

MESOSCOPIC MODELING AND SIMULATION OF LOGISTICS SYSTEMS

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Abstract: Meeting the challenge of ensuring dependable and secure logistics systems in changing competitive environments necessitates ongoing adaptation of logistics networks. Therefore, suitable methods of modeling and simulation are needed to support the adaptation process. The mesoscopic approach presented here eliminates the deficits inherent in both the microscopic and the macroscopic approach to simulation. The presented mesoscopic approach monitors quantities of objects that belong to a logical group instead of individual flow objects. The results are not obtained by counting individual objects but by using mathematical formulas to calculate the results as continuous quantities in every step Δt of the discrete modeling time. Thus, the mesoscopic approach can be described with the phrase “discrete time/continuous quantities”. The basic components of the mesoscopic modeling approach are multichannel funnels, multichannel transportation elements, sources and sinks. Furthermore, this approach differentiates different product types.

Keywords: Mesoscopic, Modeling, Simulation, Logistics Systems

1. Introduction

Two major trends can be identified in production and logistics networks. They are becoming more international and the number of actors is increasing. The rate of globally sourced goods in German enterprises is expected to increase from around 38% in 2006 to more than 50% by 2010. Roughly 75% of all German industrial enterprises expect to increase their foreign sales. More than half of these enterprises will increase their number of international production sites [1]. In some cases, enterprises of the machinery manufacturing industry cooperate with more than 2000 suppliers and several hundred logistics service providers [2]. The growing number of actors and the growing internationality increase these networks' complexity and thus their sensitivity. Furthermore, customer demands on delivery times and flexibility, numbers of variants and costs are increasing.

The increasing sensitivity to disturbances and the growing customer demands make dependable and secure production and logistics systems an important competitive advantage. Enterprises have to be able to react dynamically to changing market environments as well as disturbances and unforeseen events by adapting their logistics networks.

Therefore, suitable tools are needed to immediately assess the effects of changing conditions and disturbances so that qualified measures such as the reconfiguration of a logistics system can be devised and implemented. Mesoscopic modeling and simulation is a method to

quickly and effectively complete analysis and planning tasks related to production and logistics systems.

2. Dynamic Modeling Approaches

Two classes of dynamic models are widely used to reproduce process sequences in flow systems, namely macroscopic and microscopic models. Macroscopic models are based on differential equations, while microscopic models are based on the principles of discrete-event simulation [8]. Both approaches have several deficits.

Macroscopic models are very abstract and therefore not very accurate in their presentation of numerous different logistics objects (products, resources, etc.) and control strategies that need to be considered when solving practical problems. Microscopic simulation models represent real world objects with a high level of detail. Consequently, models in this class are often very complicated and slow and their creation and implementation are time and labor consuming.

When disturbances occur in production and logistics systems, both microscopic and macroscopic models are frequently unsuited for dealing with pressing analysis and planning tasks and therefore ensuring the logistics process is dependable and secure.

The distinct advantage of the mesoscopic approach is its easier, faster and less laborious creation of models that are easier to reconfigure than microscopic models but nevertheless allow the modeling of dynamic characteristics of analyzed processes on a level equivalent to discrete-event simulation. Figure 1 presents a comparison of the three modeling approaches in terms of simulation effort and level of detail.

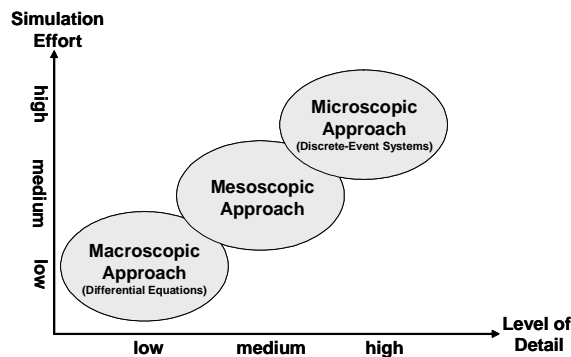


Figure 1. Dynamic modeling approaches

3. Mesoscopic and Microscopic Approaches

In many cases, the microscopic simulation of flow systems inherently contains the mesoscopic view [7]. Both the performance requirements and performance resources are often provided in an aggregated view. Furthermore, the performance results that have to be estimated with the simulation are often required in an aggregate view.

The microscopic approach, however, often disaggregates complete orders and quantities of resources into individual objects when performance processes are re-produced as in Figure 2. The calculation of performance results as conventional performance indicators based on event streams aggregates the data anew.

