GROUPING LOGISTICS OBJECTS FOR MESOSCOPIC MODELING AND SIMULATION OF LOGISTICS SYSTEMS

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ABSTRACT

The field of logistics is confronted with an increasing complexity. This mainly results from the immense amount of goods which are part of logistics systems and processes. To address that the description of logistics systems and processes is to be conducted from an object-oriented point of view by including object characteristics and their relations among each other. Therefore, in context of mesoscopic modeling and simulation, this paper presents a procedure which supports the conceptual modeling phase of the mesoscopic simulation approach in grouping and aggregation of logistics objects, i.e. goods and products, in an effective and credible way. This is considered as a method of simplification and will contribute to better model credibility and simulation efficiency as well as reducing model complexity. To demonstrate functionality and effectiveness of the proposed concept the grouping procedure is applied to a modeling and simulation task of a global supply chain.

INTRODUCTION

The field of logistics is confronted with an increasing complexity. Due to globalization production and logistics networks are becoming more international and the number of involved parties is increasing (Simchi-Levi 2008, 312). A rising variant diversity of products, a growing amount of globally sourced goods as well as an increasing availability of information due to new identification technologies contribute to that. Besides rising customer demands, decreasing length of product life cycles or increasing costs pressure, the complexity and heterogeneity of networks and supply chains mainly result from the immense amount of goods which are part of logistics systems and processes (Bretzke 2010, 1–4), (Schenk et al. 2006). This trend has an impact on the sensitivity to disturbances of supply chains, as well. According to this, tools of modeling and simulation provide suitable methods to analyze logistics systems as well as to support a fast adaptation process to changes and disturbances.

Here, the mesoscopic modeling and simulation approach is very promising due to its trade off between simulation time and accuracy as well as providing the opportunity of incorporating logical groups of objects. To address the rising diversity among the goods, which is a driving factor for complexity, the description of logistics systems and processes is to be conducted from an object-oriented point of view by including object characteristics and their relations among each other. This comprises the application of appropriate concepts for incorporating that aspect and for grouping objects as well as defining standard processes to provide efficient solutions.

In this paper we consider logistics objects to be "physical goods such as raw materials, preliminary products, unfinished and finished goods, packages, parcels and containers or waste and discarded goods. Also, animals and even people can be logistics objects, which need special care and service" (Gudehus and Kotzab 2009, 3). But besides these physical objects also information are to be considered as logistics objects, often referred to abstract objects (Arnold et al. 2008, 3), (Schenk et al. 2007).

The objective of this paper is to present a procedure which supports the conceptual modeling phase of the mesoscopic simulation approach in grouping logistics objects in an effective and credible way. This will contribute to better model credibility and simulation efficiency as well as reducing model complexity. To demonstrate functionality and effectiveness of this grouping procedure an application example related to supply chain modeling and simulation is presented.

MESOSCOPIC MODELING AND SIMULATION OF LOGISTICS FLOW SYSTEMS

Three classes of simulation models exist, namely continuous, mesoscopic and discrete. Continuous models are based on differential equations and are most frequently applied as system dynamics models to reproduce manufacturing and logistics processes (Sterman 2000). Discrete event simulation models provide a high level of detail in modeling logistics systems, but can be very complicated and slow, i.e.

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when it comes to modeling and simulation of complex and diverse system structures or incorporating different scenarios (Banks 2010).

In order to overcome the disadvantages of these traditional simulation approaches Reggelin and Tolujew developed the mesoscopic modeling and simulation approach which will be described in this section shortly. For further reading we recommend (Reggelin 2011), (Schenk, Tolujew and Reggelin 2010), (Schenk, Tolujew and Reggelin 2009). Application examples of mesoscopic models can be found in (Reggelin et al. 2012), (Reggelin and Tolujew 2011), (Schenk, Toluev and Reggelin 2009), (Schenk, Tolujew and Reggelin 2008), (Savrasov and Tolujew 2008), (Tolujew and Alcalá 2004). The developed mesoscopic modeling and simulation approach has the following characteristics:

- Less modeling and simulation effort than in discrete event models,
- Higher level of detail than in continuous simulation models,
- Straightforward development of models.

