



Klumpp, Matthias (Hrsg.)

**ild Schriftenreihe Logistikforschung  
Band 21**

Logistics capacity management –  
A theoretical review and  
applications to outbound logistics

Große-Brockhoff, Marlies  
Klumpp, Matthias  
Krome, Dirk

Große-Brockhoff, Marlies/Klumpp, Matthias/Krome, Dirk

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FOM Hochschule für Oekonomie & Management  
ild Institut für Logistik- & Dienstleistungsmanagement  
Schriftenreihe Logistikforschung

Band 21, Oktober 2011

ISSN 1866-0304

Essen

The authors thank Hella Abidi for correction references to this publication.

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**List of abbreviations**

3PL	Third party logistics provider
BME	Bundesverband Materialwirtschaft Einkauf und Logistik e.V.
DIN	Deutsche Industrie Norm
DM	Demand management
FAC	Freely assignable capacities
F/G	Finished goods
SCM	Supply chain management
WMS	Warehouse management system

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## 1. Introduction

### 1.1. Problem description

The economic recession, as a consequence of the worldwide financial crisis, is nearly conquered and the economy is recovering again. Rising demand implicates an increasing transport volume for the industry, which has already caused a shortage of shipping space in road traffic, rail traffic, air and sea freight. Through rising tonnage carried and marginal transport capacities, price increases are expected for all modes of transport. This arises from research by BME (Bundesverband Materialwirtschaft Einkauf und Logistik e.V., a federal association for purchasing and logistics) in which 165 carriers and logistics service providers were surveyed. Furthermore it shows a trend towards more flexibility within the supply chain, as well as demand for sufficient capacity from the logistics service providers. For many companies these requirements are more important than price compared to their competitors. The trends arising from this current survey (survey period: September to October 2010) point out the increasing importance of capacity management in the logistics field.<sup>1</sup>

The concept of capacity management originates from production planning and control. Capacity can be defined as “the potential of an economic or technical entity – of any type, size and structure – within a period of time.”<sup>2</sup>

The demand for products or services of many companies fluctuates and can be forecast only with variable accuracy. This unstable demand is accompanied by limited variable capacities and it is the challenge of capacity management to balance capacity demand and supply at the optimal level.<sup>3</sup> The concept of capacity management can be transferred to outbound logistics as well, where variable demand from customers is accompanied by limited capacity of storage and transport. At the same time customers require high flexibility and short lead-time, which is a huge challenge for capacity management of the production plant or the logistics service provider. At this a company has to define an adequate strategy for capacity management and has to implement the selected strategy successfully with appropriate software solutions.<sup>4</sup> From the above-mentioned trends capacity management will be assigned a part in distribution management in future for industrial companies, as well as to logistics service providers, in order to be competitive in the market and fulfil customers' requirements in a cost-efficient and flexible manner.

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<sup>1</sup> Cp. BME (2010), date 12.03.2011.

<sup>2</sup> Kern, W. (1962), p. 27, translation from German.

<sup>3</sup> Cp. Pfohl, H.-Chr. (2004), p. 167.

<sup>4</sup> Cp. BME (2010), date 12.03.2011.

## 1.2. Objectives

The objective of this paper is the application of the capacity management concept to outbound logistics. Capacity management with the adjustment of capacity demand and supply is a standard concept for industrial production. In the area of distribution, logistics capacity management does not yet cover a large area. Many industrial companies do not manage the capacity of the distribution warehouses efficiently and especially for smaller logistics providers, the requirements for flexibility as well as fluctuating quantities challenge the capacity management. In connection with this, the question of capacity management in the warehousing of finished products in addition to interim storage and transport to the customers by manufacturers and logistics service providers will be outlined and elaborated. Solutions for efficient capacity management should also encompass the customers' flexibility requirements.

The case study for this paper will be WINGAS Transport, a distributor of natural gas. The distribution is done by a pipeline system placed in Germany. It supplies customers with natural gas from Russia and Great Britain. Due to a static infrastructure, great amounts of natural gas can't be transported efficiently by road, capacities have to be planned and managed precisely. Legal obligations additionally complicate the capacity management by setting requirements for example for the design of entry and exit capacities of the pipeline system. Not least, the changing demand for natural gas has to be considered in the planning of constructing projects for existing or new pipeline capacities. The central questions are:

- How can the transport capacity for natural gas be managed efficiently, especially if the customers' demand fluctuates and is dependent on different factors?
- How can transportation capacities for the future with fluctuating demand and unknown developments be managed efficiently?

## 1.3. Scope of work

The theoretical analysis of this paper is the subject of capacity management in production, which has been already described comprehensively in specialist economics literature. The basic aspects of capacity management (requirements, supply and adjustments) are transferred and analysed subsequently under the field of logistics, while the focus is on outbound logistics, subdivided into warehousing and transportation.

At the beginning of chapter 2, capacity management is integrated in the context of general organisation and common terms and definitions are specified. Following that



capacity management is divided into planning and adjustment. Capacity planning includes the determination of requirements and supply. After the specification of requirements and supply are established they have to be adjusted in order to operate the processes in the most efficient way. Therefore different possibilities are available, which are outlined in chapter 2.4. On the one hand, capacity demand and supply can both be adjusted. Furthermore, methods of planning in operations research are briefly listed. On the other hand scheduling is an important way to adjust capacity. The processing time, which is part of the scheduling process, can be reduced to efficiently utilise capacities.

The theory of capacity management is subsequently applied to the field of logistics in chapter 3. The logistics goals have a significant effect on the processes and are described at the beginning. Further to this the general capacity theory in logistics influences transportation especially and is presented in chapter 3.2. After determination of terms and definition in connection with this, the current development of the transport market is outlined. In addition revenue management is specified, as one example of capacity management.

Following that, due to the comprehensive function of the logistics term, outbound logistics is defined to narrow the complexity of the logistics field. Finally, capacity management in outbound logistics for warehousing and transportation process is discussed in chapter 3.4. Capacity requirement and supply planning as well as capacity adjustment are worked out in detail for both operational functions.

Chapter 4 shows the application of capacity management for one transport company, WINGAS Transport. It is an example for a specific sector of logistics. Beside the capacity management for the daily business the planning of future capacities is also shown.

In the conclusion of the paper the results and solutions are summarised with reference to the central questions. Furthermore future logistics trends with corresponding impacts for capacity management in outbound logistics are forecast.

## 2. Capacity management in production

### 2.1. Organisational integration

In the course of globalisation the sphere of activity of most of the manufacturers changed dramatically. It became more dynamic and unpredictable due to expansion into international markets and consequently increased competition.<sup>5</sup>

The principal task of manufacturing companies is creation of value through transformation of input (materials, machines, manpower, services) to valuable output (products and services), offered to the customers. However, the manufacturers are confronted with the continuous challenge of satisfying the customers' requirements in the face of huge competition. As a consequence time, quality, costs and flexibility are critical factors which can be decisive for the success of a producer.<sup>6</sup>

In order to achieve the objectives related to these factors, production management is required. Different definitions of production management exist, which will be described in the next chapter. Certainly the main part of production management is production planning and control which is "to plan and control the manufacture of products by a company with reference to volume, schedule, resources and input factors and costs."<sup>7</sup>

Production management can be generally separated into structural and process organisation. Structural organisation, which is responsible for production tasks, comprises: production planning with production rough planning; planning the production program; and capacity and maintenance planning. Process organisation on the other hand, which includes the service exchange between the organisational units, is responsible for the production strategy (layout planning, etc.), production plan (optimum size of order) and capacity management in relation to machine scheduling.<sup>8</sup>

Consequently production planning and control pursues the following objectives:<sup>9</sup>

- Close adherence to schedules
- High and consistent capacity utilisation
- Short processing time
- Low inventory
- High flexibility

The basis for planning the production program is sales planning, where the demand for each period is fixed. On one hand the information is obtained from existing customer orders, on the other hand the demand is forecast using statistical information and

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<sup>5</sup> Cp. Kuhn, A., Hellingrath, H. (2002), p. V.

<sup>6</sup> Cp. Günther, H.-O., Tempelmeier, H. (2005), p.2-4.

<sup>7</sup> Gienke, H. (2007b), p. 551, translation from German by author.

<sup>8</sup> Cp. Lebefromm, U. (2003), p. 17-20.

<sup>9</sup> Cp. Schuh, G., Roesgen, R. (2006), p. 28.

trends.<sup>10</sup> With the help of sales planning, the primary demand is calculated, which is defined by the gross primary demand less inventory.<sup>11</sup> Finally the production factors also have to be roughly planned by adjusting the demand and supply of resources. The task of production demand planning is the medium-term planning of resources (operating resources, material, labour, etc.) and includes: Lead-time scheduling, capacity demand planning and capacity adjustment.<sup>12</sup>

## 2.2. Terms and definitions

The term production is not consistently defined in specialist literature. In general three meanings can be differentiated:<sup>13</sup>

- Production as a *combination* of factors, which compasses all operational functions;
- Production as a *stage* of the operation process between procurement and distribution;
- Production as a *value-creating* process, i.e. provision of commodities for purpose of consumption.

According to Günther and Tempelmeier production can be defined as “the generation of produced goods (products) from material and non-material sources (production factors) according to specific technical methods.”<sup>14</sup>

Similarly there are different definitions of the term production management. Often production management is specified merely as production planning and control.

A broader definition is derived from Pfeifer: “Duties and responsibilities, human resources, machinery and material have to be applied, controlled and coordinated, so that products and services - the result of operations - are produced in the required quantity and quality, at a fixed point in time with a minimum of charges and capital costs.”<sup>15</sup> The production process consists of separate segments including sub-processes. Segments are combined to organisational entities and are called task systems.<sup>16</sup>

The production of goods is a transformation process. Raw material (input) is converted into products (output) with the help of production factors (throughput). The production factors which are needed for the transformation can be separated into consumable and

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<sup>10</sup> Cp. Nicolai, H., Schotten, M., Much, D. (1999), p. 33-34.

<sup>11</sup> Cp. Steven, M. (2007), p.235-236.

<sup>12</sup> Cp. Schiegg, P. (2003), p. 18-19.

<sup>13</sup> Cp. Corsten, H. (1999), p. 1.

<sup>14</sup> Günther, H.-O., Tempelmeier, H. (2005), p. 6, translation from German by author.

<sup>15</sup> Pfeifer, T. (1996), quoted in Kämpf, R. (2007a), p. 5, translation from German by author.

<sup>16</sup> Cp. Pfeifer, T. (1996), quoted in Kämpf, R. (2007a), p. 5.

non-consumable resources. Consumable resources are raw materials, auxiliary materials, operating materials and pre-products. Non-consumable resources are not expended during the manufacturing process, but are available for the production process on a long-term basis. This includes manpower, properties, construction machinery and other assets.<sup>17</sup> The non-consumable resources are restricted by their capacities. Capacity can be defined as “the potential of an economic or technical entity – of any type, size and structure – within a period of time.”<sup>18</sup>

Generally this can be divided into qualitative and quantitative capacity. *Qualitative* capacity covers the characteristics and other qualities of the capacity (dimensions, allowance of accuracy, etc.). For manpower resources the qualitative aspect is, for example, occupational qualifications. *Quantitative* capacity is the quantitative potential within a certain period of time (machine hours, number and timely availability of manpower, etc.). It can be divided into minimum capacity, optimum capacity and maximum capacity: *Minimum* capacity is the minimum performance necessary for operation from an economic point of view. *Optimum* capacity is the output per time unit, at which the cost per piece is at the minimum. Finally, *maximum* capacity is defined as when the non-consumable resources are continuously in use with maximised intensity within a specific time period. Further capacity can be specified as time, area or functional aspects. The *time* aspect can be a short-term (weekly or monthly) or long-term (yearly) basis. *Area* aspects, for example, could be the individual production unit or a production system. In *functional* aspects capacities can be differentiated into machine capacity, manpower capacity and procurement capacity.<sup>19</sup>

As already mentioned, another important present-day term is flexibility. The manufacturers are forced to shorten the processing time and to respond flexibly to the customer's requirements. In general, flexibility describes the ability of a production line to be operational for different tasks in a defined period of time. The more different these tasks are and the less the restructuring complexity required, the more flexibility is obtained.<sup>20</sup> There are different types of flexibility:<sup>21</sup>

- *Short-term* flexibility: Rebuilding complexity for known tasks;
- *Long-term* flexibility: Complexity for rebuilding of unpredictable modifications in the production program;
- *Product* flexibility: Ability to manufacture known tasks in any sequence;

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<sup>17</sup> Cp. Vahrenkamp, R. (2008), p. 1-2.

