RESOURCE ALLOCATION IN MESOSCOPIC LOGISTICS NETWORKS SIMULATION

Til Hennies[a] , Yvonne Boersch[b], Juri Tolujew[c], Tobias Reggelin[d]

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

[a]til.hennies@iff.fraunhofer.de, [b]yvonne.boersch@iff.fraunhofer.de, [c]juri.tolujew@iff.fraunhofer.de,
[d]tobias.reggelin@iff.fraunhofer.de,

ABSTRACT

Resource allocation in supply chains is an as essential as complex topic due to the impact it has on the performance of the entire system. Effective resource allocations take into consideration the multitude of different objectives, the heterogeneity of resources and jobs and the dynamically changing system states and resource attributes. Simulation of these strategies is a powerful way in order to test, analyze and evaluate different strategies under changing external influences. In supply chains, quick simulation algorithms are necessary for effective decision making which is supported through the mesoscopic simulation approach. This paper provides a classification of resources and jobs within supply chains, the definition and mesoscopic formalization of possible resource allocation strategies and combinations of these and an example application of a four stage supply chain.

Keywords: Resource allocation, supply chain, mesoscopic simulation

1. INTRODUCTION

The objectives of effective resource allocation are manifold and include the reduction of lead times and waiting times of logistical flow objects, a maximization of throughputs and the minimization of the utilization degree amplitude of different resources. Effective resource management directly translates into better process management and a resulting quality increase for the customer. One of the main objectives of process simulation is the identification, planning and control of most appropriate strategies of resource allocation. Considering the heterogeneity of resources and jobs, inherent conditions of resource utilization and dynamically changing attributes, the modeling of resource allocation strategies becomes a non-trivial task.

This paper deals with the topic of resource allocation in supply chains and applies it to the concept of mesoscopic simulation that has already been presented in past HMS conferences (Hennies, Reggelin and Tolujew 2012). The mesoscopic modeling and simulation approach is based on the replication of logistical flows on an aggregated level in order to allow for quick model creation and calculation. While resource allocation strategies in discrete-event simulation models are realized only algorithmically, in macroscopic system dynamics and in mesoscopic simulation models these can also be described analytically. This paper presents the formalization of different resource allocation strategies in mesoscopic simulation models. This enables supply chain managers to quickly model and test generic strategies and combinations of these in order to make decisions of resource allocations in the respective supply chain.

2. RESOURCES AND JOBS IN LOGISTICS NETWORKS

Supply chains are globalized and intertwined logistics networks with multiple different resources and jobs. An effective allocation of resources and jobs is one of the key measures to increase the system’s performance. However, due to the complexity of resources and jobs this decision is rather complicated. A classification of resources and jobs and the definition of objectives and priorities make up the basis for strategic allocation of resources and jobs.

The term *resource* describes the totality of means of production or services and the multitude of different resources can be classified in material and immaterial resources (Schuster 2012). This first differentiation, however, is too crude for resource allocation problems in production and logistics networks, because there can be found very diverse resources from operating equipment and aids to means of transport, stock and human resources. These resource types have very different characteristics that are predetermining the application areas and the possible jobs to be executed. Therefore, it is essential to develop an appropriate classification in a more specific sense and consider all relevant attributes with the respective characteristics that come into play when strategies for resource allocations have to be selected.

In the context of resource allocation problems in supply chains many attributes besides the already mentioned *appearance* (material/immaterial) need to be considered. The *mobility* of resources describes the ability of resources of being relocated and significantly determines the material flow wherefore it has impacts on the allocation decision. The *flexibility* determines the application area of resources and the *autonomy* of resources describes an inherent requirement of further resources in order to being operated. The *availability* may be dependent of further conditions or circumstances and makes up another factor for effective allocation strategies. Resource *costs* can be operating or investment costs and also highly affect the decision about utilization and job allocation. The *degree of automation* is similar to the autonomy of resources, but has further impacts on the flexibility and correctness of the job execution, wherefore it should be considered separately. The attribute *property* refers to the actual owner of the resources – if these are the organization's own or lent resources. *Renewability* describes the possibility to reproduce the resource or not and has impacts on the decision of utilization and application area. Similarly, the *lifetime* and *substitutability* of resources are further factors that play a role for these decisions and finally, the *condition* of a resource can be different with certain effects on repairs and maintenance requirements which should therefore be considered.

The different characteristics corresponding to each of the described attributes are listed in below morphology in Table 1.