The mesoscopic modeling and simulation approach is situated between continuous and discrete event approaches in terms of level of modeling detail and required modeling and simulation effort (see Fig. 1). It supports quick and effective execution of analyzing, planning and controlling tasks related to manufacturing and logistics networks.

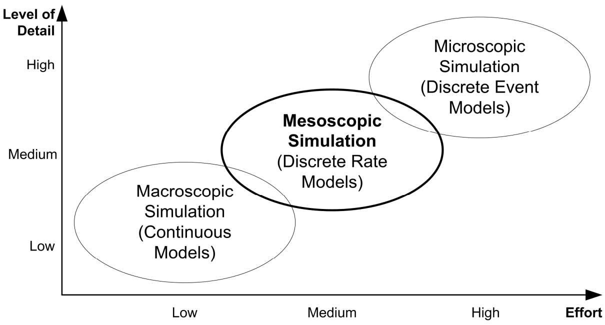

Figure 1: Classification of the Mesoscopic Simulation Approach

This mesoscopic approach is consistent with the principles of the discrete rate simulation paradigm implemented in the simulation software ExtendSim (Krahl Jan. 2009), (Damiron and Nastasi 2008). To ensure a dynamic method the mesoscopic approach monitors quantities that belong to a logical group (e.g. a batch, a delivery, etc.) instead of individual flow objects (e.g. single parts, entities, etc.). Mathematical equations are used to calculate the results as continuous quantities (piecewise constant flow rates) at certain steps of the modeling time which allows for planning events for continuous processes. This contributes to a fast modeling and simulation approach (Schenk, Tolujew and Reggelin 2010).

Even when the term mesoscopic is not explicitly applied, a mesoscopic view often already exists from the start of flow system modeling and simulation. Many practical analysis and planning problems like capacity planning, dimensioning or throughput analysis describe performance requirements, resources and performance results in an aggregated form that corresponds to a mesoscopic view (cp. Schenk, Tolujew and Reggelin 2008).

Mesoscopic models are particularly suited to the analysis of large-scale logistics networks and processes with a homogenous flow of a large number of objects. In most cases, the disproportionate amount of computation required would make item-based discrete event simulation overly complex for these applications.

Due to logistics systems and supply chains often showing a diverse and heterogeneous product or object structure respectively the opportunity to model logical groups is of significant importance to reduce modeling complexity and effort. Nevertheless, as for most descriptive modeling concepts or other simulation approaches, there is no effective support in grouping these objects to logical groups. Therefore, in the following such a procedure is presented to support the straightforward development of these kinds of models.

CONCEPTUAL MODELING PHASE

The conceptual modeling phase of a simulation study is one of the most important parts (Robinson 2008). In context that good conceptual modeling can significantly contribute to a successful outcome of a simulation study, it still is a difficult and hard-to-understand stage in the modeling process (Law 2007). Guidelines for the modeling process can be found in (Law 2007), (Pidd 1999), (Uthmann and Becker 1999).

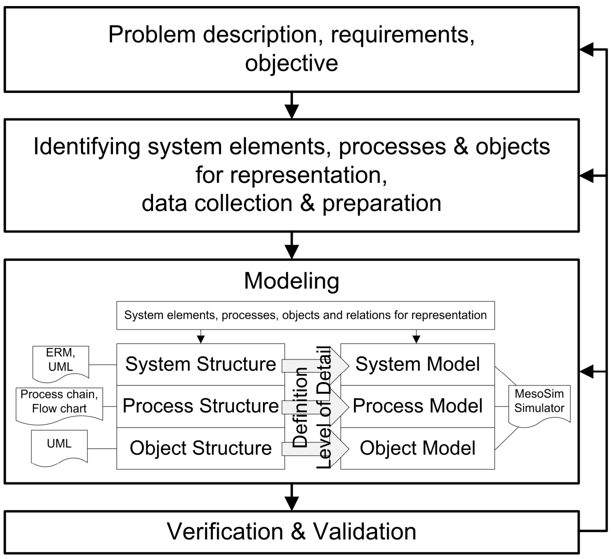

Figure 2: Steps of the Conceptual Modeling Phase for Mesoscopic Simulation

Based on existing frameworks for conceptual modeling (cp. Brooks and Tobias 1996, Pace 2000, Robinson 2004, van der Zee and van der Vorst 2005) four fundamental steps were derived for conducting the conceptual modeling phase for the mesoscopic simulation approach (see Fig. 2).

