HIERARCHICAL MESOSCOPIC SIMULATION MODELS OF PARCEL SERVICE PROVIDER NETWORKS

Björn Erichsen[a], Tobias Reggelin[b], Sebastian Lang[c], Horst Manner-Romberg[d]

[a],[b] Otto-von-Guericke University Magdeburg, [b] Fraunhofer Institute for Factory Operation and Automation IFF, [d] MRU GmbH

[a] bjoern.erichsen@st.ovgu.de, [b] tobias.reggelin@iff.fraunhofer.de, [c] sebastian.lang@st.ovgu.de, [d] info@m-r-u.de

ABSTRACT

The market for parcel service providers has been growing dynamically over the past 15 years. Especially the increasing e-commerce is one major factor for this development. According to forecasts, this development will continue in the future, which leads the parcel service providers towards several challenges. They have to adapt their existing networks to the increasing quantity of parcels. For this reason, tools for analyzing the impact of increasing quantity of parcels are necessary. This paper will present hierarchical mesoscopic simulation models of a parcel service provider's network to support analyzing and planning tasks.

Keywords: networks of parcel service providers, hierarchical mesoscopic simulation modeling

1. INTRODUCTION

Networks of parcel service providers are complex and highly dynamic systems with a high quantity of flow objects. There are different impacts (e.g. customer behavior, incidents on transfer points etc.) on those networks, which are mostly stochastic in nature. Methods like OR-algorithms or static models are not adequate to analyze those complex networks and experiments on the real system are hardly possible.

Simulation models allow gaining knowledge of the system behavior of those complex networks. Relatively common is the use of discrete-event simulation models in the field of logistics. Discrete-event simulation models are object-based and allow for microscopic simulation models. But there are some noticeable disadvantages of this method, using it for modeling and simulation of large systems with high quantity of flow objects. These disadvantages are a long simulation runtime as well as a time consuming creation and implementation phase. The mesoscopic modeling and simulation method developed by (Reggelin, Tolujew, 2011) enables quick model creation and calculation in order to perform extensive analysis of large logistic networks. The basis of this method is the use of piecewise constant flow rates to simulate the movement of flow objects. This paper presents an application of a mesoscopic modeling and simulation method on a network of a parcel service provider.

One important aspect of modeling is the selection of an appropriate level of detail for the model. There are often conflicts between a high level of detail and fast simulation runtime as well as creation time. To meet these conflicts this paper will present a concept and an application of hierarchical mesoscopic simulation modeling.

2. SIMULATION MODELS OF NETWORKS OF PARCEL SERVICE PROVIDERS

Networks of parcel service providers are a special type of logistic networks. They are in particular open transport systems and differ in several characteristics from other logistic networks such as industrial distribution and supply chain networks. Characteristics of networks of parcel service providers are (Bretzke 2008, p.312):

- *Multi-directionality:* parcels flow in both incoming and outgoing directions of a network node
- *Many-to-Many structure:* parcels can flow from any node to any other node
- *Paired transport:* loaded trucks in both directions to minimize empty journeys
- *Interrupted Transport chain:* parcel transport consists of several transport stages
- *Multi-user-system:* anyone can use parcel service providers
- *No safety stock:* since every delivery is unique it is not possible to hold a safety stock

The network of each parcel service provider has its own individual structure, depending on its business model. For example, some parcel service provider focus more on the B2B others more on the C2C or B2C segment. But all networks are based on the hub-and-spoke and direct-transport system and represent hybrid types of those. The network of a parcel service provider consists of two basic elements: Network nodes and the transport relations in between. Network nodes can represent hubs, depots, sub-depots and parcel-shops. The parcel delivery process is partitioned in three parts:

Pre-carriage, main carriage and on-carriage.

