Chapter 15
Logistic Networks and Systems

The logistic network of a company is part of the *global logistic network* that is made up of the networks of forwarders, railways, airlines and shipping companies and of industrial enterprises, trading companies and service providers. The global logistic network has many owners and users. It serves different purposes and several interests (see *Fig. 0.1* and *15.1*).

Central tasks of *network management* are to delimit the logistic network of the company and to organize its connections to the networks of suppliers, customers and service providers. For this purpose, management has to decide, which logistic tasks can be left to suppliers and customers, which should be performed by the company itself and which are better outsourced to *logistic service providers*. The boundaries of the company logistic network depend on the core competencies and on the importance of logistics for the business. In some cases, e.g. for a *car manufacturer* with a logistic network as shown in *Fig. 1.15*, the relevant network extends from the customers' customer to the suppliers' supplier.

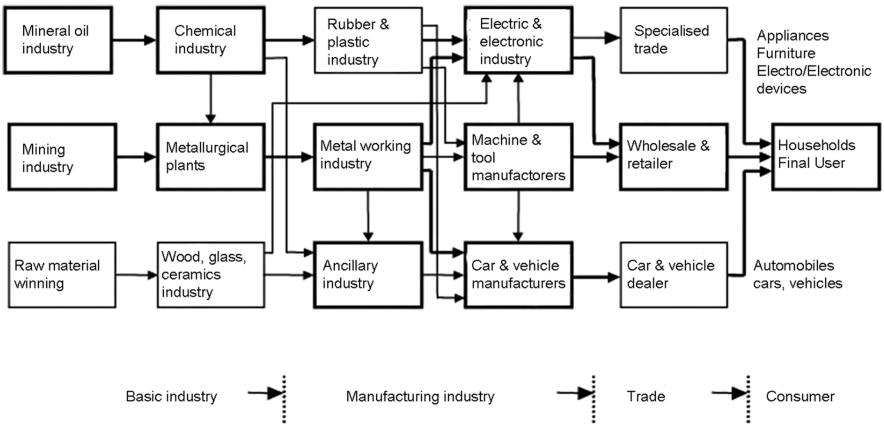

Fig. 15.1 Logistic network and supply chains for utility goods

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As explained in *Sects. 1.9* and *2.9*, the tasks of *logistic network management* (LNM), also called *supply chain management* (SCM) (Chopra/Meindl 2007; Kuhn/Hellingrath 2002; Schönsleben 1998; Simchi-Levi et al. 2008), are:

- *Strategic Logistic Management*: In order to cope with *future demand*, systems are *planned*, *organized*, *set up* and *linked* to an optimal logistic network.
- *Operative Logistic Management*: In order to execute *current orders* at lowest costs, the available supply chains and resources are *scheduled* and *operated* efficiently.

In *Part I* of this book, the general *principles* and *strategies* of modern logistics and the organizational, technical, and commercial *options* of supply chain management have been described. In addition, the methods and strategies for scheduling orders and inventories were developed. In the following *Part II*, the general rules and strategies of *Part I* are applied to logistic technology and network management. *Logistic technology* comprises design, dimensioning and optimization of *storage*, *commissioning* and *transport systems*, layout principles for *logistic sites* and strategies for *production logistics*. *Network management* is concerned with the design of *dynamic networks* and the selection of *optimal supply chains*.

After the topics and methods of logistic technology and network management have been outlined, the characteristics of *logistic service providers* and the procedure for their employment will be described. The last chapter deals with the role and importance of *people in logistics*. It closes with an outlook on the tasks and challenges for logistics of the future.

15.1 Dynamic Networks

Logistic networks and the flows of physical objects within these networks are the *action fields of operative logistics* and the *research areas of theoretical logistics*. For a long time theoretical logistics has considered only stationary flows and stable networks, although the importance of *industrial dynamics* has already been emphasized by *Forrester* in 1961 (Forrester 1961).

The independent decisions of consumers and companies cause *stochastic fluctuations* of the order flows and material flows. Varying customer behavior, technical development and changing demand generate *systematic variations* of these flows. The dynamic of the flows determines and changes the logistic networks. In the short term, swelling, shifting and decreasing flows force the actors to adjust the static and dynamic capacities of the logistic stations and transport connections. In the long term, the changes of the flows compel the *redesign of networks* and the planning of new systems.

