisions,
4. Writing of results of the transportation planning system into the corresponding objects of the blackboard.

## 5 PROTOTYPE IMPLEMENTATION

We have to select a simulation engine that fulfills the requirements summarized in Section 4.2. AutoSched AP provides most of the required functionality. Therefore, we chose this simulator. An alternative approach is the usage of simulation kernels like Parsimony (Preiss and Wan 1999) or SLX. The SLX simulator has been adapted to simulate transport networks by Brill and Whitney (1997).

We develop two approaches to model the distribution network entities based on entities that AutoSched AP provides. Our first approach models the static business objects described in Section 4.3 using stations from AutoSched AP. Vehicle entities are represented by lots. Orders are modeled as objects within the blackboard. Static and dynamic entities that are related to transportation orders maintain a link to the corresponding order objects.

Furthermore, the transportation time between manufacturers and customers is modeled by a station for each vehicle. The delay time caused by the station corresponds to the transportation time from one node of the distribution network to another one. A dynamic routing takes place after a new node of the distribution network is reached by the vehicle. The described situation is shown in Figure 3.

In the second approach, transportation orders are represented by lots. Vehicles are modeled as stations that form a batch of lots for delivery, sort the lots with respect to its position in the intended route, process each lot with its transportation time from one node to the distribution network to the next one, and finally unload it. The second approach is presented in Figure 4.

The main advantage of the first approach is the degree of freedom in routing. Vehicles can be routed to each static entity of the distribution network quite easily.

The second approach allows for a more direct usage of knowledge about the production scheduling domain. Some

analogies between the production and the transportation domain are shown in Table 1.

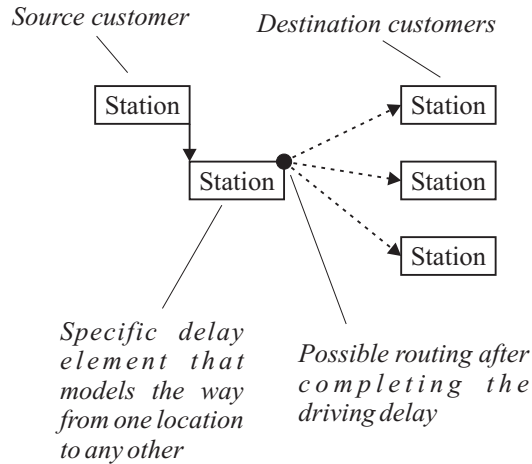


Figure 3: First Modeling Approach

Only the first variant is implemented so far within the preliminary prototype.

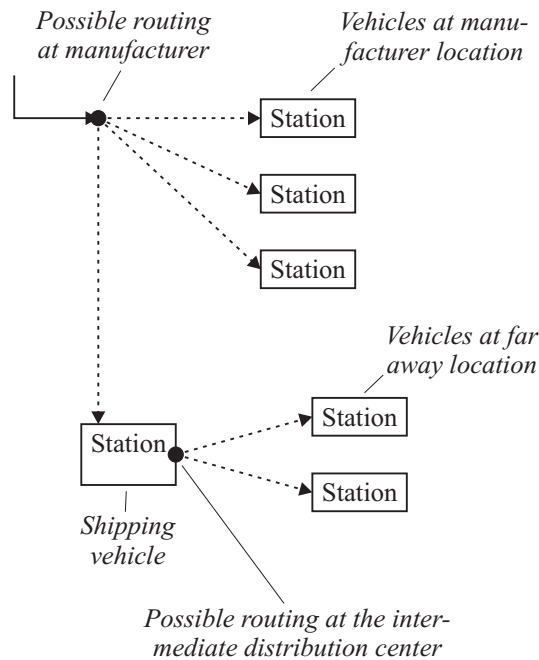


Figure 4: Second Modeling Approach

The prototype of the simulation framework is implemented in the C++ programming language. The individual components are connected via Microsoft COM+. This middleware is used because it is fast and programming language independent.

Table 1: Analogy Between Production and Transportation Domain

Production domain	Transportation domain
Assignment of lots to batches	Assignment of transportation orders to vehicles
Sequence dependent set-up times	Transportation to next customer based on route
Due dates for the lots	Time windows for transportation orders
Minimum number of lots in a batch before processing on a batch machine	Minimum load of a vehicle with transportation orders before starting its tour

Figure 5 depicts the COM+ architecture. The active components are the order generator, the initialization component, the performance assessment component, and the simulation engine whereas the other two components only react on calls of the clients. The communication between the blackboard-type data layer and the transportation planning component is bi-directional. These components work as both client and server.