To support the process of modeling a system, process and object structure, we presented an overview and examination of traditional modeling concepts in (Koch, Tolujew and Schenk 2012) that can be applied appropriately. Another important aspect in the actual modeling step (step 3) is to determine the level of detail of the system, process and product model. As for the product model of the mesoscopic simulation approach an essential and inherent part is the grouping or aggregation of logistics objects.

But there is a lack in supporting this step of the conceptual modeling phase. However, this is of significant importance to approach the increasing complexity of logistics systems and processes efficiently. Zeigler et al. also suggest as one method of simplification for simulation modeling to group components of the model (Zeigler, Praehofer and Kim 2007).

In (Law 2009), (Brooks and Tobias 1996), (Zeigler, Praehofer and Kim 2007) guidelines for determining the level of detail of a simulation model can be found. They are also related to the aspect of simplification by grouping components and elements of the simulation model.

However, these guidelines do not provide a clear procedure in how to approach the grouping of logistics objects, i.e. products or goods.

PROCEDURE FOR GROUPING LOGISTICS OBJECTS

Therefore, to support this step of the conceptual modeling phase a procedure was developed which addresses the effective and credible grouping (aggregation) of logistics objects in context of mesoscopic modeling and simulation (see Fig. 3).

The procedure is based on grouping the considered logistics objects (i.e. products that are processed through logistics systems and processes) according to relevant attributes that are of importance in a specific context of logistics problem tasks and key performance indicators. To address the nesting aspect of logistics objects, grouping is conducted for each nesting level separately. This implies the consideration of the object structure before analyzing the objects according to their attributes.

For conducting the grouping procedure on an attribute basis an attribute catalog and selection matrix will support the process of identifying relevant characteristics of the considered logistics objects. Here, we presented in (Koch and Glistau 2010) a first overview of characteristics related to object analyses in the field of logistics. These relevant attributes are also important in context of validating the grouping results according to homogeneity.