The offered services of parcel service providers such as wide geographic coverage, reliability, short delivery time and track and trace differ hardly noticeable, and don’t represent a unique selling point anymore (Bretzke 2008, p. 308). To keep and gain new customers it is important for parcel service providers to offer flexible delivery at an acceptable price (Niehaus 2005). This forces the parcel service providers to run their networks as efficient as possible in order to stay profitable. Increasing quantity of parcels can overburden the existing networks of parcel service providers and lead rapidly to inefficiency.

3. LITERATURE REVIEW

The following research can be found on modeling and simulation of parcel and postal networks:

(Larsen 2003) describes a discrete event simulation model for the postal industry to improve the performance of postal networks. He presents an extensive Postal Network Planner for analysis of the postal logistic chain. How the postal processes are exactly modelled with the discrete event paradigm is not clearly described.

The following papers describe isolated simulation models that focus on a single transfer point of a parcel or postal network.

(Cornett and Miller 1996) present the development of a flexible data driven model of the aircraft operations at the United Parcel Service Louisville Air Park.

(White et al. 2002) present an object-oriented paradigm for simulating postal distribution centers. They describe how discrete-event simulation is an established tool for the design and management of large-scale mail sortation and distribution systems.

(Swip and Lee 1991) present the application of an integrated modeling tool on a United Parcel Service reload operation.

(Tuan and Nee 1969) present a simulation program with the purpose to provide the U.S. Post Office Department with a computer model for evaluating the relative merits of alternative nonpriority mail processing, handling, and transportation plans.

(Fedorko, Weiszer and Borzecky 2012) present a simulation model of the process of package sorting at a courier service.

This paper presents the modeling of a network of a parcel service provider using a mesoscopic simulation modeling approach.

4. MESOSCOPIC SIMULATION MODEL OF A PARCEL SERVICE PROVIDER’S NETWORK

(Reggelin 2011; Reggelin, Tolujew, 2011) described a mesoscopic modeling and simulation method to support a quick and effective execution of analysis and planning tasks in the field of logistics networks. The basis for mesoscopic simulation is to model the movement of objects as piecewise constant flow rates. The beginning, ending or changing of a flow rate is controlled by events that occur in a model. This concept is employed in the discrete rate simulation paradigm, which is implemented in the simulation software ExtendSim (Krahl 2009; Damiron and Nastasi 2008). The resulting linearity of piecewise constant flow rates enables event scheduling which leads to high computational performance. To increase the level of detail a mesoscopic model also uses impulse-like flows as known from object based simulation. This is necessary to enable the modeling of bundled movements of logistic objects such as the transport of goods in a truck. Thus, mesoscopic models have hybrid characteristics (Reggelin, Tolujew, 2011).

This paper presents a mesoscopic simulation model of a parcel network. Figure 1 illustrates the conceptual model of the network structure.

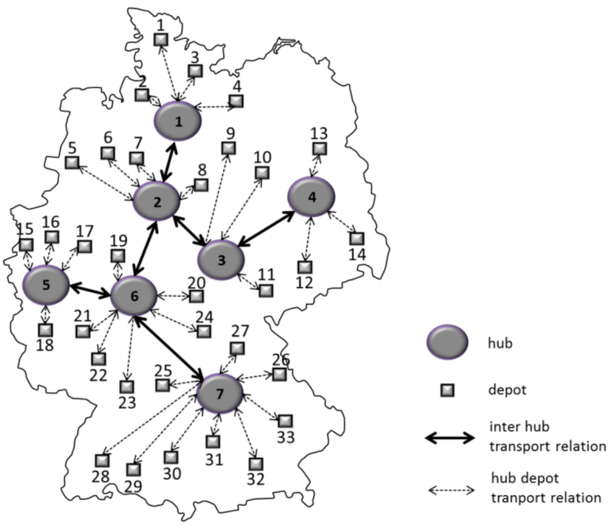

Figure 1: Network of a parcel service provider

The main components are hubs and depots. Each depot has a transport relation to a regional hub. There are also several inter-hub transport relations due to the fact that the parcel service provider operates at a high level of consolidation. The focus of this model is on the main carriages and transfer points in between. Thus, the system boundaries are the depots. All operations that take place on the per- and on-carriage are not represented in the model. Instead, a source and sink is directly connected to each depot to send and receive parcels. Figure 1 illustrates a number above each depts. The numbers represent mailing addresses which clearly identify each depot.

