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Dynamic Transport Reference Scenarios

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Introduction

Reference scenarios are a common technique in simulations allowing the evaluation and comparison of different algorithms and approaches. For transport logistic processes these approaches can be for example different strategies to select the packets to be loaded.
Different reference scenarios are required ranging from simple scenarios for easy understanding the effects up to complex and realistic scenarios comprising all major factors to be considered. As the focus here is on dynamic transport problems, the scenarios should facilitate representation of such dynamics.

Traditional scenarios

There are few scenarios which are commonly used to model logistic transport processes. Well-known examples are the Solomon Instances (Solomon 1987) and scenarios derived from them. The Solomon Instances are scenarios for so-called “vehicle routing and scheduling problems with time windows”. They consist of a list of orders, their locations and their time constraints and of a set of vehicles that have to serve the orders. Derived scenarios can also be used for “pickup and delivery problems” when pairs of orders from the original scenarios are combined to orders that have to be picked up in one location and delivered to another. However, these scenarios have major drawbacks for modelling dynamic transport processes as investigated in the CRC:

- They assume direct connections between all locations in the scenario.
- They are not dynamic in the sense that all destinations and transport orders are known in advance.
- No "travelling obstacles" such as traffic jams or road closures are assumed.

This leads to the conclusion that the traditional logistic scenarios are not suitable for the investigation of dynamic transport processes. Therefore, new scenarios have been developed and are presented here. The scenarios describe all relevant elements of the logistic transport process.

Components of dynamic transport logistic scenarios

In the following, the terms for the description of a general model for dynamic multi-modal transport networks are defined. The set of terms described here build the basis for the description of scenarios.

A model of a transport network has to represent on the one hand the infrastructure, i.e. the route network, the trans-shipment points, storage facilities and other locally fixed objects which can be shown on a map or a weighted network graph. For the representation of the route network, directed graphs are used, so parts of the terminology (vertex, edge) originate from graph theory. On the other hand, the model has to represent the movable parts of the transport process, i.e. the goods to be transported (packages) and the carriers for these goods (vehicles). Three elementary information carriers, order, suborder and shipment are introduced, which can be assigned to different packages or groups of packages. These elements permit the representation of data related to the packages including the possibility that packages can be aggregated to larger load units for sections of the transportation route taking into consideration that a given transport order can include goods for several destinations. In the following, the components of the model and their characteristics are briefly described.

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Vertices

Vertices in general are static points in the network where two or more edges meet. At vertices, load bundling/unbundling and trans-shipment tasks can take place.

The description of a vertex includes the definition of functional units located inside the vertex, like storage facilities and trans-shipment possibilities. In a multi-modal network, the transition between edges of different types in a vertex is closely linked with trans-shipment processes.

Possible types of vertices:

- Pure furcation point: A pure furcation point is a vertex without storage or trans-shipment facility, load or unload possibility. A vertex of this type, however, permits route continuation in different directions.
- Pure trans-shipment point: This is a location where only trans-shipments can take place, but the direction of travel cannot be changed. For example, this is a port where a (one way) street is terminating. The arriving trucks wait (requiring parking capacity) until a RORO[1] ship with free transport capacity arrives and transports them over water to the next vertex (harbour) where the trucks can leave the ship.
- Multi-modal vertex with limited trans-shipment possibility: This is a type of vertex which generally allows transport mode changes, but might have restrictions concerning mode change directions due to the limitations of available equipment. An example is a train station located at a road which has the capability to transfer loads from trucks to trains, but not from trains to trucks or from one truck to another.
- Pure storage vertex: A vertex which just provides storage functionality. An example for a storage vertex can be a highway car park where trucks can wait for the duration of the weekend driving ban[2]. Trans-shipment possibilities or route forks do not exist in general.

Sources and sinks

Sources and sinks are special vertices or functional units assigned to vertices of a network. A source is the sender of a package and a sink is the re-

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[1] Roll-On/Roll-Off, a type of ship where vehicles (cars, trucks, sometimes also trains) can directly drive onto the deck

[2] In Germany, heavy trucks are not permitted to drive between 0h and 22h on Sundays and public holidays, except for transports of fresh food like fish, milk, vegetables.

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ceiver of the package. The function of a source is to generate transport orders, suborders or shipments and the packages assigned to these orders. The rules, lists or distributions with which transport orders are generated at a source strongly depend on the logistic scenario considered.

Sinks receive packages and complete the transport orders. Once a transport order is completed, the order and the related packages are removed from the network. Sources and sinks have to be able to store packages until a vehicle with adequate space picks them up or an order is completed.