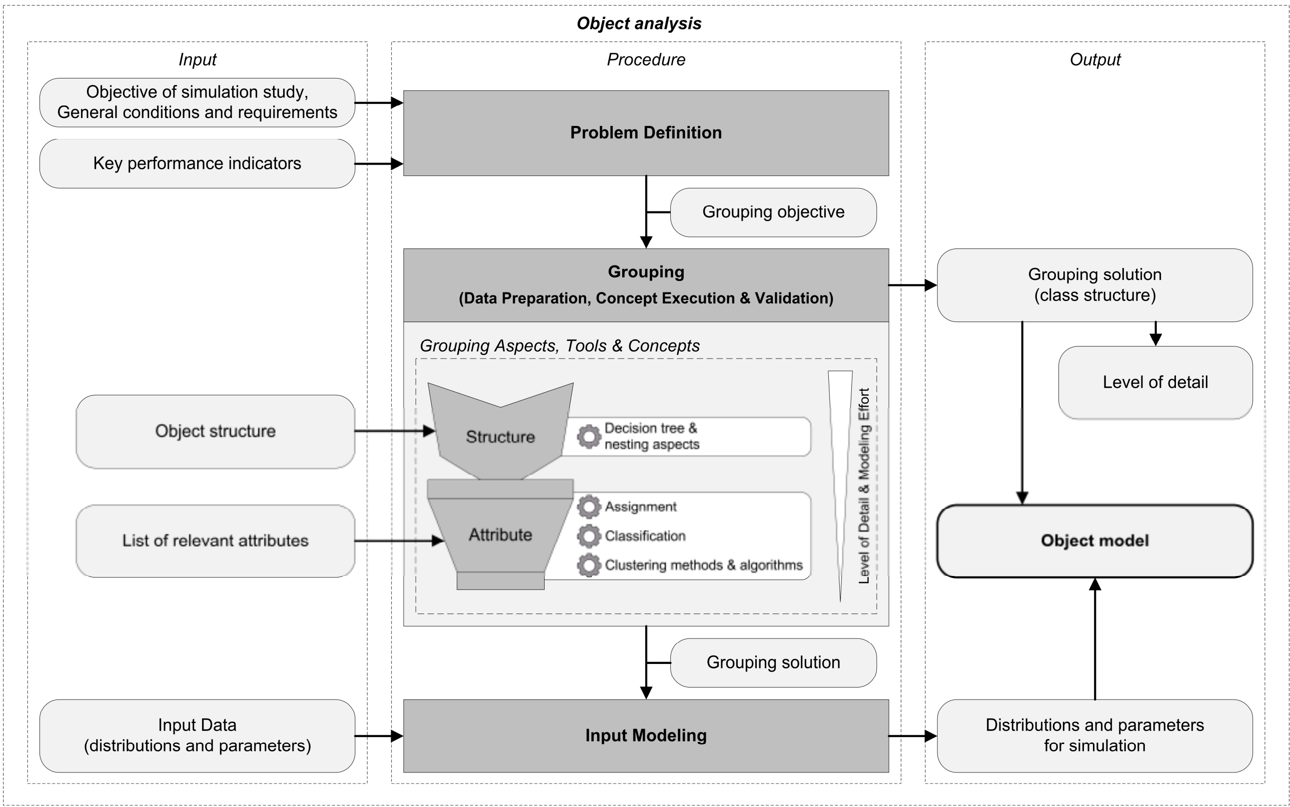

Figure 3: Procedure for Grouping of Logistics Objects

For the grouping procedure different concepts are proposed (see Fig. 3) which allow a credible and supportive grouping in context of modeling and simulation of logistics problem tasks.

The fundamental steps of the procedure are:

- Problem definition
- Grouping
  - Concept selection & data preparation
  - Concept execution & validation
- Input modeling

The problem definition is based on the problem task and objective as well as relevant key performance indicators of the related simulation study. These aspects as well as identified constraints on the level of detail, which are to be defined, have an impact on formulating the objective of the grouping procedure.

The second fundamental step of the procedure is about the actual grouping process. To obtain a representative and sufficient level of detail we propose to consider the grouping for each nesting level (cp. object structure) separately based on the identified relevant attributes.

Three different kinds of grouping concepts are proposed: assignment, classification and clustering methods. Assignment is used for assigning objects to groups that have for example equal process sequences or steps or belong to the same product family. Classification can be applied when objects are classified according to their characteristic values to preexisting categories or groups respectively (e.g. ABC-analysis). Clustering methods belong to structure-discovering concepts grouping objects into clusters which are characterized by a high level of inner-homogeneity and high level of outer-heterogeneity of the formed clusters.

These concepts are not to be considered exclusively and can be used iteratively. In applying these concepts a representative solution and a high quality of the grouping results will be obtained.

In general, the following steps have to be conducted. After identifying and collecting available data an appropriate grouping concept has to be chosen. Here, methods of multivariate data analysis, i.e. clustering methods, are of significant importance due to the multivariate and heterogenic character of the logistics objects. After preparing the data for the chosen concepts, which will contribute to forming an object structure, the grouping method can be applied. In the following the validation and control of the results according to credibility and sufficiency should be conducted.

As a last step there is the process of input modeling for the simulation model which refers to identifying the distributions and parameters of the identified groups out of the raw data of the considered logistics objects. As a consequence the groups or classes respectively can be then implemented in the simulation model.

The complete procedure should be seen as iterative. If the grouping process is not satisfactory and the obtained results, i.e. groups of logistics objects in an appropriate level of detail, are not in line with the grouping objective the procedure should be repeated.