Table 1: Morphology of resource attributes

Attribute	**Characteristics**		
Appearance	Physical/material		Virtual/immaterial
Mobility	Stationary	Moveable	Locally independent
Flexibility	Job-specific		Universal
Autonomy	Active		Passive
Availability	Completely		Partially
Costs	Low	Medium	High
Degree of automation	Computerized	Semi-autonomous	Human
Property	Internal		External
Renewability	Completely	Partially	Not
Lifetime	Short-term	Medium-term	Long-term
Substitutability	Completely	Partially	Not
Condition	Technical		Organizational

Based on these different characteristics, each resource in a supply chain can be precisely described in multiple dimensions and afterwards clustered in groups based on the relevant attributes for distinct purposes such as simulations. Relevant resources for supply chains can be subsumed into the following categories:

- *Human resources*: Important for allocation, processing and monitoring of jobs, goods and services e.g. scheduler, dispatcher, operator and driver
- *Means of transport*: Devices for the purpose of goods carriage e.g. truck, forklift and conveyor
- *Operating aids*: Required for stabilization of the manufacturing process e.g. fuel, energy, coolants and lubricants
- *Operating equipment*: Technical facilities of the manufacturing process (e.g. machinery and tools) and loading, transport and storage equipment (e.g. container, swap body)
- *Organizational resources*: Organization (planning, implementation, monitoring and control) of operational processes e.g. work instructions, policies, manuals and forms
- *Space/surface*: Available limited area for the manufacturing process e.g. premises, factory, warehouse and office building
- *Stock*: Secure the continuous manufacturing process e.g. raw material, (semi-finished) products, finished goods, product components
- *Technological resource*: Development of new production and information technologies e.g. innovative project ideas, patents and licenses

Similarly, jobs have application-specific and context-sensitive definitions. Generally spoken, jobs are complex business objects which include confirmed requests to buy, sell, deliver, or receive goods or services under specified conditions (Schönsleben 2011). In a more abstract sense, the term *job* in a supply chain covers all tasks within the order fulfillment process that require resources and time to be executed – from the customer's inquiry to delivery of a product to the customer.

This broad definition of jobs in a supply chain implies very different characteristics of these in regards to different dimensions. The *production strategy* is defined through the order decoupling point and determines the triggering of a production job. The *complexity* of a job refers to the expertise requirements of the job and the repetition rate which affects the allocation decision. The *flexibility* describes the possibility to execute one job with different resources or not. The *flexibility of the due* date is important for the scheduling process. *Lot Sizes* refer to the number of jobs that are treated as one single group within the process. The *predictability* of jobs highly depends on the demand variability and has impacts on the production strategy and the triggering of jobs. The job *priority* depends on the customer and must be taken into consideration when allocating jobs to resources. The *repetition rate* describes the frequency of the same job and may have effects on the selection of the resources for this job. Jobs can be *triggered* through different events related to demands, forecasts or consumption. The *value of an order* is another important criterion for the allocation of resources to jobs and vice versa. The developed morphology of these characteristics is illustrated in Table 2.

Table 2: Morphology of jobs attributes

Attribute	**Characteristics**					
Production Strategy	Make-to-stock	Make-to-order	Engineer-to-order	Assemble-to-order		
Complexity	Standard job		Customer-specific job			
Flexibility	Resource-specific		Universal			
Flexibility of due date	No	Low	Completely			
Lot size	Single piece	Small series	Mass production	Without lots		
Predictability	Ad hoc		Regular			
Priority	Rush order	Standard delivery time	Fixed day of delivery			
Repetition rate	No	Seldom	Frequently			
Triggering off	Demand	Forecast	Consumption			
Value of order	Small order	Standard order	Large order			

3. RESOURCE ALLOCATION STRATEGIES AND MODELS

The identified complexity of resources and jobs in supply chains makes up a broad spectrum of situations and scenarios in the supply chain where resources allocation strategies must be selected and implemented. When looking at one attribute of jobs and resources only, namely the flexibility, there arise four different scenarios that must be taken into consideration for effective resource allocation as exemplary illustrated in Table 3.

Table 3: Flexibility of supply chain resources and jobs and resulting scenarios

Flexibility	Resources are job-specific	Resources are universal
Jobs are resource-specific	One resource type executes one type of jobs, each job can be executed by one resource type	One resource type executes different types of jobs, each job can be executed by one resource type
Jobs are universal	One resource type executes one type of jobs, each job can be executed by different resource types	One resource type executes different types of jobs, each job can be executed by different resource types

The resulting scenarios define the potential strategies that can be applied within one situation. If one resource type executes one type of jobs and each job can be executed by one resource type, the only possible strategy is an explicit allocation of job “A” to resource “A” and job “B” to resource “B”. Contrarily, if one resource type executes different types of jobs and each job can be executed by different resource types, there arise many more potential strategies that need to be compared with regards to different objectives. These objectives can be manifold and the different possible strategies must be tested, analyzed and evaluated. Potential objectives include the following:

- Reduction of waiting times
- Reduction of lead times
- Reduction of utilization degree amplitude
- Reduction of resource movements
- Increase of throughputs
- Increase of utilization rates
- Increase of delivery reliability

This described complexity of resource allocation strategies in supply chains is also reflected in the corresponding models that aim at exploring this topic in more detail. It can be differentiated between *state-based* and *model-based* allocation models. While state-based allocation models are based on stationary snap-shots of the system state and adjust dynamically to changing system states, model-based allocations follow an initial prediction of future system states and therewith do not react to dynamically changing systems. Also, one differentiates between *preemptive* and *non-preemptive* strategies depending on whether jobs are allowed and able to change resources after beginning of processing or not. (Gomoluch and Schroeder 2003)

Many research publications in this field are also dedicated to the development of agent-based or market-oriented resource allocations that allow independent agents to decide which resources to use. (Kelton et al. 2010; Abramson et al. 2002; Chavez et al. 1997) However, as this is a decentralized and local decision-making process, it is a game-theoretical approach rather than strategic supply chain planning and therefore not part of this paper.

The discrete-event simulation, the most used simulation approach in modeling of production and logistics, realizes resource allocation through algorithms and verification of logical conditions. Conventional resource allocation strategies for disposition are methods like *Round-Robin*, *Weighted Round-Robin*, *First-In-First-Out*, *Last-In-First-Out* or *Fixed-Priority*. Within discrete-event simulations, at the moment of the event occurrence an algorithmic verification of resource allocation rules is executed and according to the defined strategy the allocation is realized. The discrete-event simulation software *Tecnomatix Plant Simulation* offers the user so-called resource objects for the implementation of resource allocation strategies, the *Broker* and the *Exporter*. The Exporter assorts several homogeneous resources to one group with a total capacity for job execution, but the allocation is not done individually. Also, one can control the strategy based on the definition of input behavior at each work station where defined strategies can be used from a drop-down menu which are, however, not dynamically adjustable. (Siemens PLMS Inc. 2010)

In macroscopic System Dynamics simulation, resource allocation rules can be expressed analytically and this is already implemented as standard solution in the simulation tool Vensim from the firm Ventana Inc. By utilizing the function *Allocate by Priority* the user can define resource allocation strategies in competitive situations (see Eq. 1). (Ventana Systems Inc. 2012)

$$allocation[subscript] \\ = ALLOCATE\ BY\ PRIORITY(\,request[subscript], \\ priority[subscript], size, width, supply) \qquad (1)$$

4. RESOURCE ALLOCATION IN MESOSCOPIC SIMULATION MODELS

The concept of mesoscopic simulation has been developed at the Otto von Guericke University Magdeburg and is presented in (Reggelin 2011a), (Reggelin 2011b), (Schenk et al. 2009) and (Schenk et al. 2010).

Main structural elements in mesoscopic simulation models are multichannel funnels for the replication of processes at resources. Also, there are multichannel delays for replication of planned deferments like transportation and waiting times and product classes for differentiation between distinct groups of flow objects. Funnels allow for an analytical description of resource allocations in mesoscopic simulation, because these elements are also completely analytically defined.

The mesoscopic simulation therefore introduces the variable of limiting performance μ *[number of jobs/ time unit]* of the funnel and for each channel μ^i that enables one to control the output flow λ_{out} *[number of jobs/ time unit]* leaving the funnel (λ^i_{out} for each channel). If the input flow of product 1 λ^1_{in} exceeds the limiting performance of μ^1 inventory S^1 is built up within the funnel. The limiting performance μ can be split between different product types in order to replicate resource allocation strategies. These strategies interpret jobs as products and the total number of waiting jobs in front of the resource as inventories. The allocation strategies developed are different prioritization rules that split a total limiting performance between different job types. Each strategy can be formalized through the mathematical definition of the limiting performance for each product type.

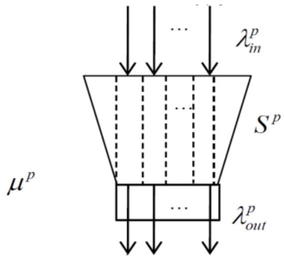

Figure 1: Multichannel Funnel in mesoscopic simulation

The topic of resource allocation has not been explicitly focused on in previous publications on mesoscopic simulation, but it is essential for effective supply chain simulation as one of the primary reasons to execute or simulate processes is to be able to reason about, forecast, and plan the best utilization of available resources. This paper presents several different strategies of resource allocation for multichannel funnels in mesoscopic simulation models. These strategies consider external factors of the situation, multivariate objectives and characteristics of jobs and resources and accordingly control the limiting performance of each channel of the funnel. Therewith, mesoscopic resource allocation strategies are centrally planned and controlled, state-based and non-preemptive. In contrast to system dynamics models, however, mesoscopic simulation models do not continuously execute new resource allocations but only at decision points with distinct events taking place when impulses or changes of the flow rates occur.