Edges

The physical connections between vertices, like roads, railways or water ways are named edges. All edges are considered to be directed. An edge therefore has an origin and a destination vertex and a fixed length. In addition, it carries information about permitted transport velocity which usually depends on the type of vehicle and the time of the day.

In multi-modal transport networks, different types of edges are possible. This leads to the possibility of having several directed edges of same or different types between two vertices, which can even be absolutely equivalent for certain types of vehicles.

Vehicles

All means of transport carrying packages along edges of a network are called vehicles. Vehicles are limited in number and can not arbitrarily enter or leave the scenario.

Each vehicle is assigned a type, e.g. ship, aircraft or truck. Each type can have further sub-type specifications, e.g. container truck (for a special type of container), hazardous material truck with special trans-shipment equipment, etc. The type of vehicle contains attributes to give vehicle dependant information about the goods the vehicle can carry and the conditions under which these goods can be transported and (un-)loaded. Further, the type implies the ability to use certain edges.

The speed with which the goods can be transported is at least limited by a maximum speed assigned to the vehicle. Further, a vehicle has a defined load capacity. A vehicle in use can have its capacity unused, partially used or fully used, depending on the orders the vehicle is carrying out.

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Packages

Each form of transport good in a fixed packing is called a package. This means, in the model, a package is the smallest unit of goods to be transported. The kind of content of a package which can imply special transport conditions and treatment during trans-shipment (e.g. frozen goods, hazardous goods etc.) is described by its type.

A package has volume and mass - or more generally, it occupies load capacity of a vehicle during transport and storage capacity during intermediate storage. Packages undergo processes of load forming in the logistic context. In the presented formalism, this load forming (bundling) is expressed using the concepts of orders, suborders and shipments.

Orders, suborders and shipments

The concept of a transport order as a model component provides information which is mandatory for the description of a logistic network. The transport order contains all the information needed for carrying out the transport of a package or a group of packages. In addition, the order may contain several suborders. There is the possibility also to specify the desired contractor if necessary.

The original order of the transport goods is generated at its source. An order is generated when there is a need to transfer goods from one location to another. For each package, there is a related transport order which contains the information needed for the execution of the transport. An order is generally completed at the destination, which is the relevant sink. The order is completed only after all the packages belonging to the order have reached the sink and have been grouped together.

Shipments are information objects describing the non-interrupted transport of a fixed amount of goods between exactly two nodes and using exactly one vehicle. This means that the shipment is only temporarily existent and it is assigned to the vehicle that is processing this shipment. As a vehicle can transport packages from different orders simultaneously, a shipment can contain packages from several orders and suborders.

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Evaluation criteria for transport scenarios

When investigating the quality of an approach, there is the need to evaluate its performance levels with respect to the aspired goals. Therefore a set of evaluation criteria is required. Considering transportation logistics, the goal is to achieve a high logistic efficiency, i.e. high performance at low cost. Two sets of possible evaluation measures are introduced in the following:

Volume-related measures

- Queued packages: This is the number of packages that are located at a vertex and waiting for transport. The higher this number, the more storage is required at a vertex, resulting in increased cost.
- Inactive vehicles: The number of inactive vehicles can be seen as a measure for efficient vehicle usage. If there is a constant number of inactive vehicles in a simulation, this means the proposed approach needs less than the allocated number, indicating potential for cost saving.
- Vehicle utilisation: This indicator gives the capacity utilisation of the active vehicles. High utilisation means the vehicles are well loaded most of the time, and there are only few empty trips.

Process-related measures

- Throughput time: This is the time from the generation of packages up to the completion of the transport order. It is an absolute measure for the completion without considering whether all the requirements given in the order are met or not.
- Punctuality rate: This is the percentage of orders that are completed in time. A high punctuality rate is one of the key measures of an efficient transport process.
- Distance per package: This compares the actual distance taken by a package with the minimum distance between source and sink. This way, it is possible to evaluate how “straight” the transport path is. Longer distances imply higher costs and increased risks for the packages.
- Trans-shipments per package: Every trans-shipment operation means risks and added costs. Therefore the number of trans-shipments should be kept as low as possible.

Most of the measures introduced here need to be used in conjunction. Otherwise, the overall performance could be bad regardless of one or two

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measures being good. For example, the vehicle utilisation could be kept high by carrying packages around on unnecessarily long trips, leading to bad values in other measures such as the throughput time and distance per package and thus decreasing the overall performance.