<sup>18</sup> Kern, W. (1962), p. 27, translation from German by author.

<sup>19</sup> Cp. Corsten, H. (1999), p. 13-18; Mussbach-Winter, U. (2007), p. 588; Kußmaul, S. (2008), p. 78.

<sup>20</sup> Cp. Kämpf, R. (2007b), p. 69.

<sup>21</sup> Cp. Kämpf, R. (2007b), p. 70.

- *Volume flexibility*: Potential to increase / decrease production activity in consideration of technical and economic aspects;
- *Adjustment flexibility*: Action on flexibility of processing, material flow and information systems in case of complete adjustment of the production program;
- *Enlargement flexibility*: Potential to improve performance of existing production processes by integration of additional processes, material flow and information systems.

Depending on the basic flexibility type, demand and specification of the production process differs.<sup>22</sup>

## **2.3. Capacity planning**

### **2.3.1 Capacity requirements planning**

The basis of capacity requirements is the generation of the production plan, which depends on customer demand. Basically, customer-oriented and market-oriented demand management can be distinguished: With customer-oriented demand planning production follows the orders from customers. This means market fluctuations affect the production directly and therefore the capacity management as well. Another possibility is the market-oriented demand planning, where sales volume is forecasted with the aim of expectation and data gained from past experience. Requirements are that the demand should be relatively constant, the products should be standardised and customers highly sensitive with regard to delivery times. In practice often a combination of these methods is used.<sup>23</sup>

If orders already exist for the goods to be produced, the delivery schedules confirmed to the customers, have to be kept. In the case of manufacturing for stock, production orders can be postponed. Consequently, priority can be given to the production orders with a fixed, requested schedule.<sup>24</sup> This measure will be discussed in chapter 2.4.1. Apart for volume, lead-time batch scheduling is also important for capacity requirement planning. With lead-time scheduling, interdependencies between production orders are shown in a network plan. The results of the scheduling are "milestones referred to capacity resp. capacity groups."<sup>25</sup> This topic will be covered in chapter 2.4.4. Another parameter used to calculate capacity requirements is the process time per capacity unit. In addition to the individual component production time, the changeover time

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<sup>22</sup> Cp. Kämpf, R. (2007b), p. 69.

<sup>23</sup> Cp. Corsten, H. (1999), p. 235.

<sup>24</sup> Cp. Corsten, H. (1999), p. 487.

<sup>25</sup> Cp. Schuh, G., Roesgen, R. (2006), p. 48.

between the batch sizes has to be taken into account. Finally the capacity requirement can be calculated according to the following formula:<sup>26</sup>

$$\text{Capacity requirement / process} = \text{changeover time} + \text{process time} \times \text{order}$$

### 2.3.2. Capacity supply planning

Capacity supply is the available capacity of resources per period, which is calculated for work centres in the production line. The capacity of a resource can be measured in output quantity or based on units of time. A work centre is defined as an organisational unit that “contains a collective of manpower and production infrastructure, to accomplish an amount of work, which does not have to be further divided through comprehensive planning and control.”<sup>27</sup> Basically, capacity can be specified as gross capacity, net capacity or effective capacity.

*Gross capacity* is the output quantity of a machine which operates non-stop in one shift. This calculation assumes the output is consistent and is not influenced by any interruptions. In practical experience the gross capacity amount is typically not achieved. If breakdowns and interruptions are taken into account due to maintenance, team meetings, breaks, etc., it is called *net capacity*. *Effective capacity* is the term used, when the set up time for the machine is also included in the calculations.<sup>28</sup>

Because a work centre consists of manpower and operating resources, capacity can be determined by both factors due to their interaction. On one hand the manpower can be the restrictive capacity and therefore cause a bottleneck. On the other hand the technical resources can impact the output potential.<sup>29</sup>

Furthermore the complexity of the manufacturing can be dissimilar. For example it can be differentiated between one-level and multi-level production. With one-level production the capacity supply is the capability of that one particular machine. For multi-level production which contains multiple manufacturing processes, the capacity is restricted to that of the machine with the lowest output level.<sup>30</sup>

To summarise, the variables which influence the maximum capacity supply of a production unit are: Production intensity, maximum feasible operating time and maximum average usable capacity. The *production intensity* shows the output of one time unit and indicates the speed of the production unit. The *operating time* displays

<sup>26</sup> Cp. Mussbach-Winter, U. (2007), p. 588-589.

<sup>27</sup> Schönsleben, P. (2004), p. 27, translation from German by author.

<sup>28</sup> Cp. Vahrenkamp, R. (2008), p. 89.

<sup>29</sup> Cp. Zäpfel, G. (2000), p. 131.

<sup>30</sup> Cp. Schierenbeck, H. (2003), p. 260.

the time interval for which the resources are effectively available. Finally, the *average capacity* indicates the availability of non-consumable resources within the given time period. There can be a difference between effective machine capacity and effective manpower capacity.<sup>31</sup>

*Capacity of manpower* is dependent on various factors:<sup>32</sup>

- Number of staff per shift
- Average attendance rates
- Working hours per staff and period
- Average number of shifts per day

*Machine capacity* on the other hand is determined by:<sup>33</sup>

- Number of machines
- Degree of utilisation
- Operation hours per time-period
- Number of operators per machine

Both capacities interact and influence the effective production capacity, which is, on the one hand, calculated from effective usable machines and manpower and the effective usable time on the other hand.<sup>34</sup>

## **2.4. Capacity adjustment**

### **2.4.1. Adjustment of capacity demand**

Adjustment of capacity demand is one option if a resource capacity is over- or under-loaded. It is also called adjustment of capacity load. The prevalent adjustment of the capacity demand is the shifting of workload into other periods. In case of capacity over-load (capacity demand higher than supply), production orders or lot sizes can be delayed into the next production period, if the due date of the order contains a certain buffer for delay. Lot sizes can be also split and partially shifted. In the event of capacity under-load (capacity demand lower than supply) upcoming orders can be released ahead of schedule or batch sizes can be increased by bringing orders forward.<sup>35</sup> For timely shifting it has to be considered that it influences the finishing time of the order, and can theoretically only be done, if enough time buffer exists. When the production

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<sup>31</sup> Cp. Corsten, H. (1999), p. 15-16.

<sup>32</sup> Cp. Lebefromm, U. (2003), p. 205.

<sup>33</sup> Cp. Lebefromm, U. (2003), p. 206.

<sup>34</sup> Cp. Lebefromm, U. (2003), p. 205-206.

<sup>35</sup> Cp. Corsten, H. (1999), p. 470.

volume is adjusted not only is the bottleneck released but also the capacities of all other resources in the line, which depend on that production is reduced.<sup>36</sup>

Apart from timely adjustment, it is also possible to distribute the production orders onto other machines or work centres which have sufficient capacity available. In the case that this alternative is feasible, the original finishing times of the orders are kept.<sup>37</sup> Besides that, a modification of a proportion of in-plant production to outsourcing is possible. In the case of capacity over-load, orders can be outsourced to external production. Additional production orders can be manufactured as a subcontractor for other manufacturing firms in the event of capacity under-load.<sup>38</sup>

If the capacity requirement was not sufficiently considered in earlier planning stages, it can lead to waiting lines at the work centre with the bottleneck. If so, priorities can be given within the sequence planning to particular customers or orders that are competing against each other for production capacity.<sup>39</sup> Therefore mainly heuristic methods with priority rules are used. There are different options for priority rules:<sup>40</sup>

- *Shortest* operation time rule: highest priority to the order with the shortest process time at the particular working centre
- *Longest* operation time rule: highest priority to the order with the longest process time at the particular working centre
- Rule of the *highest operation time balance*: highest priority to the order with the highest operation time balance for all work centres in the line
- Rule of the *shortest operation time balance*: highest priority to the order with the shortest operation time balance for all working centres in the line
- *Delivery date* rule: highest priority to the order with the nearest delivery date

Adjustment of capacity demand can be, indeed, linked to disadvantages. For instance, it can lead to an aggravation of the relationship with the customer, if orders are delayed or even cut or cancelled. Furthermore there is a risk in outsourcing production orders to subcontractors, as the quality of the products may differ or orders cannot be produced in time.<sup>41</sup>

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<sup>36</sup> Cp. Mussbach-Winter, U. (2007), p. 591.

<sup>37</sup> Cp. Mussbach-Winter, U. (2007), p. 591.

<sup>38</sup> Cp. Corsten, H. (1999), p. 470.

<sup>39</sup> Cp. Steven, M. (2007), p. 243.

<sup>40</sup> Cp. Günther, H.-O., Tempelmeier, H. (2005), p. 224-225.

<sup>41</sup> Cp. Vahrenkamp, R. (2008), p. 187.



### 2.4.2. Adjustment of capacity supply

In case the adjustment of capacity demand is not sufficient for allocation, the capacity supply has to be adapted. Generally there are three ways to adjust the capacity supply:<sup>42</sup>

- Operation time adjustment
- Intensity adjustment
- Quantity adjustment

On one hand modification of the *operation time* can be reached by extension or reduction of the working time. Therefore overtime or short-time work can be arranged, within legal requirements.<sup>43</sup> Also additional shifts can be established to expand the capacity supply. Working time adjustment measures can be realised on a short-time basis without extensive efforts. Establishing an additional shift is connected with new recruitment and elimination of shifts implicates redundancies. These arrangements are only possible on a longer-term basis.<sup>44</sup>

On the other hand the *intensity of capacities* can be adjusted by revision of the efficiency level of machines or work centres. The effect is a higher output per time unit. In order to realise this, it must first be established that the speed of production may be improved without any affect on the quality of the products.<sup>45</sup>

Characterisation of *quantitative capacity* adjustment is a modification to the number of production resources. As mentioned previously, the establishment or elimination of shifts can be seen as a timely adjustment. Due to the fact that it is connected to engagements and redundancies and as a result with a change of personnel resources, it can also be considered as quantitative adjustment of capacity. Bringing new machines into service or shutdown of work centres are also possible arrangements of quantitative adjustments.<sup>46</sup> As a function of demand trend, this represents an investment in new assets on a long-term basis to increase capacity. Contrariwise if demand is decreasing and the situation involves loss, capacities have to be broken down and concentrated.<sup>47</sup>

These measures of adjustment of capacity supply are associated with different costs. Wages for overtime are connected with surcharges, adjustment of intensity leads to higher asset depreciation and possibly to higher failure rates. Also, the assignment of

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<sup>42</sup> Cp. Lebefromm, U. (2003), p. 52.

<sup>43</sup> Cp. Günther, H.-O., Tempelmeier, H. (2005), p. 216.

<sup>44</sup> Cp. Mussbach-Winter, U. (2007), p. 593.

<sup>45</sup> Cp. Günther, H.-O., Tempelmeier, H. (2005), p. 215; Vahrenkamp, R. (2008), p. 187.

<sup>46</sup> Cp. Günther, H.-O., Tempelmeier, H. (2005), p. 215; Vahrenkamp, R. (2008), p. 187.