For the mesoscopic simulation approach the identified groups or classes respectively can be implemented as product types in the simulation model. This will reduce model complexity. This effect was already demonstrated in (Koch, Reggelin and Tolujew 2012). Here the proposed approach was successfully applied to an application example in the field of biomass logistics.

APPLICATION

The application example is based on a real-world global supply chain of a company that designs, manufactures, markets and services consumer goods. The consumer goods are transported along several supply chain stages from international suppliers to final customers. For analyzing and planning such complex supply chains the mesoscopic modeling and simulation approach is a proven and effective tool. This was for example demonstrated in (Hennies, Reggelin and Tolujew 2012). Here the advantages of an aggregated level of detail, modeling flexibility and reduced simulation effort as well as time are presented.

In this application example we consider a multi-stage supply chain. The production of the consumer goods was outsourced and is realized by international suppliers. The suppliers are distinguished as main (supplier A) and secondary suppliers (supplier B). Emergency suppliers guarantee deliveries in case of disturbances of regular supplies. The distribution of the consumer goods is conducted by distribution centers which allocate the goods to different regional warehouses. These warehouses realize the sale and delivery to the customers and each faces an individual customer demand pattern. Customers are distinguished as strategic customers (80 percent of total demand) and secondary customers (20 percent of total demand). These elements form the system structure of the model (see Fig. 4).

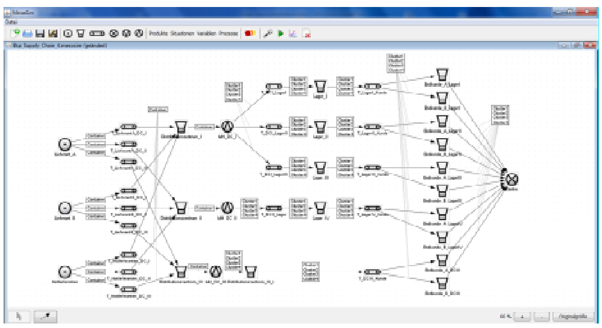

Figure 4: A Mesoscopic Model of a Supply Chain created with the Simulation Software MesoSim

Products are shipped in containers from suppliers via distribution centers to regional warehouses. At the warehouses, material handling is imitated and the products are distinguished to allow for different demand and appropriate consideration of safety stock levels. The company and the supply chain network are facing a diverse and heterogeneous product structure. In total, there are 207 different consumer goods which are produced and offered for sale. These goods have different characteristic values e.g. related to customer demand or production time.

For grouping the different logistics objects as a significant part of the conceptual modeling phase the proposed grouping procedure on an attribute basis is applied. In the following the key aspects of the presented grouping procedure are explained.

The objective of the company is an inventory level optimization at its warehouses and distribution centers under the condition of realizing as few goods movements as possible. This is to be taken into account when grouping the products.

At first the different objects or products respectively are grouped together according to their belonging to a certain product family (assignment). This reduces the number of objects from 207 to 33 objects or product families respectively. In grouping objects of the same type or kind respectively together a transparent and credible result is attained and presented.

Second, these 33 objects are grouped again on an attribute basis applying a cluster analysis (for further reading on methods of multivariate data analysis we recommend Timm 2002). As a cluster algorithm the Ward's method using a squared Euclidean distance is chosen. The objects are clustered according to two variables: production time and customer demand, which represent the identified relevant attributes. The cluster analysis was conducted with the help of the software tool IBM® SPSS® Statistics Vers. 18.0.