Economic measures are not explicitly included in the described set. However, they depend on the aforementioned volume- and process-related measures. To derive an economic evaluation for the investigated logistic scenarios, additional cost models are required that map the described measures to costs and revenues. Such models are beyond the scope of this chapter.

Example scenarios

Based on the definitions of components as described above, reference scenarios have been generated. For modelling of logistic processes, they comprise all relevant components, such as location and functionality of vertices, edges, type and initial position of vehicles and distribution of packages. Two selected scenarios, the small 4-vertex scenario and the larger Germany scenario, are described in the following subsections. The 4-vertex scenario is designed for basic testing and understanding the impact of algorithms and approaches. The Germany scenario is based on cities and motorway connections in Germany, it is needed especially for complex investigations, e.g. routing algorithms requiring the existence of multiple routes. These scenarios are intended to be used as extensible basis for investigations of dynamic logistic processes.

The 4-vertex scenario

The network used as the physical base of this scenario is shown in Figure 1. This network has only four vertices and the edges are of different types such as Highway, Road, and Railway, representing the multi-modality even in this small example scenario. An arbitrary number of vehicles of four different types can exist in the network and carry packages according to their specifications.

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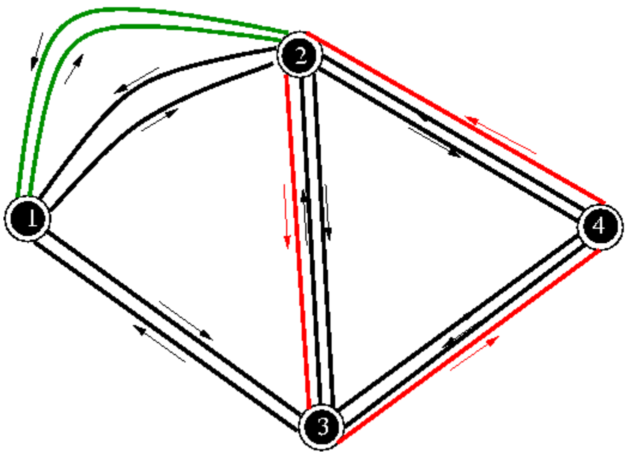

Figure 1. The 4-Vertex Scenario Topology

The network contains four vertices, numbered 1 through 4. These vertices are start or end points of different edges, and represent sources and sinks of transport goods and have various trans-shipment facilities. It is supposed that a vehicle arriving at a vertex can change to any other edge present in that vertex, given the edge accommodates that vehicle. Table 1 lists the vertices along with their properties.

Table 1. Vertex properties in the 4-vertex scenario

Vertex ID	Type	Trans-shipment type	Trans-shipment capacity [pu/h]	Trans-shipment cost per unit
1	General	Road→Road	23	1
2	General	Road→Road	40	1
		Road→Rail	100	5
3	General	Road→Road	50	2
		Road→Rail	25	3
		Rail→Road	80	3
4	General	Road→Road	120	4
		Road→Rail	42	4
		Rail→Road	70	4

The table also contains the trans-shipment options for each vertex. The capacities in package units per hour [pu/h] apply only to real trans-shipment operations. A fixed loading/unloading time of half an hour is ap-

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plied at each of the sources/sinks irrespective of the number of packages handled. It should be noted, that the transport mode of a package cannot be changed in all directions in every vertex. It is assumed that all vertices have unrestricted storage capacities for intermediate storage both for vehicles and for packages. Thus vehicles that are not involved in transport operations must idle at a vertex.

Table 2. Source properties in the 4-vertex scenario

Source ID	Location (Vertex)	Output rate [pu/h]	Destinations	Requirements (package type)
S1	1	10	40% --> 2 30% --> 3 30% --> 4	none (A)
S2	1	12.5	30% --> 2 20% --> 3 50% --> 4	cooling (C)
S3	3	15	40% --> 1 60% --> 4	none (A)
S4	4	10	70% --> 1 30% --> 2	careful handling (B)
S5	4	2.5	100% --> 1	none (A)
S6	4	25	50% --> 1 50% --> 3	cooling (C)

Sources in the sample network are the points where new packages and their "transport orders" are generated. The sources and their properties are given in Table 2. All sources are located in already existent vertices of the network and the arrivals of packages are modelled as a Poisson process (a discrete memoryless process (Trivedi 2002)). It is further assumed that a source has an unlimited waiting space where the packages can be stored until a vehicle picks them up and transports them to their destinations. As shown in table 2, the sources are not uniformly distributed over the set of vertices and their output rates are different. This allows the investigation of unbalanced load conditions. In this scenario, all vertices act as sinks, as the source specifications include all vertices in the „Destinations“ column (see Table 2).