<sup>47</sup> Cp. Lebefromm, U. (2003), p. 86-87.

reserve machines may be associated with higher energy consumption and therefore higher charges can occur.<sup>48</sup>

Finally capacities are liable to cost resistance, which means they can be built in the short- or middle term, but reduced only on a long-term basis. Due to this fact the manufacturer is confronted with conflicting goals. On one hand enough capacity is needed to handle the customer orders in time and to be competitive in the market. On the other hand the manufacturing has to be efficient in respect of charges and resources should be working to full-capacity. In the end the strategy of capacity supply is also connected to the capacity of competitors and the industry. If the total market capacity increases, the product price declines. At the same time a strategy of lean production leads to capacity reduction and has to be considered as well.<sup>49</sup>

### 2.4.3. Methods of operations research

Operations research can be defined generally as the “appliance of mathematical methods as preliminary to optimum decisions.”<sup>50</sup> Typical characteristics of operations research are the preliminary decisions, to aim for optimum solutions and to apply mathematical methods. This means that mathematical methods are used to prepare decisions for optimum targets.<sup>51</sup> Methods of operations research are often applied in capacity management. In order to use mathematical methods the problem that needs to be solved must be translated into an idealised model from reality. Therefore the relevant problem has to be defined and displayed in detail and important relations to close-by areas have to be kept. During the assignment of the problem to the model, a problem arises with the formula used to solve it (which is the mathematical model plus the question asked in the real model), which can be solved with mathematical methods and the result can be transferred to reality.<sup>52</sup>

Two different models can be created: An optimisation and a simulation model. With the optimisation model all of the problem’s important factors can be demonstrated in a system of mathematical equations and solved with mathematical methods. To contrast, in simulation models different decisions are tested with experiments or strategies. Most important methods of operations research are shown in the diagram below.<sup>53</sup>

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<sup>48</sup> Cp. Günther, H.-O., Tempelmeier, H. (2005), p. 217.

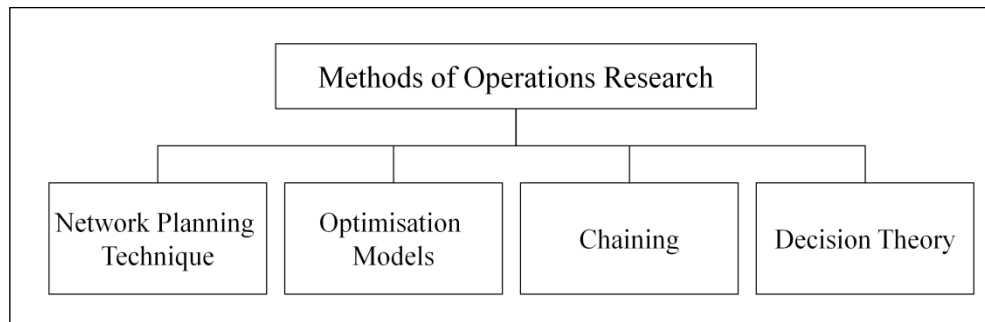
<sup>49</sup> Cp. Lebefromm, U. (2003), p. 86-87.

<sup>50</sup> Müller-Merbach, H. (1988), p. 1, translation from German by author.

<sup>51</sup> Cp. Müller-Merbach, H. (1988), p. 2.

<sup>52</sup> Cp. Müller-Merbach, H. (1988), p. 14-15.

<sup>53</sup> Cp. Hoffmeister, W. (1997), p. 222.

**Figure 1: Methods of operations research**

Source: Hoffmeister, W. (1997), p. 222.

With the network planning technique the shortest lead-time of complex manufacturing processes can be calculated. Optimisation models deliver the best solution for decision problems. In practice linear programming and dynamic programming methods are important. Linear programming is a simplified mathematical method with linear functions. Dynamic programming is used with multi-level production processes and can cope with all problems, an optimum decision for process requests. The target of the chaining theory is the balanced relationship between demand and supply in the delay system. Finally decision theory is used to determine the best possibility in case of mutually exclusive alternatives.<sup>54</sup> In practice the network planning technique is often used in capacity management. Even when the main target is compliance with lead-times, capacity (and/or finance planning) can be carried out either in parallel or successively. With network planning the entire manufacturing process can be illustrated so that time, costs and resources can be seen in an integrated way.<sup>55</sup>

#### 2.4.4. Capacity scheduling

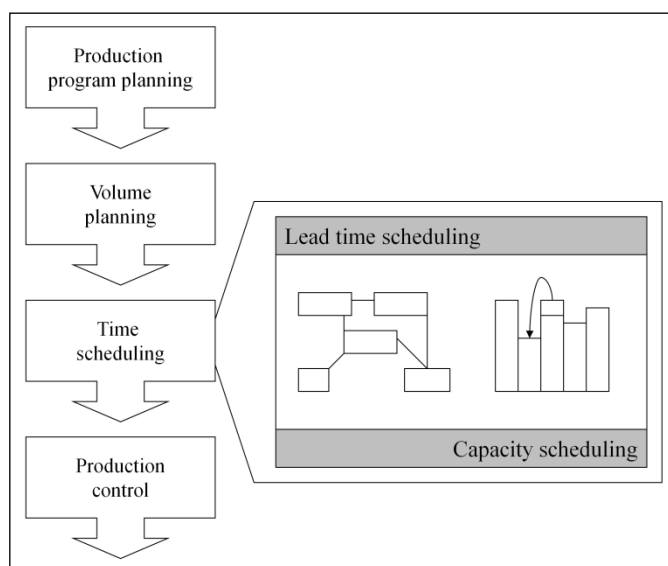
According to GÜNTHER and TEMPELMEIER capacity planning can be separated into aggregated overall planning (long-term basis) and capacity oriented production program planning (short-term basis for a specific period of time). Aggregated overall planning includes environmental changes, economic variations and long-term sales trends in production planning. Consequently resources can be flattened out over a period of time through different measures like overtime or short-time, outsourcing, etc. Generally we can differentiate between two adjustment types of demand and production supply: chase strategy and level strategy. In the case of *chase strategy*, the production quantity follows demand quantity within a specific period. This procedure is certainly only applicable if the resources are high enough to handle demand surges

<sup>54</sup> Cp. Hoffmeister, W. (1997), p. 223; Ellinger, T., Beuermann, G., Leisten, R. (2003), p. 11-14.

<sup>55</sup> Cp. Hoffmeister, W. (1997), p. 276.

and can be variably deployed. The result of this method is the avoidance of storage and related costs, indeed variable production costs can increase. In case of *level strategy*, production quantity stays stable during the period, independently from the demand. The resources are consistent and use the capacity with optimum intensity. On the other hand it leads to storage management. In practice intermediate forms are used with the help of quantitative decision models.<sup>56</sup> Short-term production program planning defines the volume for specific periods. In production planning and control systems this is structured in four steps in the majority of cases: production program planning, volume planning, time scheduling and production control.<sup>57</sup>

**Figure 2: Structure of a conventional production planning and control system**



Source: Günther, H.-O., Tempelmeier, H. (2005), p. 306.

The function of time scheduling is the chronological arrangement of operation procedures and orders. It can be split again into lead-time scheduling and capacity scheduling.<sup>58</sup> The manufacturing process is split into operation procedures, the duration is calculated for each and the start and finish dates are defined. Within lead-time scheduling, capacity restrictions are not considered. Lead-time can be divided into several parts:<sup>59</sup>

- Processing time
- Setup time
- Transport time
- Holding or waiting time

<sup>56</sup> Cp. Günther, H.-O., Tempelmeier, H. (2005), p. 142 and p. 151-154; Kiener, S., Maier-Scheubeck, N., Obermaier, R., Weiß, M. (2006), p. 177.

<sup>57</sup> Cp. Günther, H.-O., Tempelmeier, H. (2005), p. 305-307; Wannewetsch, H. (2010), p. 560-561.

<sup>58</sup> Cp. Kämpf, R. (2007c), p. 194; Günther, H.-O., Tempelmeier, H. (2005), p. 306-307.

<sup>59</sup> Cp. Corsten, H. (1999), p. 457.

With the exception of the lead-time, the process structure is important for the time scheduling. Both criteria can be illustrated in network planning technique, where structure, time, costs and resources can be seen altogether. The network plan is calculated in two different ways: forward scheduling (starting from the initial point) and backward scheduling (starting from the required finish date). With the help of this bidirectional scheduling the critical path, as well as buffer times, can be worked out.<sup>60</sup>

An operation procedure is called critical, if “the maximum available time is equal to the duration. It is called a critical path, if critical operations are following each other nonstop until the end of the project.”<sup>61</sup> The buffer time represents the available time tolerance of the operation procedure. Capacity scheduling follows lead-time scheduling in consideration of capacity restrictions. The task of the capacity scheduling is “grouping of single orders referring to single machines and identification of competition for capacities.”<sup>62</sup> The capacity load of each work centre and capacity group is summarised on a separate account and allocated to the separate machines on a timely basis. The comparison of capacity requirement and supply is called exposure profile. Here the difference between gross capacity and effective capacity has to be taken into account, as already mentioned in chapter 2.3.2. With the help of the exposure profile the workload of the single work centres and machines is identified. The exposure profile can show perfection (compliance of capacity demand and supply), an over-load or an under-load. These discrepancies can be solved through capacity adjustment methods.

#### 2.4.5. Reduction of processing time

As previously mentioned it can lead to serious problems if the order deadlines cannot be met and orders are delayed. To avoid these kinds of problems, it has to be ascertained if the processing time can be reduced to keep the delivery schedules.<sup>63</sup> A reduction of the processing time can lead to higher capacity utilisation as well. This can be achieved amongst others by miscellaneous activities:<sup>64</sup>

- Increase of *production* rate
- Reduction of *waiting* time
  - Sequence planning according to priority rules
  - Sequence planning according to the Johnson-algorithm
  - Overlapping production

<sup>60</sup> Cp. Corsten, H. (1999), p. 461-464; Schneider, H., Buzacott, J.A., Rücker, T. (2005), p. 69.

<sup>61</sup> Zimmermann, H.-J. (2008), p. 373, translation from German by author.

<sup>62</sup> Vahrenkamp, R. (2008), p. 185, translation from German by author.

<sup>63</sup> Cp. Lebefromm, U. (2003), p. 187.

<sup>64</sup> Cp. Lebefromm, U. (2003), p. 216-226; Vahrenkamp, R. (2008), p. 187-190; Corsten, H. (1999), p. 457-459; Schneider, H., Buzacott, J.A., Rücker, T. (2005), p. 70-72.

- Splitting
- *Bundling of lots*

The *production rate* is defined as working time divided by production output per shift. To shorten the processing time, the intensity of work centres has to be increased according to technical terms. The method of increasing clock frequency must be confirmed by the workers' council. Wages should rise due to surplus load, at the same time the asset depreciation of the machine increases as well.<sup>65</sup> Another alternative to decrease the lead-time is the reduction of the *waiting time*. In many cases the waiting or holding time in between separate working steps is too long, which has a negative impact on the processing time. Transit time of particular orders can be reduced by giving priorities within the waiting line. Admittedly this affects the processing time of other orders competing for the capacity. Hence it should only be used only in exceptional cases for urgent jobs.<sup>66</sup> On the other hand the sequences of orders can be determined according to the *Johnson-algorithm*. This method was developed in 1954 to optimise the processing time for two machines in series in combination with several orders. The result is to start with batches, which have shorter processing time on the first machine than on the second. Thereof lots with the shortest processing time are formed first, after that in ascending order of processing time. Following this the batches with longer operation time on the first machine are worked on, descending sorted according to the processing times of the second asset. Due to this sequence planning on one hand shutdown time of the machines is mostly avoided. On the other hand waiting times in between the different assets occur instead.<sup>67</sup> A further possibility to reduce the waiting time is overlapping production. At this, before the whole batch is finished, parts are already forwarded and processed on the next machine in the line. Consequently one batch is simultaneously worked on on different machines. Maximum overlapping time is calculated using the network planning technique. A disadvantage of this method is the increasing costs for internal transport.<sup>68</sup> Finally waiting time can also be decreased by splitting of batches. In contrast to overlapping, batches are separated and formed on different assets. Split batches can be arranged simultaneously or displaced by time. The disadvantages of this alternative are the higher setup costs of the machines.<sup>69</sup> In the end *batches* can be also *bundled*. In this process similar or identical lots are summarised and therefore set up times are avoided.<sup>70</sup>

<sup>65</sup> Cp. Lebefromm, U. (2003), p. 216.

<sup>66</sup> Cp. Vahrenkamp, R. (2008), p. 187-188.

<sup>67</sup> Cp. Lebefromm, U. (2003), p. 222; Vahrenkamp, R. (2008), p. 206.

<sup>68</sup> Cp. Vahrenkamp, R. (2008), p. 189; Lebefromm, U. (2003), p. 218; Corsten, H. (1999), p. 458-459.

<sup>69</sup> Cp. Corsten, H. (1999), p. 458; Schönsleben, P. (2004), p. 656.

<sup>70</sup> Cp. Vahrenkamp, R. (2008), p. 189.