The concept of mesoscopic simulation has been implemented in the simulation software MesoSim. The resource allocation strategies have been modeled and selected results are shown in the following. In each situation, there are always two different job types to be executed by one resource with a limited capacity that needs to be split between the different jobs. The diagrams show stock developments of job 1 (black line) and job 2 (red line) under the application of different allocation strategies. General strategies of resource-job-allocations can be based on the following approaches.

Explicitly: The most trivial solution is an explicit allocation where each resource executes one job type only. Each resource can be modeled as a separate funnel or in one multichannel funnel. In the first case the limiting performance of each channel equals the limiting performance of the funnel $\mu\,(i) = \mu$. In the second case, for an allocation of fixed proportions of resource capacity to different job types, the limiting performance of the funnel μ equals the sum of limiting performances of each job type μ^i in accordance with the capacity of the modeled resource.

$$\mu \;=\; \sum_{i=1}^{n-1} \mu\,(i)$$

This allocation reflects inflexible resource utilization without any sharing possibilities. It is only suitable for continuous and stable inflows of jobs.

Uniformly distributed: For this strategy each resource executes the same proportions of different job types. Therefore, the limiting performance of the funnel μ is split into equal proportions for each job type.

$$\mu(i) = \frac{\mu}{n}$$

Independently of demands and stock developments the output rates remain constant over time. This allocation strategy is therefore only suitable for very stable and frequent job types with high predictability and continuity.

Arrival-proportional: This allocation rule suggests that each resource executes jobs according to the proportion of arrivals of jobs. Therewith, the limiting performance for each job type is defined as:

$$\mu(i) = \frac{\Lambda(i)_{in}}{\sum_{j=1}^{n} \Lambda(j)_{in}} \mu$$

This strategy incorporates the number of different jobs to be executed by the resource and is therefore suited for less frequent jobs. It is a push strategy to assure balanced workloads at preceding stages. As illustrated in Figure 2, despite different input flows (green and blue line) of the two job types the stock developments are constant because of an adjustment of resource capacities for the execution of jobs.

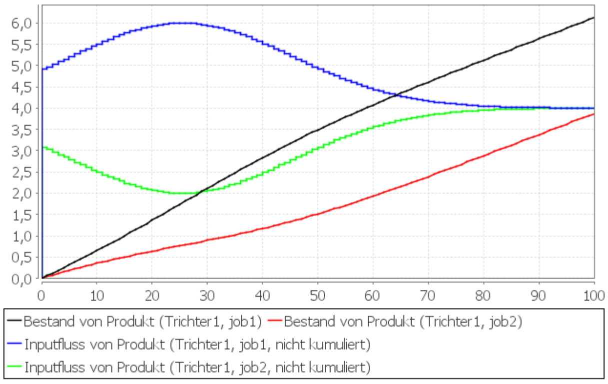

Figure 2: Inflow (green and blue) and stock development (black and red) under arrival-proportional strategy

This strategy, however, does not incorporate actual inventories that are also affected through beginning inventories or impulse-like increases and decreases, which can be seen in Figure 3, where an impulse like increase is triggered without any adjustments of the limiting performance. The additional waiting jobs are not taken into account for this strategy.

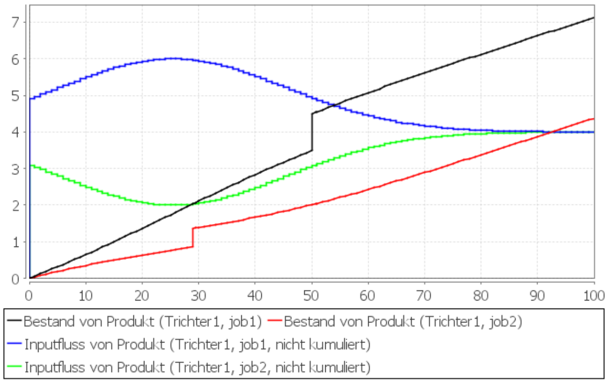

Figure 3: Inflow (green and blue) and stock development (black and red) under arrival-proportional strategy with impulse-like increase

Stock-proportional: This strategy assigns different jobs to one resource according to the proportion of inventory levels in front of the resource. If the limiting performance is adjusted based on current stock levels, impulse-like changes and beginning inventories are taken into consideration and the stock developments of different job types are balanced. The objective is to maintain moderate stock levels of products and accordingly assign the capacities. It does not look at successor operations. This strategy results in developments as shown in Figure 4 and may be applied to assure continuous realization of each job type.