For simplicity, it is assumed that there is only one general form of freight that should be transported, namely packages of unified size. Each package belongs to one of three different types, A, B, or C depending on handling requirements and risks involved (see Table 5 for definition of the package types).

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Three different types of edges are present in the network: Simple road, highway and railway. While simple roads (green colour in the figure) and highways (black) are bidirectional connections between vertices usable for vehicles of class S, the railway (red) is a ring which is uni-directional and can be used only by vehicles of type R (for vehicle parameters see Table 4). The parameters for edges, especially the path length and the allowed maximum velocity, are given in Table 3.

Table 3. Edge properties in the 4-vertex scenario

Edge ID	Start Vertex	End Vertex	Type	Length	max. Speed
E1	1	2	Highway	370	100
E2	1	2	Road	300	80
E3	1	3	Highway	250	100
E4	2	1	Highway	380	100
E5	2	1	Road	300	60
E6	2	3	Railway	400	80
E7	2	3	Highway	480	100
E8	2	4	Highway	490	100
E9	3	1	Highway	250	90
E10	3	2	Highway	400	100
E11	3	4	Railway	700	180
E12	3	4	Highway	770	100
E13	4	2	Highway	450	100
E14	4	2	Railway	500	120
E15	4	3	Highway	700	100

For vehicles, a maximum transport capacity and speed is defined. The routes of the vehicles except for the trains and their loading priorities are not predefined. The trains travel only in a closed ring in one direction.

The vehicles available in the scenario are characterized by the attributes given in Table 4. The number of vehicles and their capacities are over-dimensioned for the load that is given in the scenario. This means if an approach fails to handle the load with the given vehicles, it can be considered being very inefficient. Efficient approaches can do with far less than the given number of vehicles.

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Table 4. Vehicle properties in the 4-vertex scenario

Vehicle IDs	# of Vehicles	Type	Capacity [pu]	max. Speed	Allowed Edge Types
V01 .. V20	20	Light Truck	60	120	Road/Highway
V21 .. V25	5	Cooling Truck	100	100	Road/Highway
V26 .. V40	15	Truck	200	80	Road/Highway
V41 .. V44	4	Freight Train	2000	200	Railway

If a vehicle arrives at a vertex, the scenario allows the following actions: It can deliver packages at a sink, load new packages from a source, do trans-shipment operations by unloading a number of packages and loading other ones, wait or continue its route. In trans-shipments the specified rates and restrictions given in Table 1 apply.

As mentioned above, a relatively simple concept of packages is used in the scenario, where the only variable relevant for transport is the number of packages. However, some risks and special transport requirements are assigned to packages in the model. Therefore, three types of packages are introduced and defined in Table 5.

Table 5. Package types in the 4-vertex scenario

Package Type	Required Vehicle Type	Specialties
A	any	no specialties
B	any	5% risk of breaking during trans-shipment, 0.5% risk per hour of breaking during train transport
C	cooling vehicle	destroyed when transported in a non-cooling vehicle

The Germany scenario

The Germany scenario is based on a network of 18 cities in Germany, as shown in Figure 2. The edges between the vertices represent highway connections between those cities. This makes the scenario a single-mode scenario limited to highway traffic. The edges are directed. However, in figure 2 the directions of the edges are not shown for simplicity, and each link in the figure stand for two edges, i.e. one per direction. Thus, there are a total of 70 edges in this scenario.

In contrast to the small scenario described earlier, this scenario gives more choices for alternative routes, especially between vertices far away from each other. Therefore, it is well suited for investigation of routing algorithms. Some investigations have been completed using this scenario effectively (Wenning et al. 2005, Becker et al. 2006).