Established statistical procedures are used to calculate means and confidence intervals and estimate probabilities and distribution functions. Stable and interpretable results are only delivered when the effects of the modeled processes have been observed many times.

Therefore, the cost of implementing detailed parameters de-scribed by distribution functions is very high. Numerous (and long) simulation runs are necessary.

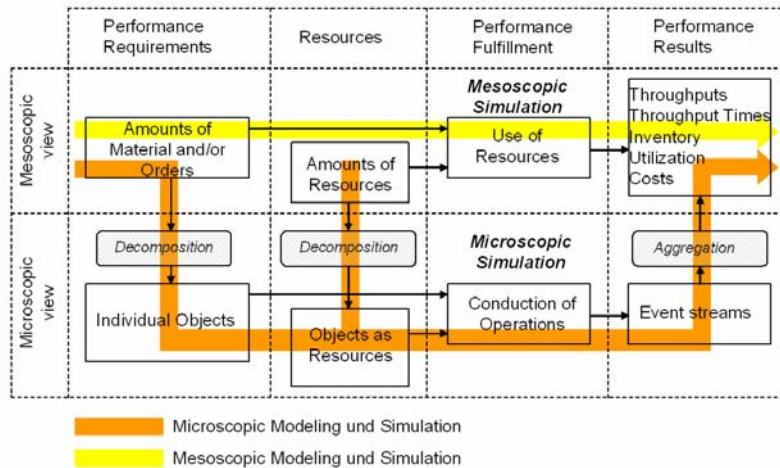


Figure 2. Mesoscopic and microscopic simulation views

As depicted in Figure 2, microscopic simulation is often employed to arrive at pure mesoscopic results from problems presented in the pure mesoscopic view. This “detour” is quite complicated and costly because it involves the decomposition and aggregation of data. Data loss and deformation seem unavoidable. Direct and dynamic transformation of mesoscopic input data (performance requirements and/or resources) into mesoscopic performance results without the aid of event-driven process modeling is the advantage of mesoscopic simulation.

4. The Mesoscopic Approach

The term mesoscopic simulation was first introduced in logistics in traffic simulation [3]. Nevertheless, a clear definition of the term mesoscopic has not been developed yet. In traffic simulation, the term mesoscopic is often applied to refer to a combination of macroscopic and microscopic simulation.

The term mesoscopic has also been applied to supply chains [4], however, not to refer to a new class of modeling but rather a special class of models based on differential equations. A clear concept of the mesoscopic approach to modeling and simulating the flow of pedestrians has been described in [9].

The mesoscopic approach monitors quantities of objects that belong to a logical group (e.g. a batch, a delivery, etc.) instead of individual flow objects. The results are not obtained by counting individual objects but by using mathematical formulas to calculate the results as continuous quantities in every step Δt of the discrete modeling time. Thus, the mesoscopic approach can be described with “discrete time / continuous quantities”.

The basic components of the mesoscopic modeling approach are multichannel funnels (see Figure 3) [5], multichannel transportation elements, sources and sinks. Furthermore, the model differentiates different product types.

The possibilities to control the modeled processes are similar to those of discrete-event simulation since any conditions can be checked in every step Δt and corresponding changes can be implemented in the system. Any user defined interpretations of primary simulation results can be made on the basis of the process data a mesoscopic model delivers. Figure 4 presents a model system structure of a mesoscopic model.

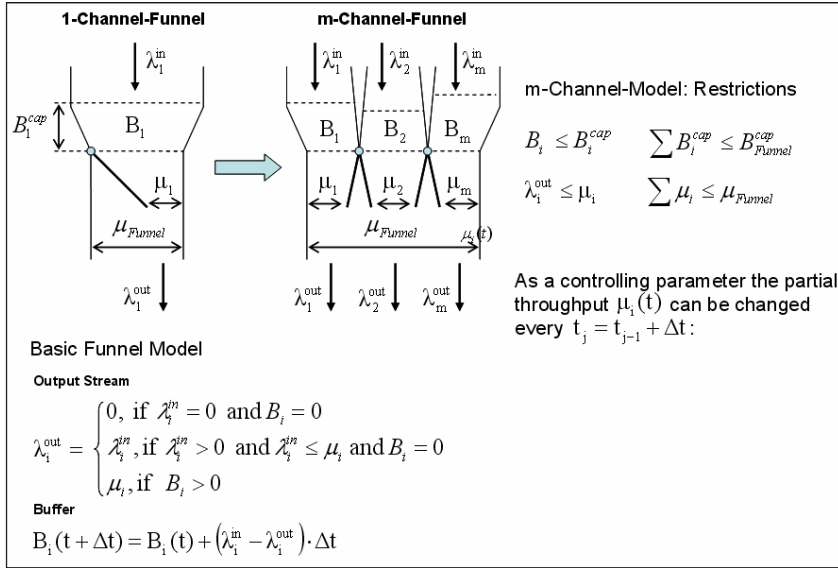


Figure 3. The funnel as a basic component of a mesoscopic model [6]