The flow objects are trucks and parcels. The movements of trucks are modeled as impulse-like flows. The movement of parcels within the transfer points (hub and depots) are modeled on an aggregated level as piecewise constant flow rates.

The model control works similar to a real parcel network. Each parcel that is send into the model has an attribute which represents the mailing address. The parcels are sent through the network and delivered to the correct depot by means of the mailing address.

Large depots represent complex production systems. Since the modeling takes place on a mesoscopic level the model doesn´t represent all processes. Figure 2 illustrates the conceptual model of a depot. The colored arrows show which simulation paradigm is used to model the movements of flow objects between the process stations. The depots represent the system boundary, therefore it´s not necessary to model a complete sorting process, because all delivered parcels go directly to the connected sink. Parcels entering the simulation model from the source are scanned whether it´s regional or supra-regional delivery. The regional deliveries go directly to the connected sink. The supra-regional deliveries are loaded into truck and transported to the connected hub.

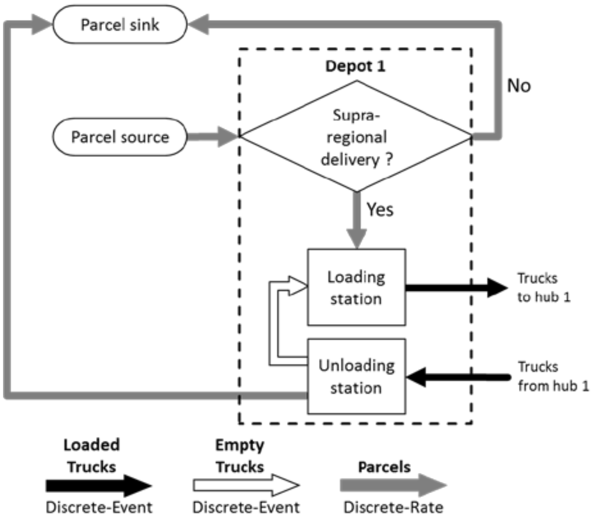

Figure 2: Conceptual model of a depot

Figure 3 illustrates the conceptual model of a hub. A hub represents a complex production system. Since the modeling takes place on a mesoscopic level the model doesn´t represent all processes but is reduced to the unloading, loading and sorting processes. In Figure 2 the colored arrows show which simulation paradigm is used to model the movements of flow objects between the process stations.

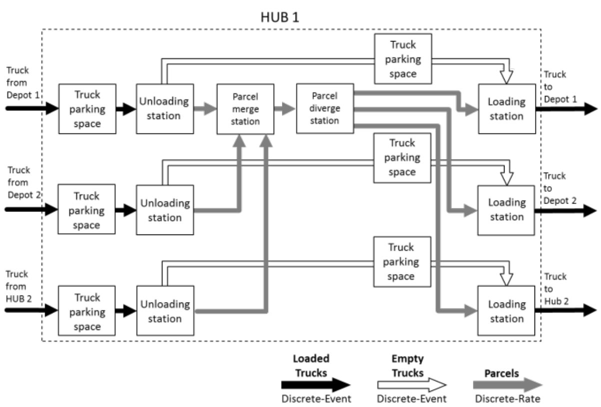

Figure 3: Conceptual model of a hub

The model is designed to allow flexible adjustments of the system parameters in external data files. The main parameters to adjust the model are:

- *Handling rates of hubs*
- *Handling rates of depots*
- *Capacity of the trucks*
- *Quantity of trucks on transport relations*
- *Speed of trucks*
- *Length of the transport relations*

The quantities and distributions of parcels entering the model are also adjusted in external data files. Figure 4 illustrates a principle data file for adjustments of parcels. Arrival depot and Departure depot are the attributes attached to every parcel that enters the model.