### 3. Capacity management in logistics

#### 3.1. Logistics goals

Logistics is defined by the Council of Supply Chain Management Professionals (CSCMP) as “the process of planning, implementing, and controlling procedures for the efficient and effective transportation and storage of goods including services, and related information from the point of origin to the point of consumption for the purpose of conforming to customer requirements. This definition includes inbound, outbound, internal, and external movements.”<sup>71</sup>

GÜNTHER and TEMPELMEIER specify logistics as “a complete description of the individual functions and levels of the company which has, as its goal, the optimisation of the flow of products and materials in respect of the related stream of information.”<sup>72</sup>

Based on the overlapping function of logistics, it influences various business objectives, which can be roughly summarised as the following:<sup>73</sup>

- Quality
- Costs
- Delivery
- Flexibility

The weighting of these objectives is determined by company policy and strategy as well as the industrial sector or market situation.<sup>74</sup> As already explained in the introduction of this paper, flexibility and short lead-time is becoming more and more important in times of globalisation and fast-changing markets. In contrast to this, cost is still the significant factor for competing in the market in many industries.

As *quality* is not the key objective of capacity management, it will not be considered further in this paper. The other items mentioned are strongly connected with the management of capacities and will be illustrated in detail.

Minimising *costs* is one of the most important targets of manufacturers as this is a significant factor in staying competitive in the market, especially at the present time of globalisation and rapid decline in price in some markets due to high competition. In the case of logistics the cost “encompasses the value management of the use and application of the factors of production which are involved in logistics services.”<sup>75</sup>

Basically logistics, goods and services can be differentiated into physical transfer

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<sup>71</sup> CSCMP – Council of Supply Chain Management Professionals (2010), p. 114.

<sup>72</sup> Günther, H.-O., Tempelmeier, H. (2005), p. 9, translation from German by author.

<sup>73</sup> Cp. Schönsleben, P. (2004), p. 36.

<sup>74</sup> Cp. Schönsleben, P. (2004), p. 36.

<sup>75</sup> Göpfert, I. (2002), p. D5-39, translation from German by author.

processes (warehousing, transportation, etc.), planning and management processes (route planning, inventory management, etc.) as well as other processes relating to the attainment of logistics goals.<sup>76</sup>

Minimisation of physical logistics costs can be accomplished by different methods: For incoming goods, for example, the *just-in-time concept* can be applied, which means delivery of the purchased goods exactly at the time they are needed at the line. Interim storage during the production process is dependent on the accuracy and the method of production planning and control as well as the manufacturer's general strategy. While costs are reduced or minimised, due to avoidance of storage, there is an increased risk of production delay or stop if an unexpected situation or problem occurs.<sup>77</sup> In addition to this, the storage management of the outbound warehouse is related to the market situation and the company's strategy. In the case of commissioned production the storage of finished goods can be an unintended issue. In the event of manufacturing according to sales forecasts and market trends, the management of the distribution warehouse is an important factor that requires much attention in order to optimise charges and capacity.<sup>78</sup>

On the other hand optimisation of *deliveries* is one of the main logistics targets. In today's markets compliance with delivery dates and short lead-times are major competitive factors. To reach this target, process times have to be shortened as much as possible and transportation has to be planned accurately in order to utilise capacities, reduce the lead-time as well as the delivery charges.<sup>79</sup>

Finally, *flexibility* is a significant factor in competing with other producers or suppliers. As already mentioned in chapter 1.1., flexibility is becoming more and more important in times of globalisation. To meet customers' requirements, it is a challenge for logistics as well as production planning to be as flexible as possible and to optimise available resources.<sup>80</sup>

In summary, it can be seen, on one hand, all of the above-mentioned logistics objectives are significant for a manufacturing company, but on the other hand the goals necessitate a trade-off. To reach one target, it means that one or several others have to be disregarded. For instance, storage of goods (incoming and outgoing goods as well as interim storage during the production process) generates high costs as well as capital commitment, which can be often avoided by improved and optimised planning

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<sup>76</sup> Cp. Göpfert, I. (2002), p. D5-41.

<sup>77</sup> Cp. Pfohl, H.-Chr. (2010); p. 173 and p. 184-186.

<sup>78</sup> Cp. Pfohl, H.-Chr. (2004), p. 125-126.

<sup>79</sup> Cp. Pfohl, H.-Chr. (2004), p. 99-100.

<sup>80</sup> Cp. BME (2010), date 12.03.2011.



and organisation. On the other hand this leads to rising costs for the planning and management processes. This trade-off, producing opportunity costs, has to be taken into account. In the end opportunity costs have to be set against each other according to company policy. Opportunity costs “exist in that, which has to be given up in order to complete the activity.”<sup>81</sup>

## 3.2. General capacity theory in logistics

### 3.2.1. Terms and definitions

Capacity has already been defined in general terms in chapter 2.2. as the “the potential of an economic or technical entity – of any type, size and structure – within a period of time”<sup>82</sup> and can be separated into quantitative and qualitative capacity. This definition can also be transferred into the area of logistics where there are many entities with restrictive capacities which must be considered in the logistics planning and operations to meet not only the company objectives but also the customer’s requirements.

Logistics includes mainly the processes of warehousing and transportation as well as the related flow of information.<sup>83</sup> As a consequence the following types of capacity can be defined:<sup>84</sup>

- Storage capacity
- Handling capacity
- Transportation capacity
- Information capacity

*Warehouse capacity* is defined as the maximum number of loading units (pallets, boxes, cartons, etc) a warehouse can process. It is called *homogeneous warehouse capacity*, if all storage yards are designed in the same way, which includes dimensions, bearing capacity, security, etc.<sup>85</sup>

*Handling capacity* includes sorting and placing into and removing from stock, as well as loading and unloading from the transport. It connects the internal and external flow of goods as well as the different means of transportation and warehousing. Handling capacity is therefore the total operating performance within a defined period of time.<sup>86</sup>

*Transportation capacity* is dependent on the dimensions of the cargo hold as well as

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<sup>81</sup> Cp. Sieg, G. (2007), p. 5.

<sup>82</sup> Kern, W. (1962), p. 27, translation from German by author.

<sup>83</sup> Cp. CSCMP – Council of Supply Chain Management Professionals (2010), p. 114, date 13.06.2011.

<sup>84</sup> Cp. Pfohl, H.-Chr. (2004), p. 106.

<sup>85</sup> Cp. Arnold, D., Furmans, K. (2009), p. 176.

<sup>86</sup> Cp. Fleischmann, B. (2002), p. A1-7.

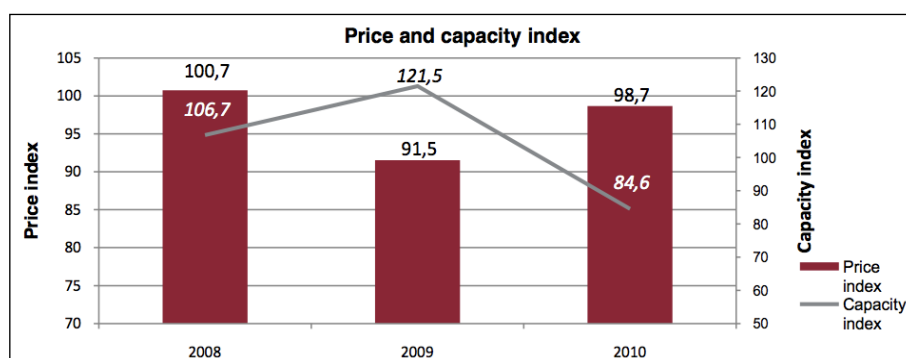
the permitted loading capacity. Therefore the goods are measured in packaging units, loading units or in volume units (for bulk goods).<sup>87</sup>

Information logistics comprises the “capture, storage, processing and output of data which are necessary for the control and monitoring of the flow of materials and information in a transport and warehousing system.”<sup>88</sup> It consists of components hardware and software. *Information capacities* can be defined in connection with this as the maximum performance, the information system is able to provide.<sup>89</sup>

### 3.2.2. Current development of the transport market

The *Transport Market Monitor* report, an initiative of the logistics platform TRANSPOREON and Capgemini Consulting, provides information about transport market development in Europe, based on different indices affecting the prices and the market. One of these indices is the capacity index, which “is an indicator for *available capacity*, the ratio between absolute demand and capacity. The capacity index is calculated by comparing the average number of bids in response to a transfer request over time.”<sup>90</sup> In case the capacity index increases, the degree of competition increases as well – this has a positive effect on offers for transport charges. The capacity index is subject to fluctuations. In figure 3 the effects of the financial crisis and the related decline in production is apparent in the transport market. In 2010 the cost level was still low and East European forwarding companies were expanding their operation in Western Europe.<sup>91</sup>

Figure 3: Price and capacity index by yearly comparison (2008-2010)



Source: Capgemini Consulting, TRANSPOREON (2011a), p. 5, date 13.06.2011

<sup>87</sup> Cp. Gudehus, T. (2010), p. 898.

<sup>88</sup> Heinrich, M. (2006), p. 460, translation from German by author.

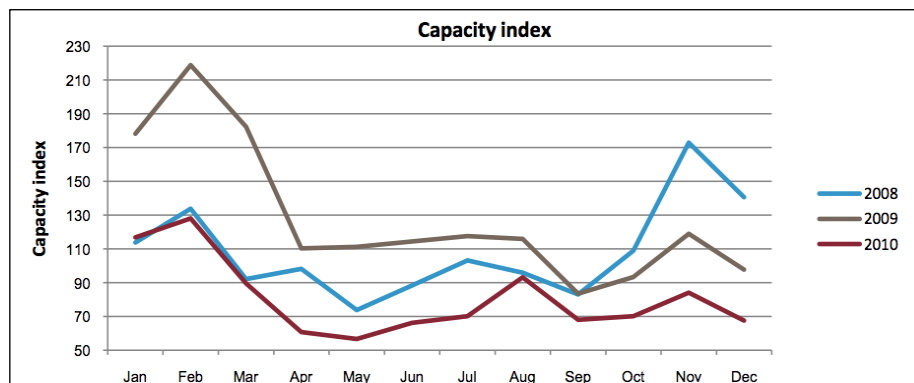
<sup>89</sup> Cp. Heinrich, M. (2006), p. 460.

<sup>90</sup> Capgemini Consulting, TRANSPOREON (2011b), p. 4, date 13.06.2011.

<sup>91</sup> Cp. Capgemini Consulting, TRANSPOREON (2011a), p. 5 and 11, date 13.06.2011.

Apart from annual fluctuations, seasonal fluctuations during the course of a year can also be observed. Generally capacity demand is lower at the beginning of the year and in the summer time due to seasonal fluctuations in the various industries. In September and October the decrease in available capacity can be explained by the peak season of the consumer goods industry for example.<sup>92</sup>

**Figure 4: Capacity index 2010 by month**



Source: Capgemini Consulting, TRANSPOREON (2011a), p. 13, date 13.06.2011

In general, density of value (ratio of goods value to weight) increased in Germany while lot sizes decreased since the middle of the 1980s. This can be explained by the relocation of manufacturing with high intensity of primary products (labour intensive) to foreign countries and a decrease in stock level. This resulted in longer transport distances and increased demand for flexible supply, which can be fulfilled best with road traffic.<sup>93</sup>

Container shipping also contends with fluctuating capacity. Until 2009 this branch experienced a high rate of expansion, but suffered a setback in 2009 because of the global financial crisis, when container handling decreased for the first time. Due to a sharp decrease in capacity demand about 12% of ships could not be employed. In 2010 the branch recovered and is now the fastest growing mode of transport. Over the next few years an increased capacity supply is expected as well as a simultaneous increase in demand. Therefore the difficulty of over-capacity is attenuated. Admittedly capacity restrictions at ports can lead to challenges for container shipping.<sup>94</sup>

Due to limited space at ports an increased requirement for handling capacity cannot be satisfied by an expansion of space. Therefore efficiency per quay metre (boxes per time unit) as well as storage capacity per hectare yard in TEU (twenty feet equivalent

<sup>92</sup> Cp. Capgemini Consulting, TRANSPOREON (2011a), p. 13, date 13.06.2011.

<sup>93</sup> Cp. Ickert, L., Matthes, U., Rommerskirchen, S. et al. (2007), p. 58, date 13.06.2011.