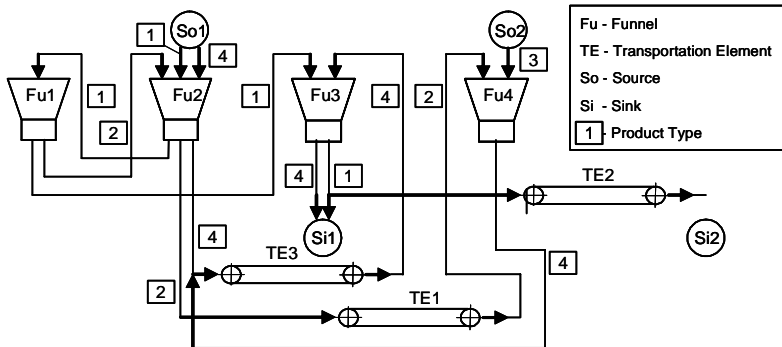


Figure 4. Exemplary system structure of a mesoscopic model

5. Application of the Mesoscopic Approach

Figure 5 presents the structure of the mesoscopic model developed. The mesoscopic approach was applied to model and simulate some of the processes in a logistics service provider’s hub. The example shows that the mesoscopic approach is a suitable method for quickly dealing with analysis and planning tasks, calculation of key performance indicators and comparison of different variants of control strategies in production and logistics systems. In order to keep the model clear, only a small part of the distribution network of a logistics service provider is modeled. However, the mesoscopic approach allows easily handling models of any size since the computing time does not depend on the number of modeled objects.

The model represents the receiving area, the intermediate storage, the consolidation, the shipping area and the transportation to the next processing center. Three two-channel funnels are the main components of the model. Furthermore, two transport elements for modeling the transport to the two destinations are used. The two product types represent the two different destinations of the outgoing goods. For Δt 1h was used.

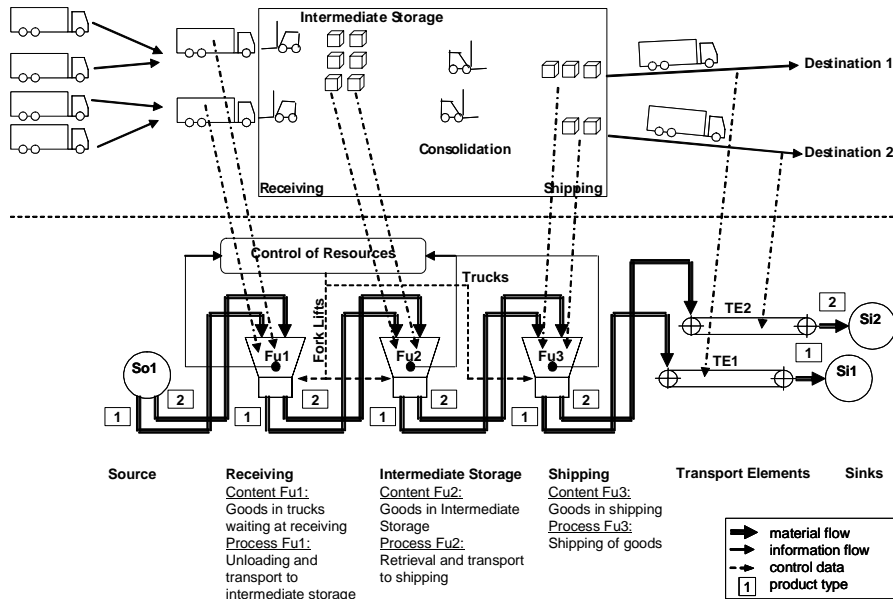


Figure 5. Mesoscopic model of processes in a logistics hub

In every Δt the preceding component determines the input stream of the succeeding component (funnel or transportation element) and the resource control determines the output stream of a component. The content of a component (funnel or transport element) is the difference of these two streams.