Quantity of parcels	Arrival depot	Departure depot
124	7	1
244	3	1
365	6	1
144	12	1

Figure 4: Parcel quantity and distribution adjustment

During simulation, various performance data are collected and reported in multiple output reports. The model collects detailed performance data regarding the throughput of all hubs and depots as well as the running time of all parcels.

5. HIERARCHICAL MESOSCOPIC SIMULATION MODEL OF A PARCEL SERVICE PROVIDER´S NETWORK

A central question in modeling and simulation is the choice of level of detail of the model (Balci 1989). Finding the right level of detail is even for experienced simulation engineers not a trivial task. A high level of detail leads to a time consuming creating phase and a long simulation run time. A low level of detail involves the risk of modeling system components inaccurately, which can lead to invalid simulation results or reduce the adjustability of system parameters (Wenzel et al. 2008, p.128). This paper presents an approach for hierarchical mesoscopic modeling and simulation in order to meet the problem described above (Lulay 1998).

The main idea of a hierarchical mesoscopic simulation is that at first a system is modeled on a mesoscopic level of detail. Afterwards specific components of the system that have to be analyzed in more detail are modeled another time with a higher level of detail, which is still within the mesoscopic level. These sub-models are connected through switches with the main model. Thus, it is possible to manually switch the hierarchy and therefore the level of detail. Modelling a system component several times on different levels of detail leads to a time consuming creation and implementation phase. But for extensive simulation experiments hierarchical modelling and simulation can be beneficial. For less detailed experiments the hierarchical system components operate on the hierarchy with lower level of detail. That leads to a relatively fast run time of the simulation model. Only for detailed experiments the system components operate on the hierarchy with higher level of detail. For the expansion of the analysis capabilities of the simulation model presented in section 4 the mesoscopic hierarchical modelling and simulation approach was applied. Therefore, the hubs were modeled a second time on a higher level of detail. Figure 5 illustrates the conceptual model of a hub on a higher level of detail. Compared to the hub illustrated by Figure 3 it represents more processes. Since the movements of parcels between the process stations are modeled as piecewise constant flow rates the level of detail is still on the mesoscopic level.

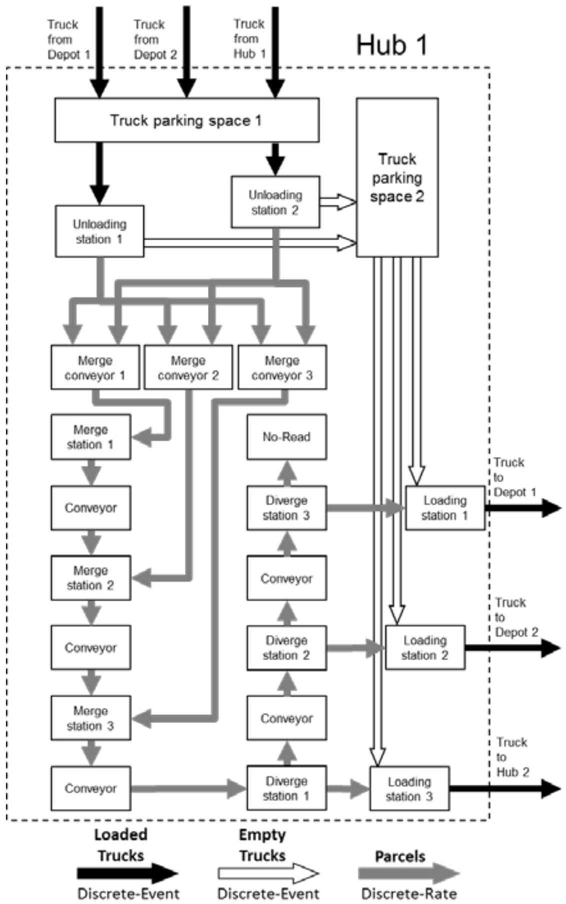

Figure 5: Conceptual model of a hub

This level of detail allows analyzing specific components of the hub. For example, the impact of a damaged or slow running conveyor is analyzable. The main parameters to adjust the hub are:

- *Loading rate*
- *Unloading rate*
- *Speed of parcel sorter*
- *Length of parcel sorter*
- *Capacity and speed of feeding lines*

Figure 6 illustrates the principle concept of a hub with different levels of detail. Manually can be set whether a hub operates on a hierarchy with a lower or hierarchy with a higher level of detail. The hierarchy that doesn´t maintain a transport relation can´t receive any loaded trucks. Thus, no operations will take place on this hierarchy that burden the system.

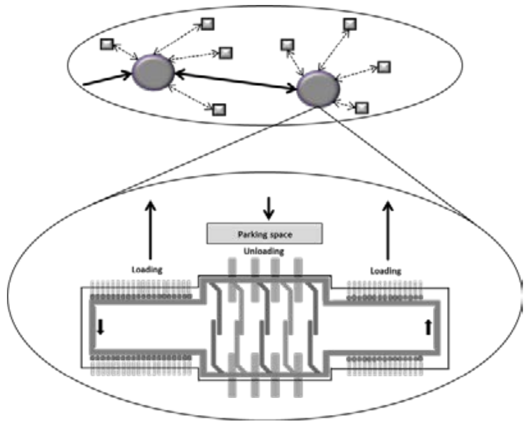

Figure 6: Hub hierarchies

6. EXPERIMENTAL RESULTS

The extensive measurements that are taken during the simulation runs allow specific analysis of the system behavior. In this section a few examples of explorative and user configurable graphs will be given to show the merits of the simulation model as a tool for analyzing the behavior of a parcel network under various conditions. In a sensitivity analysis the reaction of a parcel network to changing parameters are investigated. Therefore, the simulation results of a basis model setting are compared to results of individual parameter variations.

Figure 7 illustrates the percentage of parcels which need less than 48 hours for delivering.

Figure 7: Analysis of performance data – delivery time

The quantity of parcels was increased by 10 and 20 percent and the simulation results compared to the basis model setting. In conclusion, it is obvious that the parcel network is not able to process the increasing quantity within an acceptable period of time. The network performance clearly decreased.

Figure 8 illustrates the mean delivery time on specific delivery routes. The simulation results of the basis setting are compared to the results of the settings with a quantity of parcels increased by 10 and 20 percent. The results show that all delivery routes have an increased mean delivery time for the increasing quantity of parcels. This analysis approach is useful to discover critical delivery routes that may emerge as the quantity of parcels increase.

The hubs of the simulation model operated on a lower level of detail to gain the simulation results presented above. The following example shows the use of a higher level of detail. Therefore, hub 1 operated on the hierarchy with the higher level of detail during the simulation runs.