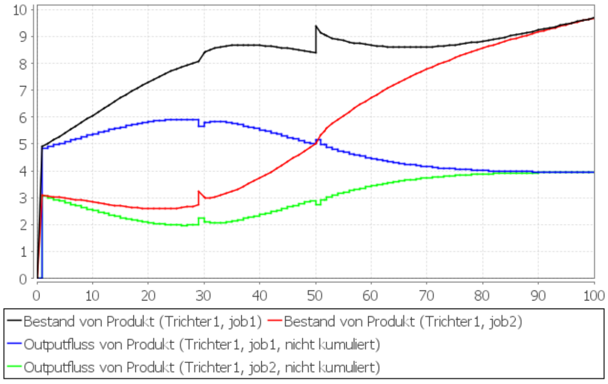

Figure 4: Outflow (green and blue) and stock development (black and red) under stock-proportional strategy with impulse-like increase

Stock-development-proportional: Each resource executes jobs to maintain similar stock developments of different job types. The resulting inventory levels of different jobs run in parallel independently of arriving jobs. The strategy aims at maintaining the same pace of inventory changes of different product types as can be seen in Figure 5. This strategy is suitable to assign resources to jobs from equally important customers with different ordering volumes.

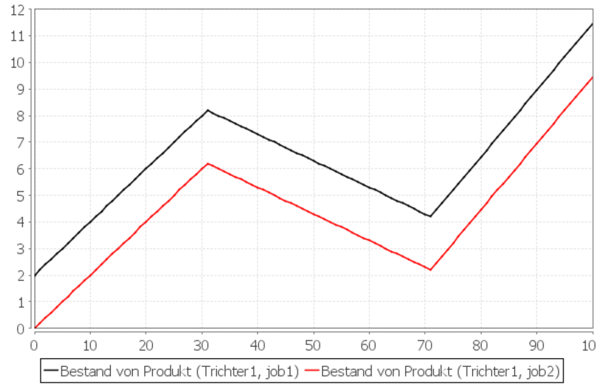

Figure 5: Stock developments (black and red) under stock-development-proportional strategy

Demand-proportional: In this strategy each resource executes jobs according to the proportion of demands. Demands can be defined at the sinks of the system where customers are replicated. If the demand rates at sinks are defined as d^p, the resulting limiting performance is calculated as:

$$\mu(i) = \frac{d(i)}{\sum_{j=1}^{n} d(j)} * \mu$$

Depending on the different demands over time the resource capacities are controlled. An example for this strategy would be the higher prioritization of a lead buyer compared to followers.

Absolute priorities: each resource executes jobs according to absolute job priorities. As long as there are highest priority jobs waiting in front of a resource, the resource capacity is completely dedicated to this job before executing the others. The resulting limiting performance for the product type of the currently highest priority jobs equals the limiting performance of the funnel and therewith the total capacity of the resource.

Relative priorities: This strategy suggests that each resource executes jobs according to previously defined relative priorities of different jobs. If the priority of a product is defined as p^i, the resulting limiting performance for each job is:

$$\mu(i) = \frac{p(i)}{\sum_{j=1}^{n} p(j)} * \mu$$

Relative priorities are equivalent to a fixed proportional assignment of resource capacities to the different job types. This prioritization can also be changed over time, which can be seen in Figure 6 that shows the prioritization of two job types over time and the resulting stock developments. The relative priority of job 1 (black line) is at the beginning higher than the one of job 2 (red line) while at time step 30 this situation turns the other way around. The entire time both jobs are executed, but with different resource capacities.