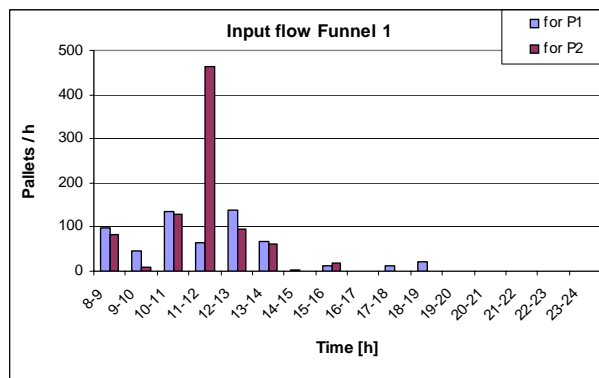


Figure 6. Input streams of the hub

The input data of the model have been prepared according to the choice of Δt . Figure 6 shows the real input stream of the logistics hub for the two product types. Figure 7 depicts the maximum throughputs of the forklift team in pallets/h distributed over the day. The maximum throughputs do not depend on the location in the hub where the forklifts are doing their jobs. The capacity of the resource of outgoing trucks is limited to 1 truck/h that can leave to destination 1 and 2 trucks/h to destination 2. A truck is only allowed to leave the hub if the content of funnel 3 reaches 50 pallets.

The resource forklifts determines the maximum throughput of funnel 1 and 2. The resource of outgoing trucks determines the maximum throughput of funnel 3. In every Δt a change of

the assigned capacities allows the control of the model. Any strategies of control can be represented and compared with the model.

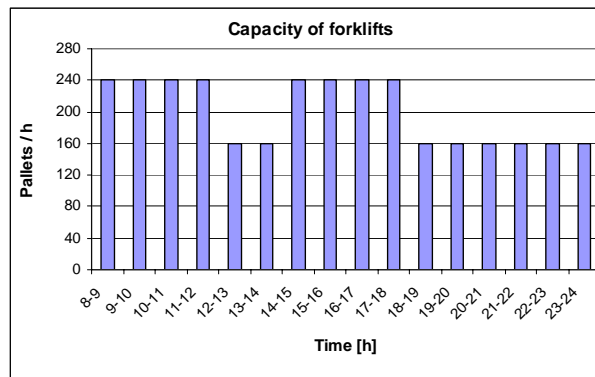


Figure 7. Capacities of the forklifts

Exemplary, the following three control strategies of the resource forklift in funnel 1 and 2 are compared:

- Strategy 1:
This strategy assigns fixed fork lift capacities. The same capacity is assigned to every funnel for every product type.
- Strategy 2:
This strategy assigns to funnel 2 only as much capacity that maximum one truck per hour and per product type can leave the hub. The remaining capacity is assigned to funnel 1.
- Strategy 3:
This strategy assigns the capacity proportional to the contents of the funnels.

Furthermore, in every Δt it is possible to choose a different strategy and to adapt all strategies.

For any component of the model and any product type, the following five variables are sequentially calculated for every Δt (see Figure 8):

- Store_Start_Δt: content at the beginning of interval Δt ,
- Input_Δt: input flow during interval Δt ,
- Power_Δt: assigned maximum throughput during interval Δt ,
- Output_Δt: calculated output flow during interval Δt and
- Store_End_Δt: content at the end of interval Δt .

Figure 8 depicts the product amounts as real numbers which corresponds to the modeling principle of “continuous amounts”. Output data is recorded in tables and formatted graphically in quantity-time-diagrams. Figure 9 depicts the contents of the funnels and transport elements for the three different resource allocation strategies. Strategy 3 works best since all the goods can be loaded onto the outgoing trucks during the work day. In strategy 1, content remains in funnel 1 (waiting trucks at the receiving) and in strategy 2, content remains in funnel 2 (intermediate storage). In the end of the simulation, small amounts of products remain in funnel 3 for all three strategies because the amount of 50 pallets to fill a truck has not been reached yet.