<sup>94</sup> Cp. Deutsche Bank Research (2011), p.1, date 13.06.2011.

unit) must be increased. Existing processes will have to be optimised and improved, and new systems and processes for container handling will have to be developed during this time to handle the increased volume of containers.<sup>95</sup>

Air freight also had to accept losses in 2009 because of the worldwide financial crisis which triggered over-capacity. Since 2010 the industry is on the upswing again which will, presumably, continue for the future as well.<sup>96</sup> Besides the specific capacities of the separate aeroplanes, the capacity of airports is a matter of high concern. It includes the dimensions of the starting and landing capacities, handling capability, number of available slots (time frame for starting and landing), etc.<sup>97</sup>

### 3.2.3. Revenue management

*Revenue management*, also called *yield management*, will be specified in the following chapter as one example of capacity management. It derives from the deregulation of American air traffic in 1978. Airlines were allowed to decide freely about which connections they offered and the ticket price. This led to price differentiation in the first instance, after that forecasting systems and capacity controlling were implemented.<sup>98</sup>

The term revenue management is not used consistently in the specialist literature, but numerous definitions exist. The instruments of revenue management are partly centred on the definition, in other definitions characteristics of the area of application are accentuated.<sup>99</sup>

In connection with capacity management in logistics one of Klein's definitions is applicable to this paper: "Revenue management comprises a series of quantitative methods in order to reach a decision about accepting or declining insecure demand with scattered arrival times and different values. In the process the objective remains to utilise the available, inflexible capacity of the time period in most efficient way."<sup>100</sup> The other, numerous, definitions of revenue management will be disregarded in this paper.

The general task of revenue management is to forecast, evaluate and monitor demand and adjust the available capacities correspondingly.<sup>101</sup>

The typical characteristics which are required to apply revenue management, according to the specialist literature, are<sup>102</sup>

- Mostly fixed capacities,

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<sup>95</sup> Cp. Franke, K.-P. (2010), date 13.06.2011.

<sup>96</sup> Cp. Deutsche Bank Research (2010), p.1, date 13.06.2011.

<sup>97</sup> Cp. Vahrenkamp, R. (2007), p. 38, date 13.06.2011.

<sup>98</sup> Cp. Klein, R., Steinhardt, C. (2008), p. 2-3.

<sup>99</sup> Cp. Klein, R., Steinhardt, C. (2008), p. 6.

<sup>100</sup> Klein, R. (2001), p. 248.

<sup>101</sup> Cp. Daudel, S., Vialle, G. (1994), p. 31.

<sup>102</sup> Cp. Klein, R., Steinhardt, C. (2008), p. 8-9.

- Non suitability for storage of goods, or perishability of capacities in the case of non utilisation,
- High fixed costs for provision of capacity,
- Highly random demand fluctuation,
- Possibility of advance booking,
- Possibility of segmented price differentiation.

Revenue Management can be subdivided into three steps: Strategic, tactical and operational revenue management. Strategic revenue management includes segmentation of demand as well as differentiation of products, services and prices. It also includes the capacity strategy. Tactical revenue management defines the capacity for each segment (capacity configuration). In the operational revenue management the decision to accept or reject is made in real-time (capacity control).<sup>103</sup>

The instruments of revenue management are price differentiation, capacity control, and overbooking control. Capacity control is the core element of revenue management. It should support the implementation of price differentiation as well as adjust the effects of fluctuating demands.<sup>104</sup>

In the field of logistics revenue management is applied to the allocation of loading capacity. Air freight especially meets the demand for applying revenue management. In connection with this, attention should be paid to different capacity requirements due to the variable volume and weight of freight. Furthermore, fixed capacity agreements with key customers must be considered, as they are not available for sale elsewhere without prior agreement. Due to their specific characteristics, revenue management can only be applied to customised solutions, which will not be explained or described further.<sup>105</sup>

This paper will not dwell on other methods of capacity management in the field of general logistics due to their complexity.

### **3.3. Terms and definitions of outbound logistics**

Logistics can be classified in four distinct groups by function: inbound logistics, manufacturing logistics, outbound logistics and waste logistics.<sup>106</sup> This chapter will deal only with outbound logistics, which can be generally understood as the “process related

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<sup>103</sup> Cp. Thonemann, U. (2010), p. 522; Klein, R., Steinhardt, C. (2008), p. 18-22.

<sup>104</sup> Cp. Klein, R., Steinhardt, C. (2008), p. 69.

<sup>105</sup> Cp. Klein, R., Steinhardt, C. (2008), p. 30-31.

<sup>106</sup> Cp. Pfohl, H.-Chr. (2010), p. 17.

to the movement and storage of products from the end of the production line to the end user.”<sup>107</sup>

In this context the term *physical distribution* in the narrow sense of the expression is often used as synonym for outbound logistics but in a broader sense physical distribution is used as generic term for inbound and outbound logistics, which are both connected directly with the market.<sup>108</sup>

Outbound logistics starts at the end of the production line and ends with the allocation to or arrival at the customer. The area of activities covers planning, controlling and monitoring of the physical flow of goods as well as the associated flow of information.<sup>109</sup>

It covers the processes of warehousing, transportation, handling as well as picking and packing. During the outbound logistics process the goods are not generally physically modified, but it serves as a spatial and temporal bridge-over.<sup>110</sup>

The design of the distribution network is influenced by the marketing policy of the manufacturer. During the build-up of the network the following issues have to be considered:<sup>111</sup>

- Number of warehouses
- Function of warehouses
- Location of warehouses

The warehousing of goods can fulfil different functions: Of most importance for outbound logistics is balance as well as protection. Other tasks, such as speculative or adding value activities are predominantly relevant for inbound and manufacturing logistics and will be not outlined here in detail.<sup>112</sup> The balancing function can be defined as the bridging of time between the end of the production and the physical delivery to a distribution warehouse or customer. As already defined in chapter 2, batch size scheduling is important in the production process and can lead to a requirement for storage at the point of outbound logistics to overcome the gap between the end of production and, for example, the customer’s requested delivery date. Additionally, warehousing can be used as a buffer to secure deliveries to customers in highly fluctuating markets, and meet the customer’s requirement for short lead times. These activities reinforce the company’s ability to compete in highly sensitive markets.

Warehouses in distribution systems can be aligned with different strategies:<sup>113</sup>

- Level of centralisation

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<sup>107</sup> Cp. CSCMP – Council of Supply Chain Management Professionals (2010), p. 134, date 13.06.2011.

<sup>108</sup> Cp. Pfohl, H.-Chr. (1974), p. 577.

<sup>109</sup> Cp. Jünemann, R. (1989), p. 53.

<sup>110</sup> Cp. Pfohl, H.-Chr. (2010), p. 7-8 and p. 198.

<sup>111</sup> Cp. Jünemann, R. (1989), p. 55.

<sup>112</sup> Cp. Münchhalfen, J. (2008), p. 65-66.

<sup>113</sup> Cp. Ehrmann, H. (2005), p. 352-354.

- Company-owned warehouse / third party warehouse
- Level of automation
- Coordination of stored goods
- Warehouse system

Sometimes goods are delivered to the customer directly from the production warehouse, but in most cases goods are transhipped via distribution, central or even local warehouses. The level of centralisation depends on company policy and the market characteristics. Production warehouses are basically company-owned warehouses, as they are located within the factory. Central and regional warehouses can also be contract warehouses that are operated by third party logistics providers. Decision criteria for this strategy can be investment costs, operating costs, manpower requirement, and level of dependency or capacity variables. The level of automation can be differentiated between manual, mechanical and automatic warehouses. The coordination of stored goods influences the space requirements which, in turn, impacts the logistics costs. Herewith we can distinguish between storage with fixed bin location and random storage at which random storage requires computer-controlled storage of the goods. Finally the warehouse can be operated with calculation of stock, consumption, calculation or validation of inbound goods, stock and outbound goods.<sup>114</sup>

Apart from warehousing, transportation is a major part of outbound logistics. Transportation is the spatial bridge-over by means of transportation. A transportation system consists of the goods to be conveyed, the means of transportation and the transportation process. We can differentiate between internal and external transportation: For outbound logistics only external logistics is relevant. In external logistics the means of transportation can be divided into different systems of freight haulage: Road traffic, rail traffic, air freight, inland water transport, and ocean freight. Transportation can be operated directly, with transshipment, or interim storage. Therefore it is advantageous that packing of goods is simplified by use of e.g. pallets. The transport modes are often used in combination depending on the lead-time requirements and cost objectives. With *intermodal transports*, the different modes should be combined in a reasonable way and loadings should be simplified as much as possible. This can be achieved by piggy-back traffic or container traffic.<sup>115</sup>

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<sup>114</sup> Cp. Ehrmann, H. (2005), p. 352-354.

<sup>115</sup> Cp. Pfohl, H.-Chr. (2010), p. 149-159.

### **3.4. Capacity management in outbound logistics**

#### **3.4.1. Capacity planning and adjustment in warehousing**

Warehousing can be defined as the buffer between incoming and outgoing goods. The necessity for warehousing arises when timing and the quantitative structure of the commodity flows are desynchronised. The general functions of warehousing have already been described in chapter 3.3. Storage capacity planning will be outlined in the following chapters.

##### **3.4.1.1. Capacity requirements planning**

The basis of capacity requirement planning for warehousing is the coordination of the production program. Here production planning is connected to the demands for the finished goods. We can differentiate between make-to-order and make-to-stock production. Make-to-stock is used for mass production of the following categories in products: Standardised, large-lot production, and short lead-time, due to supply from distribution warehouses. With make-to-order production, however, the goods are manufactured only after receiving an order from the customer. Warehousing is irrelevant in this process as the goods are typically delivered promptly after production. As a consequence make-to-stock production is used as a basis for the considerations in this paper.<sup>116</sup> The process of storage generally consists of the following sub-processes:<sup>117</sup>

- Placing into stock by means of stock device,
- Keeping goods on hand in storage yard,
- Releasing from stock by means of stock device.

An additional function of most warehouses is consignment: The picking and packing of units according to given orders.<sup>118</sup> As a consequence the capacity of a warehouse is not only related to the storage space, but also to other entities which require space for handling and consignment, output of stock devices and ramps, warehouse staff, etc.

The amount of stored goods results from the production and distribution plan. The capacity of the storage yard can be defined as the “maximum number of individual loading units which can be stored in a warehouse area.”<sup>119</sup> Admittedly the quantity of merchandise is not decisive, but packaging or loading unit is a determinant for capacity

<sup>116</sup> Cp. Vahrenkamp, R. (2008), p. 118.

<sup>117</sup> Cp. Gudehus, T. (2010), p. 565.

<sup>118</sup> Cp. Gudehus, T. (2010), p. 565; Lempik, M. (2002), p. B8-5.

<sup>119</sup> Gudehus, T. (2010), p. 572, translation from German by author.



requirement planning in warehousing. Besides protecting the goods during warehousing and transportation, the package also alleviates the storage and enables better utilisation of the available storage capacity.<sup>120</sup> Details about the packing units must be included in the master data to ensure optimum calculation of capacity: Number of goods per packaging unit, type of packaging (for example box or pallet), dimension of the packaging unit, weight, stackability, etc.<sup>121</sup> Disregarding the storage space, the required capacity for handling and consignment must also be included in the planning. Accordingly, the inventory turnover of the particular product has to be taken into consideration for the calculation of capacity requirements. The warehouse turnover displays how often the inventory changes in a specific period of time. Hence it can be extrapolated to the average inventory and, therefore, to the average time between production and distribution.<sup>122</sup> Handling and consignment of goods requires capacity of different entities: On one hand a handling area is needed to physically manage the turnover. Often a special area for consignment and building of loading units is also needed. On the other hand stock devices and conveyers are required to transport the loading units between storage and handling areas or ramps. The type of conveyer as well as the particular output is defined by the characteristics of the product (e.g. bulk cargo or general cargo). Conveyers (continuous and non-continuous conveyers) are also restricted by their capacity and can only handle a limited volume of units per time period. A fork-lift truck, for example, has the capability of moving one to four pallets at a time. A hand fork-lift truck, however, is only able to move one pallet. In the event that the conveyer has to be manually operated, this capacity requirement has to be considered as well. In addition to the equipment, loading platforms are necessary for loading and unloading of the outgoing orders. The capacity of platforms is dependent on the order volume and required loading time.<sup>123</sup> In the end the staff resources also have to be taken into account for the whole warehouse operation, including administration tasks. The manpower requirement is dependent on the automation level of the warehouse, as well as the turnover volume and operation time. The quantitative, qualitative and timely staff requirement is calculated within the manpower requirement computation.<sup>124</sup>

In connection with capacity requirement planning, seasonal fluctuations also have to be considered. The manufactured quantity is, for instance, stable over the time period in

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<sup>120</sup> Cp. Pfohl, H.-Chr. (2010), p. 135.