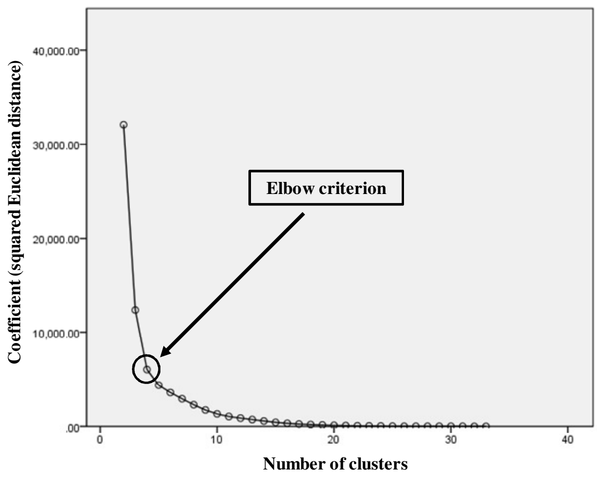

Figure 5: Scree Plot

As a result of the cluster analysis there are several possible cluster solutions. To determine the most appropriate cluster solution a dendogram and a scree plot provide means for decision support. According to the elbow criterion, the scree plot indicates that a cluster solution of four clusters seems to be the most probable solution (see Fig. 5).

But also a cluster solution of two clusters seems to be a reasonable choice. To further validate the homogeneity within the clusters and the heterogeneity among the clusters (which is an important criteria for having an optimal cluster solution) the F-Values of the clusters are considered. The F-Value is a statistical measure of how distinct the cluster groups are. A F-value of less than 1 indicates a homogenous group (Backhaus et al. 2011, 395–455).

Thus, according to the F-Value, Table 1 and Table 2 show that a cluster solution of 4 clusters is deemed as a better and more homogenous solution. Therefore, we choose to group the consumer goods into 4 different groups representing the product types for the simulation model.

Table 1: F-Values for a 2-Cluster Solution

	F-Value	
Cluster	1	2
Production time	**1.39**	0.76
Customer demand	**1.07**	0.09

Table 2: F-Values for a 4-Cluster Solution

	F-Value			
Cluster	1	2	3	4
Production time	0.17	0.92	0.71	**3.49**
Customer demand	0.07	0.01	0.02	0.25

Due to the fact that we also consider the shipment of containers in the model (cp. nesting aspect), we have to add one product type to the model.

In total, it is possible to reduce the number of logistics objects from 208 (including one object type for the containers) to 5. These 5 product types represent the product structure as well as the characteristics of the related products or objects respectively.

Thus, the level of detail is characterized by implementing 4 clusters (plus 1 for the container) as well as their determined distributions and parameters, according to input modeling, into the simulation model. This level of detail is in line with the objective and allows effective simulation in context of the problem statement.

In grouping the logistics objects together with the help of the proposed procedure the amount of entities that need to be considered for computations in the simulation run can be reduced. This has a positive effect on the simulation effort without neglecting aspects of transparency and credibility that impact model accuracy and validity.

Results of simulation runs show that the determined and chosen level of detail contributes to output data that allows for testing scenarios and retrieving statements on how to solve the problem task of the simulation study (see Fig. 6). There was no necessity for further aggregating or decomposing the data to, for example, improve model accuracy or validity.