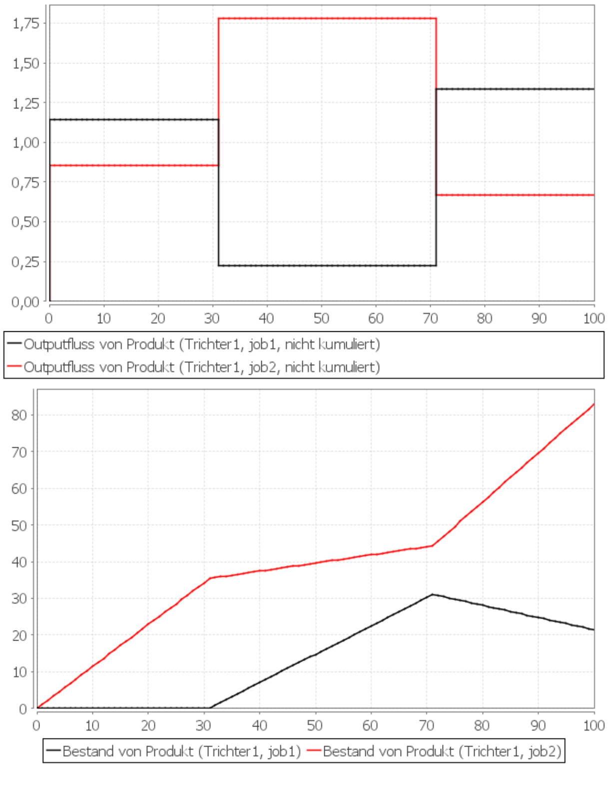

Figure 6: Stock developments (black and red) under relative priorities strategy

Arrival order: Following this strategy, each resource executes jobs according to the arrival order (FIFO, LIFO, etc.). This case is just another example of priorities and therefore not explicitly mentioned here.

Waiting time proportional: This strategy balances waiting times in front of resources which is applicable to jobs that include perishable goods for example. The jobs with longest waiting times in front of the machine are executed next.

Remaining time proportional: This strategy prioritizes jobs according to the remaining time until delivery to customer. Each resource assigns its capacities according to the urgency of the order.

5. APPLICATION EXAMPLE

In logistics networks, these strategies must be defined for several resources separately and the combination ultimately defines the performance of the system. The application example within this paper is an abstract supply chain of several stages that compares a push strategy with a pull strategy. The supplier delivers raw materials to the first production stage where semi-finished goods are produced. In the next stage goods are finished and in the last step they are customized for the delivery to the customer. Two different products are produced and supplies are subject to variability. The objective is the quick satisfaction of customer demands within the supply chain. External conditions for both strategies are the same and they run in parallel so that a direct comparison can be made. The structure of the modeled supply chain is shown in Figure 7.

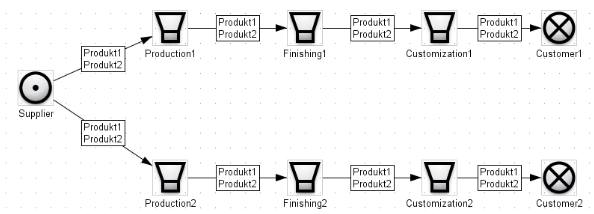

Figure 7: Structure of supply chain application example

The push strategy applies a combination of the arrival-proportional and stock-proportional resource allocations strategies and the particular elements react on the predecessor operations. More specifically, the production element applies the arrival-proportional resource allocation, the finishing element the stock-proportional allocation and the customization element only passes on the demanded products to the customer, if available. The pull strategy contrarily applies demand proportional strategies that are focused on successor operations. The customization element executes jobs according to demands coming from the customer and accordingly allocates resource capacities. The finishing and production elements apply the exact same proportion of resource allocations in order to fill up outflowing product types at the successor's inventory.

Three scenarios have been tested that are differing in the respective replenishment variability coming from the supplier. Within the first scenario, the replenishment variability of both products is very low, in the second scenario it is high for product 1 and in the third scenario for both products. This replenishment uncertainty represents unreliability and unpredictability of resupplies in the supply chain.

The study aims at exploring the effects of these different allocation strategies of every stage of the supply chain on the objective of customer satisfaction. Therefore, the stock developments at the customization stage are compared in order to uncover stock-outs as indicators of the inability to deliver to the customer. The following diagrams show the stock developments of the customization elements for the two product types as a result of different resource allocation strategies under three scenarios. The first diagram always shows the inputs from the supplier (to illustrate the variability), the second one the stock developments at the customization element applying the push-strategy and the third one the corresponding element using the pull strategy.

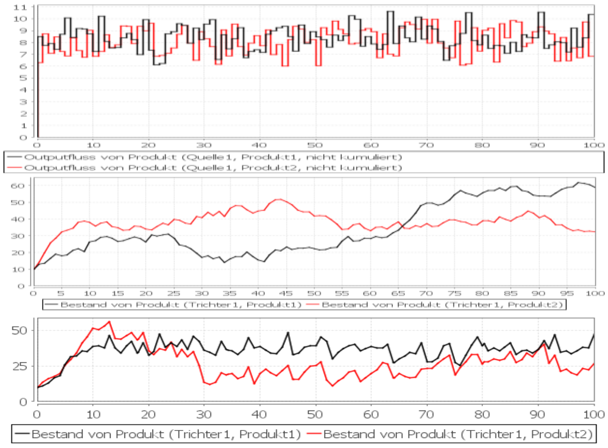

Figure 8: Supplier inputs and stock developments at final SC-stage under push and pull strategy and low replenishment variability

The first scenario (see Fig. 8) shows that both strategies are able to handle the low degree of supply uncertainty for both products and allocate resources effectively to ensure satisfaction of customer demands. The second scenario (see Fig. 9) has a higher replenishment variability for one product (black) that for the other (red). While the push-strategy only leads to few stock-outs and is mostly able to adjust to this variability coming from the supply side, the pull strategy results in several stock-outs at the last stage. This occurs, because the resources have been allocated based on demands only without taking actual available materials into account and this results into wastage of available resources.