<sup>121</sup> Cp. Gudehus, T. (2010), p. 445 and p. 449.

<sup>122</sup> Cp. Schulte, G. (2001), p. 483.

<sup>123</sup> Cp. Seeck, S. (2010), p. 279; Gudehus, T. (2010), p. 589.

<sup>124</sup> Cp. Gienke, H., Kämpf, R. (2007a), p. 24.

case of level production strategy, even the demand fluctuates. This strategy affects the capacity requirements for storage depending on the demand and market situation.<sup>125</sup>

#### 3.4.1.2. Capacity supply planning

Capacity supply planning for adequate storage yardage is important in particular, as stock consumes most of the warehouse space. The capacity by storage yard is the maximum number of loading units a storage facility can carry. As outlined in the previous chapter 3.4.1.1., the capacity demand can fluctuate within a time period due to various factors. For this reason the provision of capacity supply has to be calculated accurately to minimise the logistics costs and, therefore, maximise the effectiveness of the warehouse. Here the allocation of the inventory within specific time periods (for instance per day or per shift) can be analysed with the help of the warehouse management system and visualised via histograms or density functions. To determine the appropriate storage capacity the *confidence level* is decisive: That is the frequency by which an assigned value (in this case the number of the storage yards) is exceeded. The confidence level is defined as the probability the warehouse capacity is sufficient to store the total inventory.<sup>126</sup>

In the context of capacity supply planning the *type of bearing* is also essential. Types of bearing can be differentiated, firstly according to the allocation of the storage yard, where it can be distinguished between fixed and random storage. With fixed warehouse systems the loading units are explicitly allocated to a storage position and not moved during the storage period. This type of storage is advisable for storage of non-homogenous goods. With random storage, however, the loading units can be assigned to every available storage yard and therefore it can be recommended for homogenous articles. Admittedly this storage system requires a high level of administration and must be managed effectively via a warehouse managements system.<sup>127</sup>

Another classification can be made under *technical storage types*. Here the differentiation is between ground storage and high-bay racking. For this type of storage many varieties are possible, which will not be discussed in this paper in detail. In principle the type of storage is dependent on the characteristics of the goods, as well as the complexity and processing time of the operation.<sup>128</sup> Commodities can be differentiated into different types: General cargo and bulk cargo as well as gas and

<sup>125</sup> Cp. Günther, H.-O., Tempelmeier, H. (2005), p. 152-154.

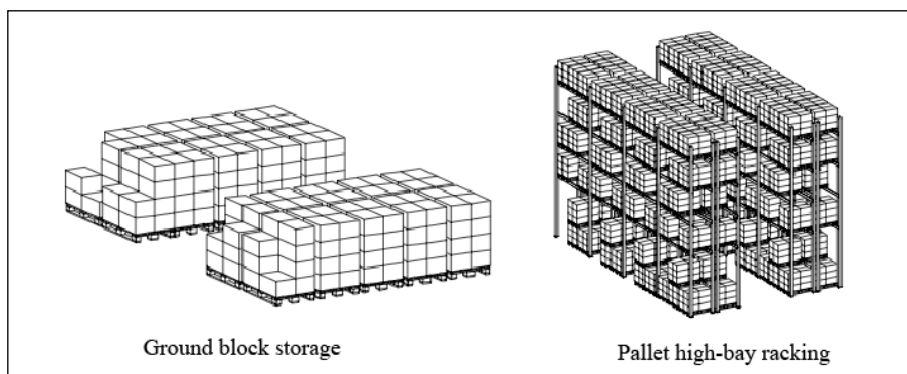
<sup>126</sup> Cp. Rall, B. (2002), p. C2-46 - C2-47; Smith, J.D. (1998), p. 489-493.

<sup>127</sup> Cp. Rall, B. (2002), p. C2-46 - C2-47; Weber, R. (2009), p. 260.

<sup>128</sup> Cp. Rall, B. (2002), p. C2-37 - C2-46.

liquids. General cargo can be handled as units and comprises constant frames, storage units like loaded pallets, or bins filled with gas/liquids. In this paper only general cargo will be considered. Ground storage is the easiest type of storage and can be executed without stacking, with block storage or by linear storage. Whilst ground storage in the narrow sense is connected with a suboptimal utilisation of space, block and linear storage are dependent on the stackability of the loading units. In the case that units are not stackable, it opens up the possibility of high-bay racking which allows better utilisation of the storage space as well as simplified access to the stored goods. Summing up, the technical type of storage is highly relevant to the utilisation of the storage space.<sup>129</sup>

**Figure 5: Examples of technical storage types**



Source: Gleißner, H., Femerling, J. Chr. (2008), p. 90-91.

Disregarding the capacity of the storage yard, the supply of the handling area capacity needs to be also taken into consideration during the planning period. Therefore the incoming and outgoing shipments are to be analysed by such aspects as loading volume per transport mode, frequency of shipments, average loading time, and total number of transport modes per period.<sup>130</sup> The capacity of handling equipment, such as conveyers, can be measured firstly with the numbers of conveyers then differentiated by type like fork-lift, hand-lift, etc. Additionally the hours of operation service and number of transported goods should be considered. In connection with this the maintenance of technical equipment must also to be included in the supply planning. During the maintenance procedures the conveyer capacity is not available.<sup>131</sup>

Finally staff assignment has to be taken into account for capacity planning. The capacity supply of manpower is subject to timely fluctuations and can be slightly adjusted on a short-term basis due to flexible working time models. Also in this

<sup>129</sup> Cp. Pfohl (2010), p. 124-126.

<sup>130</sup> Cp. Smith, J.D. (1998), p. 475.

<sup>131</sup> Cp. Buchholz, J. (1998), p. 294.

calculation time off due to vacation, illness, advanced training or other reasons must be considered.<sup>132</sup> Certainly planning of the capacity supply is dependent on the dynamic environment and therefore has to be controlled on a regular basis, in case conditions or storage needs change, in order to secure efficient provision of requirements.<sup>133</sup>

### 3.4.1.3. Capacity adjustment

Where capacity supply and requirements are not synchronised they have to be adjusted to achieve the logistics objectives. Two options can be classified: assimilation of capacity demand, and optimisation and adjustment of capacity supply.

Depending on the market situation and strategy of the manufacturer, inventory can be avoided as far as possible when the production of goods is synchronised with distribution. With this type of aggregated overall planning the capacity utilisation of production fluctuates and must be high enough to absorb maximum demand. This re-arrangement of the production structure implicates fundamental modifications where many factors have to be considered in order to make a decision.<sup>134</sup>

Capacity adjustment of storage space can be considered on both a long-term and short-term basis. In principle – independent from the fact of whether a company-owned or a contracted warehouse is used for warehousing activities – a manufacturer can demand storage yard and handling consignment by third-party logistics providers. Short-term outsourcing may be the only alternative to overcome peak load. Temporary usage of external storage space can indeed involve comparatively high logistics costs. In the long run a company has to decide between investing in, expanding or building its own new warehouse space or utilising a contracted warehouse instead (maybe with a long-term agreement). The advantages of contracted warehouses are the avoidance of investments, substitution of fixed costs with variable costs, and the utilisation of flexible labour times for load fluctuations, as well as specialised staff. Generally the labour costs of logistics service providers are lower compared to manufacturing companies which are subject to collective labour agreements. In the end contracted warehouses are recommended in highly fluctuating markets as a suitable measure of capacity enlargement and reduction in the short-term. In the case of increased capacity requirements in a stable market, investment in a company-owned warehousing is more efficient.<sup>135</sup>

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<sup>132</sup> Cp. Günther, H.-O., Tempelmeier, H. (2005), p. 126-128.

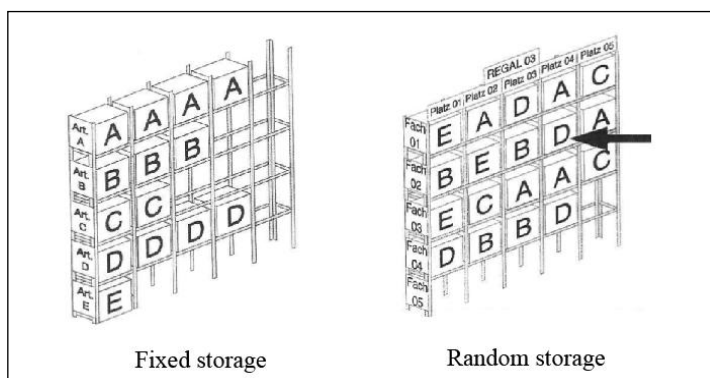
<sup>133</sup> Cp. Smith, J.D. (1998), p. 506.

<sup>134</sup> Cp. Günther, H.-O., Tempelmeier, H. (2005), p. 152-153.

<sup>135</sup> Cp. Fortmann, K.-M., Kallweit, A. (2007), p. 47-48.

The utilisation of available storage capacity can be optimised by the application of random storage pictured in figure 6. This type of allocation of the storage yard is particularly advantageous in the case of highly fluctuating demand. This method of stock-keeping requires the operation of a warehouse management system for controlling and monitoring the storage areas. Additionally, the technical storage system of the warehouses can be modified in order to adjust capacity requirement and capacity supply. Subject to specification of the storage unit, high-bay racking may be a better alternative for utilisation of the warehouse space.<sup>136</sup>

**Figure 6: Comparison of fixed and random storage**



Source: Wannenwetsch, H. (2010), p. 317-318.

Handling capacity and consignment, which is dependent on quantitative and qualitative capacity of warehouse staff, can be adjusted by working hours and shift schedules. For the short-term overtime and short-time work can be established, for the long-term engagement or suspension can be applied.<sup>137</sup> Qualitative capacity must also be considered in conjunction with this. Within the scope of human resource development the quantitative capacity of the warehouse staff is improved by further training in order to manage the changing technical and product-specific requirements.<sup>138</sup>

Another possibility to relocate the storage on a long-term basis is to make a consignment stock agreement with strategic customers. A consignment stock is set up by a manufacturer or supplier at the warehouse or a 3PL (*third party logistics provider*) warehouse nominated by the customer. The customer provides the agreed warehouse capacity and bears the costs of storage and handling, the ownership of the goods as well as the responsibility for minimum and maximum inventory levels remains by the supplier. Even if the capacity of the consignment stock is limited to the maximum stock of inventory agreed between the parties, it allows the manufacturer to dispatch the

<sup>136</sup> Cp. Pfohl, H.-Chr. (2010), p. 123-126.

<sup>137</sup> Cp. Mussbach-Winter, U. (2007), p. 593.

<sup>138</sup> Cp. Günther, H.-O., Tempelmeier, H. (2005), p. 127.

goods directly after production and therefore to avoid interim storage and additional handling in distribution warehouses.<sup>139</sup>

### 3.4.2. Capacity planning and adjustment in transportation

Transportation can be defined as the spatial bridge-over by means of transportation as already mentioned in chapter 3.3. Freight traffic is generally possible via land, air or sea. Furthermore goods traffic can be subdivided into means of transportation: Ground transportation can be arranged as road haulage, rail transport or pipeline haulage. Air freight is another method of transportation that can be used. For water transportation we differentiate between inland water transport and ocean freight. Besides this, there are further ways to breakdown the categories, but they will not be examined here in detail.<sup>140</sup> Goods can generally be classified into different types: General cargo, bulk cargo, gas and liquids. These different types of goods require different specifications as to their means of transport.<sup>141</sup> Only general cargo will be examined within the scope of this paper.