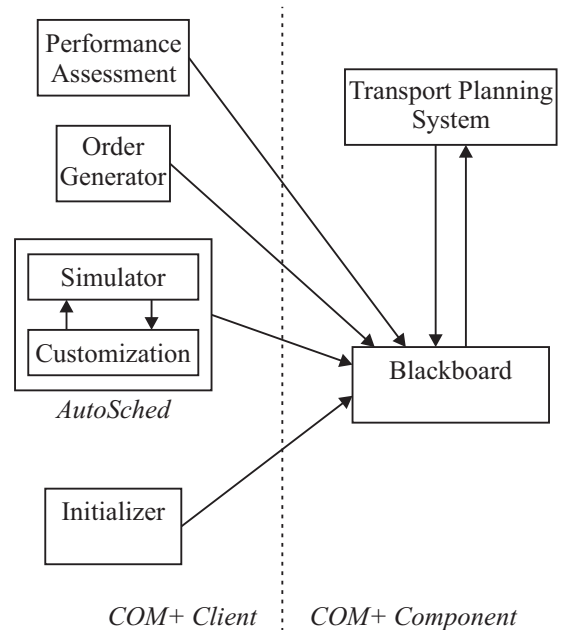


Figure 5: COM+ Layer Architecture

## 6 CASE STUDY

We present a case study where we apply the suggested framework to the performance assessment of cooperative transportation planning approaches. The transportation planning scenarios are described in the next section. The used simulation model is presented in Section 6.2. The used transportation planning approaches are discussed in

Section 6.3. We present the results of simulation experiments in Section 6.4.

### 6.1 Planning Problem

For the sake of simplicity, we consider only two manufacturers. Each of them has one intermediate distribution center that is delivered by couriers from shipping companies. We assume that only deliveries with own local and far away vehicles take place, i.e. the third case in Section 2 is excluded.

The planning scenario is based on a real-world data set that is collected in the German food industry. The considered customer network consists of 550 different customers. They are located in Germany as shown in Figure 6.

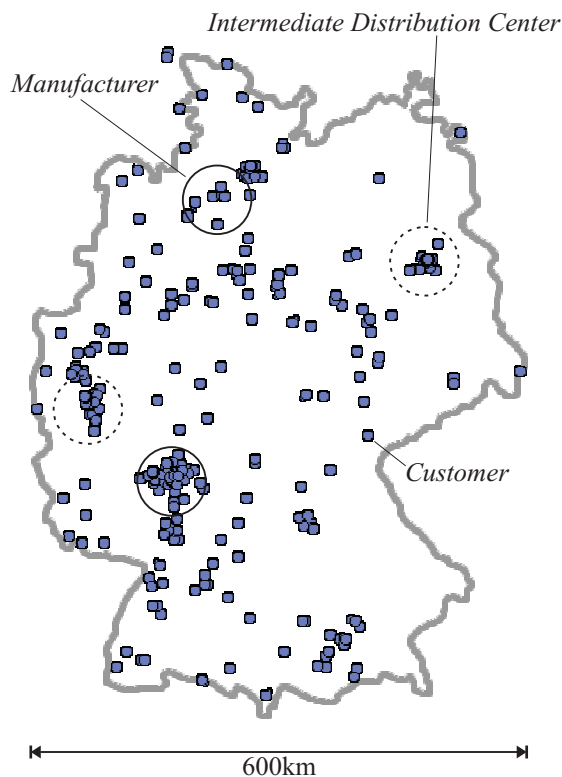


Figure 6: Distribution Network for Germany

The planning task consists in determining whether it makes sense when the two manufacturers use their vehicles in each intermediate distribution center to transport also the transportation orders of the other manufacturer or not. Therefore, we consider isolated and cooperative planning approaches for the following two transportation planning scenarios.

In the first scenario, the two manufacturers have ten local vehicles and seven vehicles at the intermediate distribution center. 26,282 transportation orders have to be delivered within one year. We expect reduction in transporta-

tion time and number of kilometers driven by the vehicles because appropriate transportation orders of the two manufacturers can be shipped together within one vehicle.

The second scenario includes one manufacturer with an overload of transportation orders sent to the customers. Hence, many transportation orders will be late. In contrast, the second manufacturer has only a few transportation orders. We expect a smoothing effect between overload and a workload that is too small.

Ten vehicles are used to perform the local delivery. The first manufacturer has seven additional far away vehicles assigned to its intermediate distribution center whereas the second manufacturer has only two additional vehicle in its intermediate distribution center. The total number of orders is also 26,282 within one year as in the first scenario.

### 6.2 Used Simulation Model and Performance Measures

We simulate one year. In our experiments, a warm-up period of ten days is selected.

The transportation orders used in the simulation experiments are generated in the following way. Incoming orders are concentrated in the morning. Therefore, we use for the ready date  $r_{ij}$  of the transportation order  $j$  for manufacturer  $i$  the expression

$$r_{ij} \sim U[24k, 12\alpha + 24k], k = 0, \dots, 365, \quad (1)$$

where we denote by  $\alpha \in (0, 1]$  a parameter that controls how early in the morning the transportation orders are ready. In our experiments we use  $\alpha = 0.50$ .