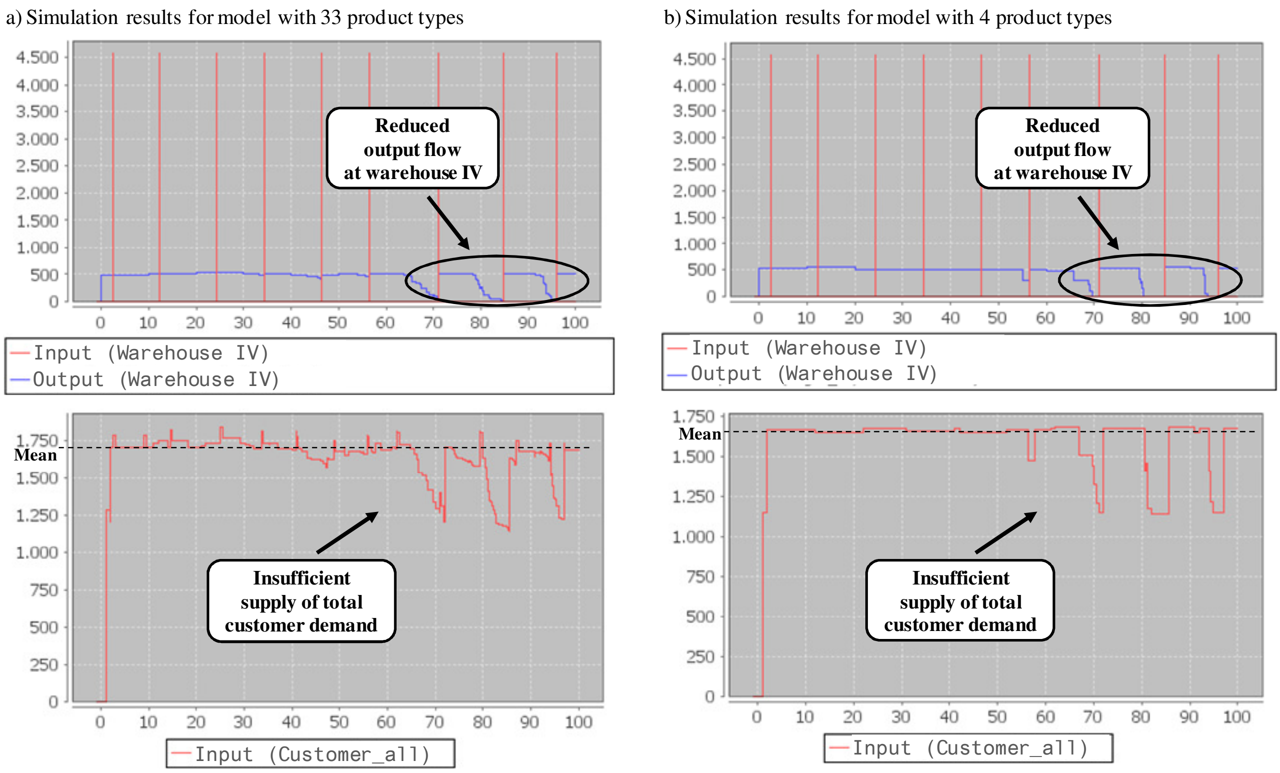

Figure 6: Comparison of exemplary Simulation Results for different Level of Detail

In comparing the simulation results of the model using 4 product types (plus 1 for the container) to a more detailed simulation model implying 33 product types (representing the different product families) it becomes apparent that there is no significant impact on the simulation results (see Fig. 6). There are just minor differences in the occurrence of certain events over the simulation time. Thus, the reduced number of integrated product types does not result in a significant reduced accuracy and validity of the simulation results and conclusions.

CONCLUSION

The paper describes the challenges that are incorporated with the increasing complexity of logistics systems and processes. This complexity is mainly caused by the increasing diversity and heterogeneity of the logistics objects, i.e. the goods processed through the logistics system. Therefore methods for simplification are needed. Zeigler et al. also suggest as one method of simplification for simulation modeling to group components of the model (Zeigler, Praehofer and Kim 2007).

Here, the mesoscopic modeling and simulation approach requires support in grouping logistics objects for simplification purpose in an effective and representative way, because there is a lack in supporting the composition and decomposition of logical groups of logistics objects. However, this is of significant importance to approach the increasing complexity of logistics systems and processes efficiently.

Therefore, the paper presents such a procedure for grouping logistics objects in an efficient way supporting the determination of the right and appropriate level of detail for the simulation model and the considered problem task and logistics system. The benefits and effects of the presented grouping procedure as well as its relevance to the field of logistics were demonstrated by an application example in the field of supply chain modeling. Here the volume of to-be-considered logistics objects was reduced by 97.5 percent resulting in 5 product types to be implemented in the simulation model.

In general, the proposed procedure supports the conceptual modeling phase enhancing the outcome of a simulation study. Model complexity can be reduced while allowing for better model credibility and simulation efficiency. In contributing to less modeling and simulation effort without reducing accuracy and validity of simulation results there is added value to the simulation of logistics systems. This in particular provides benefit to industry applications.

With the described procedure as a part of the conceptual modeling process of the mesoscopic simulation approach there is also support to the modeler in the modeling and decision making process as well as contribution to a transparent, effective and qualitative conceptual modeling phase.

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