#### 3.4.2.1. Capacity requirements planning

Capacity requirements for transportation are, on the one hand, dependent on the vertical structure of the distribution system. This is defined as the stratification of warehouse levels within a distribution system from end of production to the customer. It is called *one-level distribution* when the disposition of goods is arranged from one central warehouse to the customers. *Multi-level distribution* includes several levels of warehouses (for example warehouse at the manufacturing facility, central warehouse, regional warehouse, distribution warehouse) that fulfil different tasks. Depending on the transport route, there are different capacity requirements. For transportation from the manufacturing plant to a central warehouse, for instance, the flow of commodities can be bundled and, therefore, the entire available capacity in the selected transport can be utilised. Transport from a production plant, or central warehouse, directly to customers instead, may cause sub-optimal utilisation of transport capacity due to lower batch sizes of shipments.<sup>142</sup> The application of the optimal means of transportation requires knowledge of the following specifications: type of goods to be conveyed, shipping volume, transportation distance as well as the requested lead-time. Furthermore the consistence of freight has to be known. Bulk cargo freight is loose solid, liquid and

<sup>139</sup> Cp. Vahrenkamp, R. (2005), p. 221.

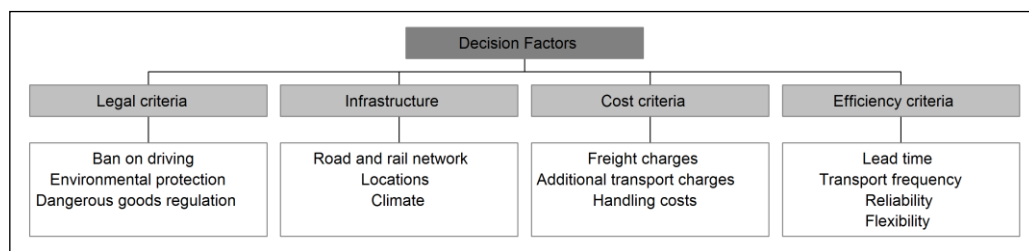
<sup>140</sup> Cp. Pfohl, H.-Chr. (2010), p. 154-155.

<sup>141</sup> Cp. Pfohl, H.-Chr. (2010), p. 124.

<sup>142</sup> Cp. Winkler, H. (1977), p. 12-14; Vastag, A. (1998), p. 13-15.

gaseous materials, whereas general cargo is calculated in discreet loading units. Additional transfer requests may arise according to any special characteristics of the commodities: perishability, fire hazard, sensitivity, risk of shrinkage, value, etc.<sup>143</sup> Furthermore the selection of the means of transportation will be effected in accordance with the logistics goals explained in chapter 3.1. The means of transportation is selected according to whether or not it can attain the objectives. The choice of the means of transportation is, though, particularly dependent on different factors shown in figure 7.<sup>144</sup>

**Figure 7: Decision factors for means of transportation**



Source: Ehrmann, H. (2005), p. 200.

A further important parameter for the appropriate selection of the means of transport, as well as capacity planning, is the character and volume in respect of the packaging of the goods to be transported. Packaging is defined according to DIN 55405, Part 6, as “the creation of a package/a packaged unit by combining packaging goods and packaging through the application of packaging procedures, manually or using packaging machines or devices.”<sup>145</sup>

As with storage, the packaging of goods has a significant function. It should afford the optimal utilisation of transport volume by both design and dimension. At the same time the weight should be as low as possible. Further requirements for packaging are: shock-proof, stackable, manageable, etc. As the packaging has a major influence on the logistics processes, even relatively small changes can be advantageous in respect of transportation and should be continuously analysed and improved.<sup>146</sup>

*Unitization* is the process of the generation of logistics units. It is defined as the aggregation of goods into major logistics units to aid the handling and quantification of goods and therefore minimise transportation costs. The requirements for unitization are inter alia the standardisation of packaging and design as well as stackability. Basically, all packaging can be used to build a logistics unit. The most frequently used packaging

<sup>143</sup> Cp. Gudehus, T. (2010), p. 774-775.

<sup>144</sup> Cp. Ehrmann, H. (2005), p. 200.

<sup>145</sup> Deutsches Institut für Normung e.V. (2006), date 08.07.2011, translated from German by author.

<sup>146</sup> Cp. Pfohl, H.-Chr. (2010), p. 136-139; Jünemann, R. (1989), p. 121-124.

is certainly the pallet. It is a loading unit, which can be used for transportation, storage and stacking with forklifts or other conveyers. There are several distinct designs of pallets, for example flat pallet or box pallet. A standardised pallet with the dimensions 800mm x 1,200mm is called a euro-pallet and often used for common transportation.<sup>147</sup> Further specifications for loading equipment will not be discussed in this paper due to its complexity.

### 3.4.2.2. Capacity supply planning

Capacity supply of transportation is primarily dependent on the means of transport. Each means of transportation comprises a predetermined transport capacity that is regulated by the dimension of the cargo hold as well as the permitted carrying capacity. Therefore the goods are measured in packaging units, loading units or in volume units (for bulk goods).<sup>148</sup> Table 1 shows the loading capacity of selected means of transportation in commonly used loading units.

**Table 1: Capacity by means of transportation**

Means of transportation	Carrying capacity (t)	capacity	
		number	loading unit
<b>Road traffic</b>			
Transporter	2,6	5	PltStp
Truck	7,5	17	PltStp
Semi-Trailer	27	34	PltStp
<b>Rail traffic</b>			
Standard waggon	50	36	PltStp
		2	TEU
Large capacity waggon	100	60	PltStp
		4	TEU
Half-train	up to 1,600	12 to 16	Waggons
		60	TEU
Block-train	up to 4,000	17 to 32	Waggons
		120	TEU
<b>Sea traffic</b>			
Inland navigation vessel (Europe)	3.000	up to 60	TEU
Feeder vessel small	5.000	500	TEU
Feeder vessel big	20.000	1.200	TEU
Container vessel	80.000	8.000	TEU

1 PltStp = 1 pallet storage place (euro-pallet)  
1 TEU = twenty feet equivalent unit (20"-container)

Source: Gudehus, T. (2010), p. 801.

A survey of Prograns, a consulting firm specialising in the transport market, conducted on behalf of the German *Federal ministry for traffic, construction and city development* in 2007, shows that the predominant mode of transport in Germany is road traffic. In 2005 around 82.6% of the goods volume was transported via trucks. Road traffic is the most flexible mode of transport and is efficient for smaller loading units. According to estimations in the survey, the volume of road traffic will increase by 44% until the year

<sup>147</sup> Cp. Pfohl, H.-Chr. (2010), p. 141-146.

<sup>148</sup> Cp. Gudehus, T. (2010), p. 898.



2050. Similarly, rail traffic will increase by 83% and inland water navigation by 50%.<sup>149</sup>

**Table 2: Volume per mode of transport in Germany in 2005**

Mode of Transport	Qty of Goods Traffic		Freight Traffic Performance	
	in m t	share	in bn tkm	share
<b>Road traffic</b>	3,078	82.6 %	404	69.9 %
<b>Rail traffic</b>	317	8.5 %	95	16.4 %
<b>Inland water navigation</b>	237	6.4 %	64	11.0 %
<b>Pipelines</b>	95	2.6 %	17	2.9 %
<b>Total</b>	<b>3,727</b>		<b>581</b>	

Source: Ickert, L., Matthes, U., Rommerskirchen, S. et al. (2007), p. 4.

As well as this, the demand for sea-traffic via container-vessels will increase according to estimates of specialists. At the same time the global freight capacities of container-vessels are expanding, which may lead to over-capacities instead of shortage.<sup>150</sup>

Several different entities are involved in the transportation process: The shipper, which is an industrial, trading or service enterprise, does not generally arrange the transport by themselves, but makes use of freight forwarding companies or logistics service providers. In this context an accurate classification of the different institutions is not possible; as with the internationalisation and globalisation the service providers are more and more specialised in certain customers, branches or additional services and definitions become unclear. In general, according to German legal specifications, these definitions can be classified as follows:

- *Forwarding companies* are operators of means of transportation and therefore usually acting as carriers. Carriers are obliged, according to German law „to convey the goods to the point of destination and deliver them to the consignee“.<sup>151</sup>
- *Forwarding agents* are commissioned to organise the carriage of goods for a third party. This is also regulated under German law: „By means of the forwarding contract the carrier is obliged to secure the despatch of the

<sup>149</sup> Cp. Ickert, L., Matthes, U., Rommerskirchen, S. et al. (2007), p. 4, date 13.06.2011.

<sup>150</sup> Cp. Deutsche Bank Research (2006), p.1, date 13.06.2011.

<sup>151</sup> HGB (2006), § 407, translated from German by author.

goods.<sup>152</sup>

- The trend in logistics, in the course of globalisation and flexible markets, resulted in 3PLs who offer an entire range of services. It is also known as contract logistics.

Often service providers specialise in certain means of transport, in particular air and sea freight.<sup>153</sup> Transportation coordination offered by logistics service providers is not restricted to a single means of transportation, but can also include *intermodal transports*. In this process the advantages of different means of transport are expediently combined in order to simplify the shipping of goods. This means the transfer between the different modes of transport generates marginal turnover complexity. Generally, intermodal transport can be differentiated between piggyback and container traffic.<sup>154</sup>

Seasonal fluctuations must also be considered in planning the capacity supply. In the course of one year the availability of transport capacity fluctuates due to seasonal variable demand in different industries. For consumable goods, for example, the peak season for transportation is the fourth quarter of the year, hence the demand in the first quarter of the year is usually lower.<sup>155</sup>

Available transport capacity is advertised worldwide through freight exchanges on the internet. The objective of freight exchanges is the connection of demand and supply and therefore to optimise the utilisation of capacity and the avoidance of empty transporters. This can be achieved through consolidation of orders. The administration via online databases simplifies the handling of demand and supply. *Teleroute* is an example of a virtual freight exchange, mainly for road traffic. Alongside basic capacity, specific product characteristics can also be considered. However, virtual freight exchanges are of minor importance, as they are not convenient for time-critical and complex shipments, which became more and more dominant at the present time.<sup>156</sup>

#### **3.4.2.3. Capacity adjustment**

Capacity adjustment in transportation represents the balance of capacity requirement and capacity supply. On one hand, the distribution structure of the company can be modified and therefore a better degree of capacity utilisation can be accomplished.

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<sup>152</sup> HGB (2006), § 453, translated from German by author.

<sup>153</sup> Cp. Pfohl, H.-Chr. (2010), p. 264-273.

<sup>154</sup> Cp. Pfohl, H.-Chr. (2010), p. 160-165.

<sup>155</sup> Cp. Capgemini Consulting, TRANSPOREON (2011b), p. 4, date 13.06.2011.

<sup>156</sup> Cp. Werner, H. (2010), p. 176-177; Lempik, M. (2002), p. B8-18.

Distribution via a central warehouse requires long transport distances. Alternatively, multi-level distribution results in short distances to downstream warehouses or customers. Hence the flow of commodities between the particular depots can be bundled (if they are not time-critical) and available capacities can be efficiently utilised and transport costs can be decreased. For final delivery to the customer optimal route planning and scheduling is more cost effective.<sup>157</sup>

The standard problem of route planning is described as follows: From a warehouse or transition point, different downstream warehouses or customers are supplied within a specific time period. The assumption for this is that the requirement can be covered with one shipment and that congruous means of transport, with identical capacities, are available. Indeed route planning experiences some problems: The assignment of customers to the routes as well as the determination of the order within the route. Route planning is subsequently operated with the help of heuristic methods within the operations research.<sup>158</sup> A further problem of route planning exists in the possibility of capacity restrictions as the commodities – particularly in forwarding agencies – are not homogenous but may have different dimensions and stacking factors. If details of the shipments are known (dimensions, weight, stackability) corresponding solutions for optimisation of loading space can be applied.<sup>159</sup>

Furthermore, optimisation of transport packaging can lead to a better utilisation of the available capacity. Requirements for transport packaging are a preferably low weight; additionally form, dimensions and stability should allow for optimum use of loading space. Admittedly this may not affect the protective function of the packaging of the product.<sup>160</sup> The packaging of the tea-light candles at IKEA provides an exemplary study for the improvement of packaging: Originally, tea-light candles were sold in bulk in bags. After a reformation of the packaging they were packed, stacked in blocks. With this improvement around 30% of the loading space per truck could be conserved.<sup>161</sup>

Agencies and forwarding companies on the other hand can establish fusions and transport alliances, and offer global services in order to be competitive in the market. Therefore the forwarding agencies offers can comprise multiple modes of transport that counter capacity restrictions in transport infrastructure.<sup>162</sup>

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<sup>157</sup> Cp. Winkler, H. (1977), p. 12-14; Vastag, A. (1998), p. 13-15.