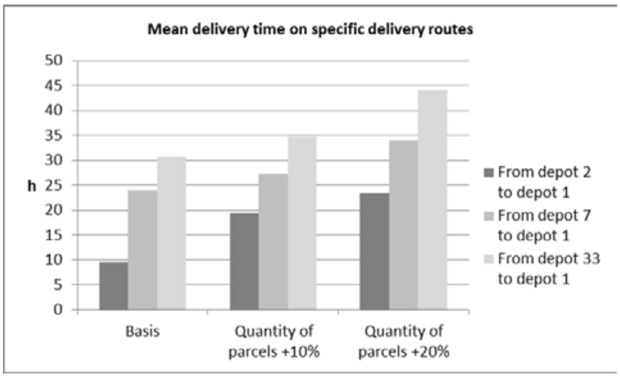

Figure 8: Analysis of performance data – parcel routes

Figure 9 illustrates the throughput of hub 1. The graph shows how the daily throughput of hub 1 changes as the speed of the parcel sorter is reduced. Therefore, the parameter speed of parcel sorter is reduced by 10 and 20 percent. The simulation results are compared to the basis setting of the model. During a simulation run every day parcels departure from the depots expect for Sundays. In Figure 9 Sunday is presented by Day 7, the parcel network doesn´t operate on that day and parcels don´t departure from the depots. It is obvious that the reduction of speed of the parcel sorter decreases the daily throughput of hub 1.

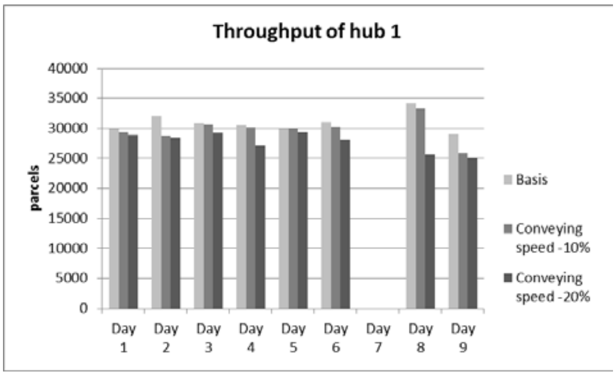

Figure 9: Analysis of performance data – throughput

This analysis approach is useful for daily operations. For example, it allows analyzing the impact of incidents on parcel sorters that may occur during the hub operations. Thus, short-term measures can be taken more accurately.

7. SUMMARY

This paper presented a simulation model of a parcel service provider´s network. A mesoscopic modeling and simulation approach is applied to create a model on a sufficient level of detail that allows quick simulation runs and analyses to support planning tasks. Furthermore, a hierarchical modeling and simulation approach is applied to allow analyses of specific system components in order to support daily operations. The model is flexibly configurable and collects various performance data during simulation runs. Several examples of simulation results were presented to give an insight about the analytical capability of the simulation model. Finding bottlenecks and weak points in the parcel network leads to the next step of taking appropriate measurements. For this task, the simulation model can be used to create operating curves finding the ideal setting for the various model parameters.

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AUTHORS BIOGRAPHY

Björn Erichsen is a master student at the Otto von Guericke University Magdeburg. He received his bachelor of science in industrial engineering from the University of Applied Sciences Lübeck in 2013.

Tobias Reggelin is a project manager at the Fraunhofer Institute for Factory Operation and Automation IFF and Otto von Guericke University Magdeburg. His main research and work interests are logistics system modeling and simulation and the development and conduction of logistics management games. Tobias Reggelin received a doctoral degree in engineering from Otto von University Magdeburg. Furthermore, he holds a diploma degree in industrial engineering in logistics from Otto von Guericke University Magdeburg and a master's degree in Engineering Management from Rose-Hulman Institute of Technology in Terre Haute, IN.

Sebastian Lang is a master student at the Otto von Guericke University Magdeburg. He received his bachelor of science in industrial engineering in logistics from the Otto von Guericke University Magdeburg in 2014.

Horst Manner-Romberg has a reputation as a distinguished expert in the express and postal market. The little group of companies led by him specializes in market research, projects and studies in the express, postal and airfreight segments on both the supply and the demand side. In the course of his career, Horst Manner-Romberg was involved in the founding and development of several (still existing) express networks. Moreover, being a member of the board of the association BdKEP for many years, he decisively worked on the industry's public image. In this context he was also involved in the creation of the new apprenticeship 'CEP merchant'. He is an author of reference books as well as of numerous articles in trade journals or business papers. Moreover he is the editor of the CEP News and of the KEP-Meldungen, two of the most up-to-date and competent information services for the CEP industry.