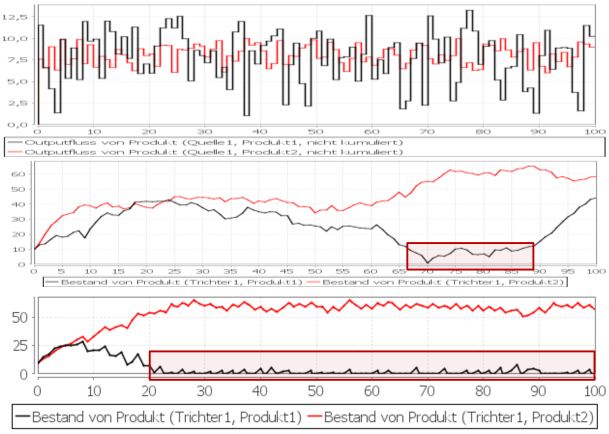

Figure 9: Supplier inputs and stock developments at final SC-stage under push and pull strategy and high replenishment variability for one product

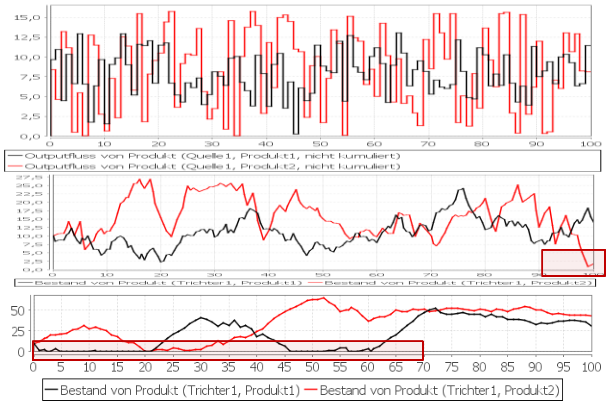

Figure 10: Supplier inputs and stock developments at final SC-stage under push and pull strategy and high replenishment variability

In the last scenario (see Fig. 10), the push strategy enables one to avoid any stock-out situation using the same resource capacities like the pull strategy that results into several stock-out situations. These are the by far better results due to the focus on the supply side in a situation where supply uncertainties are very high. The results of the study imply a direct relationship between the variability of resupplies and the advantageousness of a push or pull strategy in terms of resource allocation. While the pull strategy in this example is well-suited for stable replenishments, with increasing variability the system's performance is higher under an application of the push strategy. This study only considers customer satisfaction as objective and does not incorporate costs or other objectives that will need to be included in further research. It shows, however, the simple implementation of different resource allocation strategies in mesoscopic simulation models and the flexible adjustment to more complicated supply chains.

6. CONCLUSION

The complexity of resource allocations in supply chains is very high due to the different characteristics of jobs and supply chains and the resulting scenarios that complicate decision making in these situations. In order to facilitate an analysis and decrease the complexity, this paper provides a classification scheme for resources and jobs in logistics networks and supply chains and a description of resulting decision scenarios. Based on these analyses, different modeling techniques have been presented as well as the respective implementation of resource allocation strategies within the simulation models. The suitability of the mesoscopic simulation approach for supply chains necessitates a simple realization of different resource allocation strategies. These can be analytically described, because the corresponding mesoscopic simulation elements - multichannel funnels - are also completely analytically described. Different prioritization rules have been presented and their implementation using the software MesoSim has been shown. A model of several stages has been developed to test and analyze different combinations of these strategies. The example illustrates the straight-forward replication of the desired allocation strategies in the mesoscopic simulation model and software MesoSim. Further research will be dedicated to the combination of different strategies within one system to enable supply chain managers to quickly test and analyze different resource allocation strategies for their supply chains and how the mesoscopic simulation models support the decision making process.