<sup>158</sup> Cp. Ehrmann, H. (2005), p. 490-491.

<sup>159</sup> Cp. Graf, H.-W. (1998), p. 238.

<sup>160</sup> Cp. Pfohl, H.-Chr. (2010), p. 136.

<sup>161</sup> Cp. Wilhelm, S. (2006), p. 53.

<sup>162</sup> Cp. Ickert, L., Matthes, U., Rommerskirchen, S. et al. (2007), p. 61, date 13.06.2011.

Another possibility for capacity adjustment is variation of the transport mode or relocation of transport routes. With strong demand for road freight (for example, because of seasonal fluctuations) the mode of transport can be changed to rail freight. With this, however, the lead-times may be longer. Furthermore, a displacement to container-vessel is possible, if it is not restricted due to the extension of the lead-time. A side effect here may also be a reduction of the warehouse storage period as it will be transposed onto the transporting time. Also, transport charges may be lower compared to road freight, but this is dependent on different factors (for instance pre-carriage and onward-carriage, handling charges, etc.). Finally, it is possible to revise the loading or unloading place or port, which can offer available capacity. Cargo can be rerouted more easily, and without additional reloading, if it is transported by intermodal transport via container.

In summary, different possibilities for capacity adjustments are possible, depending on the characteristics of the commodities as well as the company structure and policy. In the end it is recommended that a manufacturer makes use of logistics service providers as they are specialists in the transport markets and can react flexibly according to the shippers' and customers' requirements.

#### 4. Case Study: WINGAS Transport

WINGAS Transport GmbH is a subsidiary of WINGAS which was founded in 1993 as a subsidiary of Wintershall and Gazprom Germania. The company is responsible for the transport of natural gas to consumers like public utilities, regional distribution companies, industrial concerns and power stations in Europe. The transport takes place in a pipeline system which is connected to pipelines from Russia and Northwest Europe and to West Europe's largest gas storage facility in Rehden and has a length of around 2,100 km. WINGAS Transport (like other gas distributors) sales natural gas in form of capacity rights, this means in rights which guarantee the buyer a defined capacity over a certain period of time in the pipeline system of WINGAS Transport.

Capacity Management has an important role in natural gas distribution. Natural gas as one of the main energy sources in Germany and Europe is regulated by national and international laws to secure an adequate provision with this energy source. These laws have effects on the capacity management of gas distributors. According to the EnWG (§20 1b) every operator of a natural gas pipeline system, which is the case for WINGAS Transport, has to provide entry and exit capacities that allow an easy system access without setting a transaction-dependent transport path. And according to the Gas Grid Access Ordinance (GasNZV) capacities have to be used in a certain way, e.g. in the temporal order of customer demands. Beside these and other regulations there has been a growing demand for natural gas in the past which has to be satisfied by a quite static infrastructure (owing to the fact that a transport of gas over longer distances has to be realized by pipelines). Another development of the recent past is the transfer to competitively market structures with more intermediaries between the point of extraction and consumption of natural gas. These developments indicate a complicated distribution and the need for a technically matured capacity management. Therefore, WINGAS Transport has a specific way of capacity calculation. The first objective of the company is to determine freely assignable capacities (FAC)<sup>163</sup>. These capacities are characterized thereby "a customer:

- a.) can connect a capacity right at an entry point with a capacity right at any exit point of the market area for a specific transport service or
- b.) can connect a capacity right at an exit point with a capacity right at any entry point of the market area for a specific transport service."<sup>164</sup>

The first restrictions for FAC are bottlenecks. WINGAS Transport structures bottlenecks in four categories:

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<sup>163</sup> The following text about the first and second objective is based on: WINGAS Transport (2011a), date 18.08.2011

<sup>164</sup> Cp. WINGAS Transport (2011a), date 18.08.2011, p.5

1. Technical station capacities: The maximum fixed capacity (this determines how much natural gas can pass the station in a time unit if the flow isn't interrupted) of a station. There are several kinds of stations in a pipeline system like for example measurement stations, filter stations or drying stations. The technical station capacity derives from the technical design of a station (e.g. the material used during the construction). So it can be measured by analyzing the blueprints of the stations. One problem is that it only shows the capacities of the individual stations without considering the system integrity which results from the interaction of the stations.
2. Bottlenecks in the pipeline system: The pipeline system is the main instrument for transportation of natural gas. It connects all the stations. Natural gas has to be compressed (realized by compressor stations) during transportation. But even with the best compressing technology and materials for the pipeline there is always a loss of pressure depending on the length of transportation. To determine the maximum capacity respectively the possible bottlenecks in the pipeline system WINGAS Transport has to consider several aspects as there would be the entry pressure (pressure of natural gas when it enters the system of WINGAS), the capabilities of compressor stations, the direction and the length of transport. Beside these considerations a load scenario has to be created basing on the maximum reserved capacity (measured in kWh/m<sup>3</sup>). WINGAS as well as many other gas companies uses the simulation program called SIMONE<sup>165</sup> for these kinds of simulations. Beside these simulations real load-flows of the past years are used by the company.
3. Compressor bottlenecks: Although compressor stations belong to the stations of a pipeline system they are counted among an own category thanks to their great importance for natural gas distribution. WINGAS Transport is in the procession of nine compressor stations. The maximum pressure in these compressors lies between 84 and 100 bars and the maximum transport capacities lie between a maximum of 300,000 m<sup>3</sup>/h and 3,340,000 m<sup>3</sup>/h.<sup>166</sup> In addition to these purely technical restrictions the compressor capacity also depends on the load scenarios, their entry and exit pressures and their transport directions.
4. Other bottlenecks: Other aspects that are able to reduce the capacity are particularly gas pressure measurement and control plants and the gas quality according to the contracts with customers.

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<sup>165</sup> SIMONE Research Group (2011), date 17.08.2011

<sup>166</sup> Cp. WINGAS Transport (2011b), date 18.08.2011

As sold capacities increase the turnover and profit it is the aim of WINGAS (and any other gas distributor) to maximize the FAC. Therefore, all bottlenecks have to be considered (in the case of WINGAS not cumulative but initial) because their capacities are the maximum capacities of the whole pipeline system including all stations. For this reason it is worthwhile for the gas distributor to arrange flow commitments that for example contain a high entry pressure so that bottlenecks reduce the FAC as little as possible.

A second, smaller objective of the company is to determine limited assignable capacities. These are capacities for which customers can only connect a capacity right at one entry respectively exit point with one specific exit respectively entry point. This connection may also only be possible under special conditions like a certain transport direction (conditions are mentioned in the capacity right). The limited assignable capacities can arise from situations in which all capacities in many bottlenecks are used and only some limited capacities are still available like for example a transport of a certain amount of natural gas in a certain time between the entry point in Kienbaum and the exit point in Malinow. Because of this limitation WINGAS Transport may only achieve a small price for these capacities, but it may still be worthwhile as the capacities are already installed and another transportation order won't create much additional costs. Therefore, it is important to determine all capacities in the context of capacity management.

WINGAS Transport also investigates the possible future of natural gas distribution. The company published such an investigation under the title "Ermittlung des langfristigen Kapazitätsbedarfs / Evaluation of longterm capacity demand"<sup>167</sup> on 01.04.2011. This will be an integral part of the capacity management because of a legal obligation (§ 17 GasNZV, released on 08.09.2010), which commits to an annual evaluation of the longterm capacity demand of all gas network providers in a market area in collaboration. The market area of WINGAS is called GASPOOL and spans a large part of Germany from the Danish border to the Saarland. The gas network providers in this area beside WINGAS Transport are Gasunie Deutschland Transport Services GmbH, ONTRAS – VNG Gastransport GmbH and Statoil Deutschland Transport GmbH. The evaluation has a planning period of ten years. For the creation of the evaluation different input data is used, as there would be:

- Macroeconomic data: economic or political developments that can't be influenced by the gas network providers. As an example the evaluation forecasts a decline of the demand for natural gas for the future because of two

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<sup>167</sup> The following text about the future capacity demand is based on: WINGAS Transport (2011c), date 18.08.2011

studies created on behalf of the Federal Ministry of Economics and Technology (BMWi) and the Federal Environment Ministry (BMU, only responsible for one study).

- Microeconomic data: influenceable economic developments concerning directly the gas network providers. As an example WINGAS Transport can forecast an increase of required capacities to West Europe from the end of 2012 because of a project (NORDSTREAM-project) which will expand the company's network.
- Data of network planning: This data is obtained from individual load-flow simulations of the gas network providers.

Considering all available input data this evaluation comes to the conclusion that the need for capacities will decrease in the next ten years. Apart from some regions with growing capacity demand this decrease will maybe make it necessary to reduce existing capacities. The evaluation closes with a reference to a study (network development plan TYNDP) from the European network of transmission system operators for gas (ENTSOG) which also forecasts the capacity demand for a ten year period. This study predicts a growing demand which will make it necessary for WINGAS Transport to build up to 175 km of new pipes.



## 5. Conclusion

The objective of this paper was the application of the production capacity management concept to the field of outbound logistics. Especially at the present time of fluctuating global markets, customers' demand varies greatly together with their requirements for short lead-times and high flexibility.<sup>168</sup> This leads to challenges for manufacturers and logistics service providers in order to provide the required capacities for warehousing and transportation at the time needed and in sufficient quantity. This paper should bring solutions for the central questions stated at the beginning:

- How can the warehouse capacity for finished goods be managed efficiently, especially if the end-customers' demand fluctuates and is dependent on different factors?
- How can transportation capacities in different transport modes with fluctuating demand and short lead-times be managed efficiently?

The basis for capacity management – independent of production or outbound logistics – is the customer's demand planning. To ensure efficient utilisation of capacities an anticipatory planning of the capacity requirements and supply is necessary. The stability of the demand forecasts and, therefore, the capacity requirements are dependent on different factors: Industry characteristics, market situation and development, performance of competitors, strategic management decisions, etc.

In addition the capacity supply must be determined in order to harmonise it with the requirements. Capacity supply in production can occasionally be adjusted by outsourcing, but this depends on the complexity of the manufacturing process and the related means of production. In the event of highly automated manufacturing of technical products especially, outsourcing may be restricted. The adjustment of capacity supply in outbound logistics, however, is more flexible due to the engagement of external logistics service providers. The processes of outbound logistics are mostly outsourced, at the present time, for warehousing as well as for transportation. Therefore the manufacturer profits from the service provider's expertise and can manage the required capacities more flexibly.

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<sup>168</sup> Cp. BME (2010), date 12.03.2011.

After determination of capacity requirements and supply they have to be adjusted in order to utilise the capacity as efficiently as possible. While in production capacity management the scheduling and reduction of processing time is a matter of capacity adjustment, in the field of logistics the efficient utilisation of space is of foremost importance. Admittedly handling capacities are also an important restriction on capacity that must be taken into consideration during capacity management in outbound logistics. Via scheduling of loading times and efficient termination of transport, for example, capacities can be utilised optimally.

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## Die Publikationsreihe

Schriftenreihe Logistikforschung / Research Paper Logistics

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In der Schriftenreihe Logistikforschung des Institutes für Logistik- & Dienstleistungsmanagement (ild) der FOM werden fortlaufend aktuelle Fragestellungen rund um die Entwicklung der Logistikbranche aufgegriffen. Sowohl aus der Perspektive der Logistikdienstleister als auch der verladenden Wirtschaft aus Industrie und Handel werden innovative Konzepte und praxisbezogene Instrumente des Logistikmanagement vorgestellt. Damit kann ein öffentlicher Austausch von Erfahrungswerten und Benchmarks in der Logistik erfolgen, was insbesondere den KMU der Branche zu Gute kommt.

The series research paper logistics within Institute for Logistics and Service Management of FOM University of Applied Sciences addresses management topics within the logistics industry. The research perspectives include logistics service providers as well as industry and commerce concerned with logistics research questions. The research documents support an open discussion about logistics concepts and benchmarks.

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**ISSN 1866-0304**