Due dates are chosen in a similar way. We use the following expression for the due date of transportation order  $j$  of manufacturer  $i$ :

$$d_{ij} - r_{ij} \sim U[dist, dist + \beta u], \quad (2)$$

where the quantity  $dist$  denotes the smallest time that is necessary to send the transportation order  $ij$  to the customer. The quantity  $u$  is an appropriate upper bound for due dates. The parameter  $\beta \in (0, 1]$  controls the tightness of the due dates. Here, we use the values  $\beta = 1$  and  $u = 3$  days in our experiments. Note that in a more realistic setting time windows have to be constructed for each transportation order based on expression (2).

We are interested in the total number of driven kilometers and the total transportation time. Furthermore, we measure the total number of on-time and late transportation orders in our experiments.

### 6.3 Planning Approach

We determine transportation plans with a horizon of ten hours every three hours starting at 8 am each day until noon. The following simple decomposition heuristic is used to calculate the plans:

1. **Decomposition into zones:** The distribution network is segmented into different zones. We obtain a zone by assigning each customer to the nearest distribution location, i.e., either a manufacturer or an intermediate transportation center.
2. **Initial tour formation:** The assignment of transportation orders to vehicles is performed individually for each distribution location. Load constraints and constraints related to the maximum number of hours of work are taken into account. An Earliest Due Date (EDD) type policy is used for choosing transportation orders. Starting with one initial transportation order, the vehicle is filled with transportation orders that have customers that are closely located to the customers of the initial transportation order.
3. **Route Selection:** We have to select a route for each vehicle. Therefore, we have to solve a traveling salesman type problem with additional soft due date constraints. Because of the NP-hardness of the traveling salesman problem we have to look for efficient heuristics. In this research we use a simple rule that is inspired by the Apparent Tardiness Cost (ATC) dispatching rule in manufacturing (cf. Pinedo 2002). Starting from an empty sequence of customers to be visited, we choose the next customer location by the following rule:

$$I_{ij}(t) := \frac{1}{t_{ij}(l)} \exp\left(-\frac{\max(d_{ij} - t_{ij}(l) - t, 0)}{\bar{t}}\right), \quad (3)$$

where we denote by  $t_{ij}(l)$  the time that is required to drive the vehicle from the previous customer  $l$  to the customer that corresponds to the transportation order  $ij$ . Here, we denote by  $\bar{t}$  the average transportation time from one customer to a second one. The current time is denoted by  $t$ .

Note that in case of the cooperative planning approach it is sometimes a good strategy to send transportation orders from the first to the second manufacturer to use the local vehicles of the second manufacturer.

### 6.4 Results of Computational Experiments

The results of the first scenario are depicted in Tables 2 and 3. The results show that the cooperative planning ap-

proach is about 25% better than the isolated one with respect to the required driving time of the vehicles.

Table 2: Driving Time and Distance for the First Scenario

	Total Time (thousand h)	Total distance (Mio km)
<b>Cooperative</b>	52	5.0
<b>Isolated</b>	38	3.5

Table 3: Delivery Delay for the First Scenario

	Isolated Scenario		Cooperative Scenario	
	On-time	Late	On-Time	Late
<b>Manuf. 1</b>	95%	5%	96%	4%
<b>Manuf. 2</b>	87%	13%	92%	8%

The results of the second scenario are presented in Tables 4 and 5. The number of orders that are delivered on-time of the second manufacturer increases in the cooperative scenario, whereas the vehicle utilization of the second manufacturer is increased.

Table 4: Driving Time and Distance for the First Scenario

	Total Time (thousand h)	Total distance (Mio km)	Orders delivered
<b>Cooperative</b>	35	3.3	22,572/ 26,282
<b>Isolated</b>	38	3.5	26,282/ 26,282

Table 5: Delivery Delay for the Second Scenario

	Isolated Scenario		Cooperative Scenario	
	On-time	Late	On-Time	Late
<b>Manuf. 1</b>	95%	5%	96%	4%
<b>Manuf. 2</b>	27%	73%	92%	8%

## 7 CONCLUSIONS

In this paper, we described a simulation framework for assessing the performance of cooperative transportation planning approaches. We derived several design criteria for such a framework. A prototype implementation based on the simulation engine AutoSched AP is described. One of the advantages of the suggested framework is the clear se-



paration between the transportation planning approaches and the simulation models. Hence, we ensure reusability of the transportation planning software because we do not need to implement the algorithms within a proprietary simulation software.

There are several directions for future research. We are interested in encapsulate the transportation planning algorithms into staff agents of the ManufAg multi-agent-system framework (Mönch and Stehli 2005). Therefore, we have to couple multi-agent-systems based on ManufAg with our simulation framework. This approach allows us to assess the performance of a broad class of transportation planning schemes ranging from completely centralized to fully decentralized approaches.

It seems fruitful to combine ant colony optimization approaches for transportation planning (Doerner et al. 2006) with software agents. However, carry out all the necessary details is part of future research.

It seems to be possible to investigate and answer more strategic logistic system design questions like what is an appropriate number of vehicles or immediate distribution centers. Here, we believe that simulation-based optimization approaches have to be applied. Again we can use the suggested simulation framework in this situation.

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