	Time= 12		Strategy= 3		
	Store_Start Δt	Input Δt	Power Δt	Output Δt	Store_End Δt
Source 1 (System Input Flows)					
for P1				63,00	
for P2				462,00	
Funnel 1 (Trucks unload)					
for P1	32,86	63,00	28,68	28,68	67,18
for P2	31,88	462,00	147,75	147,75	346,13
Funnel 2 (Store)					
for P1	112,26	28,68	33,59	33,59	107,36
for P2	100,23	147,75	29,99	29,99	218,00
Funnel 3 (Trucks load)					
for P1	32,88	33,59	50,00	50,00	16,46
for P2	39,89	29,99	100,00	50,00	19,88
Transport 1					
for P1	100,00	50,00		50,00	100,00
Transport 2					
for P2	50,00	50,00		0,00	100,00
Sink 1 (System Output Flow)					
for P1		50,00			
Sink 2 (System Output Flow)					
for P2		0,00			

Figure 8. The Kernel of the mesoscopic model

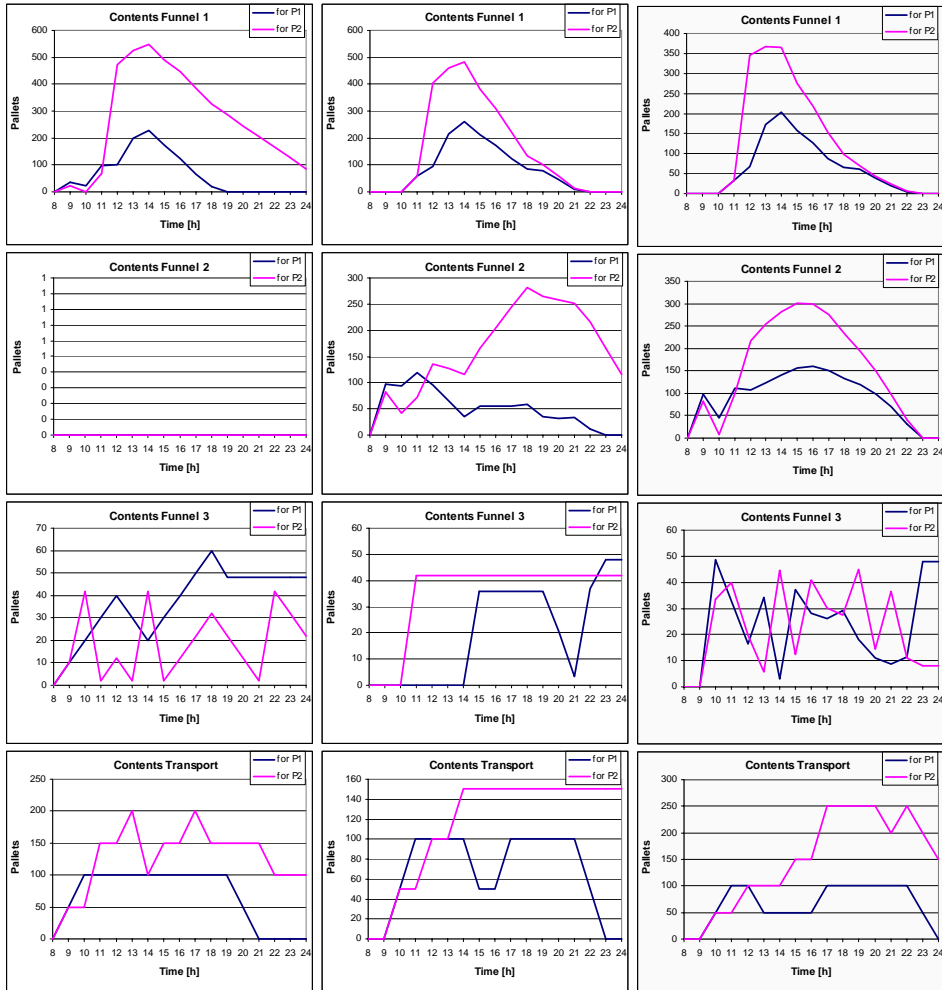


Figure 9. Outcome of three different resource allocation strategies (left: strategy 1, middle: strategy 2, right: strategy 3)

6. Summary

The mesoscopic approach is a suitable method for quickly dealing with analysis and planning tasks in production and logistics systems. Moreover, it bridges the gap between common microscopic and macroscopic models. The development of mesoscopic models is associated with less effort than for traditional discrete event simulation models. Advantages of the mesoscopic approach are the following:

- high flexibility in preparing input data for the simulation (e.g., formulas, established distribution functions, empirical functions or real event protocols can be used),
- universal and easy structure of the internal model data (see figure 6),
- no restrictions for modeling complex control algorithms,
- high performance for computing the model code,
- clear presentation of simulation results,
- no need for using commercial simulation software.

Future research tasks are, among other things, the development of a systematic approach for determining Δt and the proof of transferability of the mesoscopic approach to other application domains.

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