REFERENCES

Abramson, D., Buyya, R. and Giddy, J., 2002. A Computational Economy for Grid Computing and Its Implementation in the Nimrod-G Resource Broker In: *Future Generation Computer Systems (FGCS) Journal*, 18(8), 1061-1074

Chavez, A., Moukas, R. and Maes, P., 1997. A Multi-agent System for Distributed Resource Allocation, *ACM Press*, 323-331

Gomoluch, J. and Schroeder, M., 2003. Market-based Resource Allocation for Grid Computing: A Model and Simulation. In: *Proceedings of the First International Workshop on Middleware for Grid Computing*, Rio de Janeiro

Hennies, T., Reggelin, T., and Tolujew, J., 2012. Mesoscopic Supply Chain Simulation, In: Bruzzone, Gronalt, Merkuryev, Piera, Talley eds. *Proceedings of the International Conference on Harbor Maritime and Multimodal Logistics M&S*, pp.85-90

Kelton, D.W., Kasaie, P., Vaghefi, A. and Naini, S.G.R., 2010. Toward optimal resource-allocation for control of epidemics: An agent-based simulation approach. In: *Proceedings of the 2010 Winter Simulation Conference*, 2237-2247

Reggelin, T. 2011, *Mesoskopische Modellierung und Simulation logistischer Flusssysteme*, Otto-von-Guericke-Universität Magdeburg

Reggelin, T., Tolujew, J., 2011, A Mesoscopic Approach to Modeling and Simulation of Logistics Processes. In: Jain, S., Creasey, R. R., Himmelspach, J., White, K. P., Fu, M. (Eds.) Proceedings of the 2011 Winter Simulation Conference,IEEE, Piscataway, pp. 1513-1523

Reggelin, T., 2011b, Mesoskopische Modellierung und Simulation logistischer Flusssysteme. In: Wimmer, T., Grosche, T., eds. Flexibel-Sicher-Nachhaltig: Kongressband 28. Deutscher Logistik-Kongress, Hamburg, DVV Media Group, pp. 287-290

Schenk, M., Tolujew, J., Reggelin, T., 2010, A Mesoscopic Approach to the Simulation of Logistics Systems. In: Dangelmaier, W., Blecken, A., Delius, R., Klöpfer, eds. Advanced Manufacturing and Sustainable Logistics, Berlin, Springer, pp. 15-25.

Schenk, M., Tolujew, J., Reggelin, T., 2009. Mesoscopic Modeling and Simulation of Logistics Networks, In: Preprints of the 13th IFAC Symposium on Information Control Problems in Manufacturing, Moskau, pp. 287-290

Schönsleben, P., 2011. Integrales Logistikmanagement: Operations und Supply Chain Management innerhalb des Unternehmens und unternehmesübergreifend, Springer-Verlag Berlin Heidelberg, 17-19

Schuster, T., 2012. Modellierung, Integration und Analyse von Ressourcen in Geschäftsprozessen, Dissertation, KIT Scientific Publishing, Kalsruhe, 35-49

Siemens Product Lifecycle Management Software Inc., Siemens PLMS Inc. 2010. Tecnomatix Plant Simulation 10 Step-by-Step Help, Available from: http://m.plm.automation.siemens.com/en_us/Images/PlantSimulation_Step-By-Step_ENU_tcm1224-143387.pdf pp. 174-181 [accessed 28 February 2013]

Ventana Systems Inc., 2012. Allocation by Priority, Available from: http://vensim.com/allocation-by-priority-alloc-p/ [accessed: 28 February 2013]

AUTHORS BIOGRAPHY

Til Hennies is a project manager at the Institute of Logistics and Material Handling Systems at Otto-von-Guericke-University Magdeburg and Fraunhofer Institute for Factory Operation and Automation IFF. He holds a degree in industrial engineering and management from Otto-von-Guericke University Magdeburg and a Master's degree in Engineering Management from the Rose-Hulman Institute of Technology, IN, USA. His main research and work interests are logistics system modeling and simulation.

Yvonne Boersch is a Master student at the Otto-von-Guericke-University Magdeburg and graduate research assistant at the Fraunhofer Institute for Factory Operation and Automation IFF. She received a Bachelor's degree in industrial engineering and management logistic from Otto-von-Guericke University Magdeburg.

Juri Tolujew was a lecturer and then assistant professor at the Technical University of Riga from 1976 to 2001. Since 2001, he has been a Research Manager at the Fraunhofer Institute for Factory Operation and Automation IFF in Magdeburg. He earned his Habilitation in Simulation Technology from Otto-von Guericke-University Magdeburg in 2001. Since 2005, he has also been a member of the faculty of the Institute of Logistics and Material Handling Systems at Otto-von-Guericke University Magdeburg. His main research and teaching interests are the mathematical modeling and simulation of logistics systems and networks.

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 and management from Otto-von-Guericke University Magdeburg and a master's degree in Engineering Management from Rose-Hulman Institute of Technology in Terre Haute, IN.