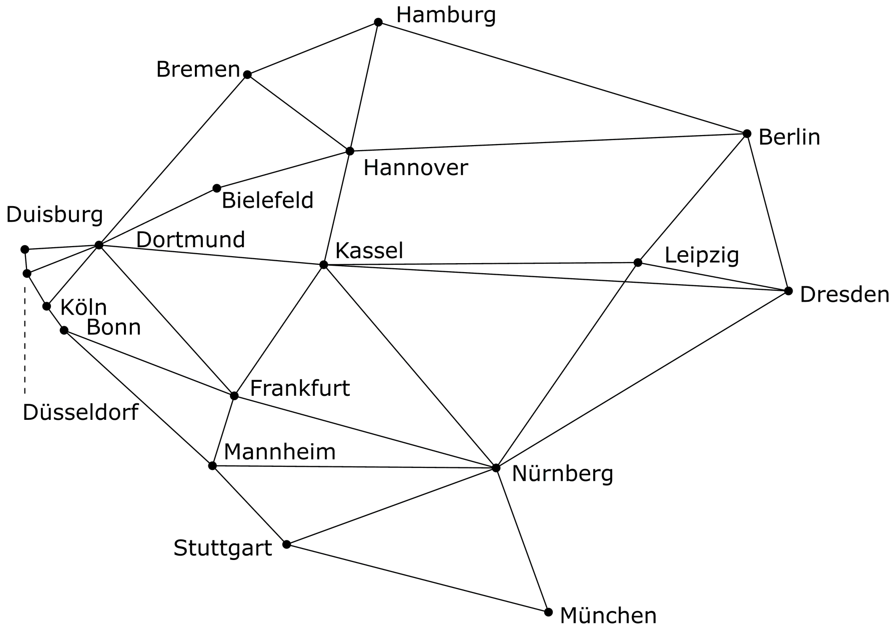

Figure 2. The Germany scenario

Each of the vertices in this scenario is origin for some packages and destination for others, which means that there is a package source at each vertex, and each vertex is acting as a sink. The output rate of the sources depends on the size of the city, ranging from 2 pu/h in Kassel up to 34 pu/h in Berlin. The vehicle distribution also depends on the city size. In total, there are 71 vehicles, each with a capacity of 60 pu and a maximum speed of 120 km/h. The basic version of the scenario assumes a fixed maximum edge speed of 100 km/h, but it provides the opportunity to introduce random occurrence of traffic jams individually for each of the edges, specified by an occurrence probability, an average delay that each vehicle experiences and an average duration of the traffic jam.

In addition to the logistic network, this scenario is overlaid with a definition of the communication capabilities on the edges. All edges are fully covered with GPRS, and partially covered with UMTS. Figure 3 shows the

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GPRS (blue) and UMTS (red) coverage. The idea behind the integration of communication capabilities is to simulate also the communication volume that arises from the autonomy and cooperation of the logistic components. This way, the simulations can also be used to study aspects concerning the wireless traffic that is generated.

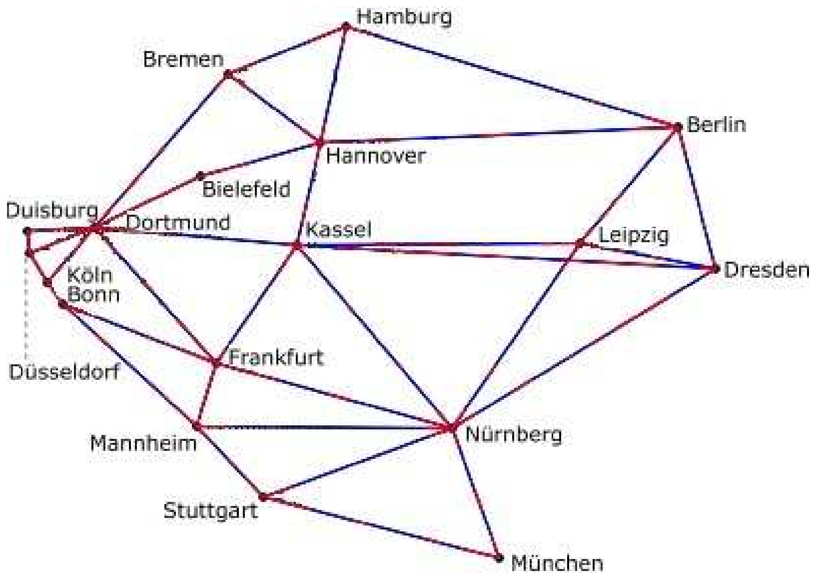

Figure 3. GPRS (blue) and UMTS (red) coverage in the Germany scenario

The use of this scenario and its components, with especial emphasis on communication parts, in a discrete-event simulation is presented in detail in (Becker et al. 2005).

Summary

In this chapter, components for modelling of dynamic logistic networks have been introduced and evaluation parameters have been listed. Two example scenarios are given which can be used for the evaluation of approaches in these dynamic networks. These scenarios are examples that might not contain all aspects relevant for a specific approach, but they can easily be extended or other scenarios can be created based on the defined components.

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