The research into dynamic networks and the investigation of its structures, processes, laws and principles are still in an initial stage. The strategies for planning, scheduling and operating dynamic networks have not yet been studied systematically. Possibilities and limitations of technique, organization and scheduling and the interactions between technology and economy of dynamic networks are still quite unknown.

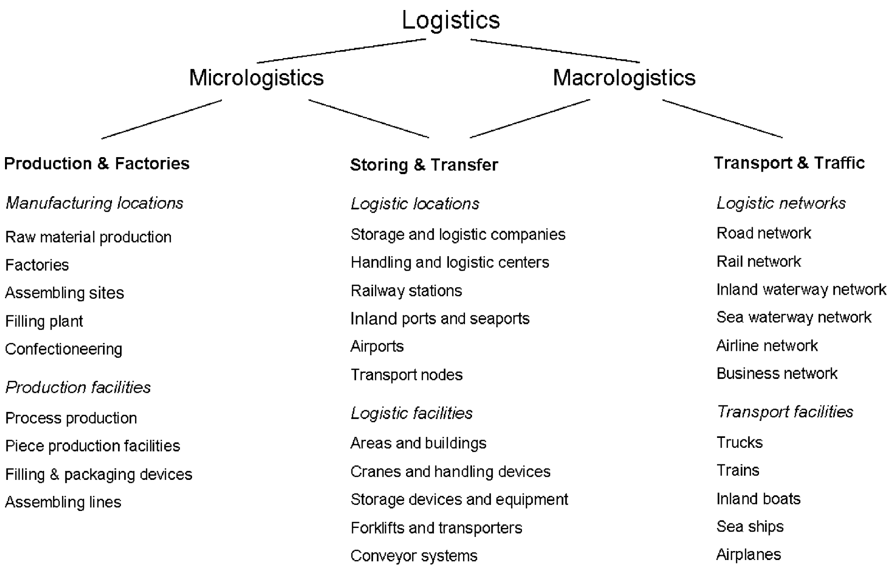


Fig. 15.2 Action fields and research areas of logistics

Similar to architecture or informatics, logistics is an applied science. It has to offer answers to questions of practical relevance and should develop methods to solve actual problems. Whoever wants to achieve certain goals in logistics must have a clear picture of the *action fields* shown in *Fig. 15.2*. Managers need plans of the network and systems of the company and records of the available resources, capacities, distances and interfaces of the stations and transport connections. They should know the logistic services, their costs and prices, and observe the *logistic markets*. In some field of logistics, the required information is available quite completely and accurately, in other fields it is still lacking.

15.2 Hierarchy of Logistic Systems

A *logistic network* is a number of sources, sinks and intermediate stations which are linked by transport connections and passed by physical objects. The *material flows* in the logistic network are initiated and controlled by *data flows*. Some data run together with the material flows, others are conveyed by separate *data networks*.

Analogously to *Internet*, *Extranet* and *Intranet* the logistic networks can be differentiated into *Intralog*, *Extralog* and *Interlog*:

- *Intralog* is the internal logistic network of a production site or logistic station.
- *Extralog* is the external logistic network spanned between the production sites and logistic stations of the company, its suppliers and its customers.
- *Interlog* is the connection of the logistic networks of all households, companies, service providers and other actors of an economy.

Generally, a logistic network is multi-functional and composed of sub- and part-systems with different and special functions.

Part-systems of the *Intralog* are machines, robots, stores, commissioning systems and handling stations, which are connected by cranes, conveyors and vehicles. Planning, building, connecting and operating these part-systems are tasks of *internal logistics* or *Intralogistics* (Ackerman et al. 1997; Arnold 1998; Apple 1972; Bode/Preuß 2004; Frazelle/Apple 1994; Günthner/Heptner 2007; Hung/Fisk 1984; Meller et al. 2004).

Subsystems of the Extralog are the *supply networks* for material and parts, the *distribution networks* for finished products, the *recycling networks* and the Intralogs, which are connected by external transport systems. These subsystems and their relations are subjects of *external logistics*, *extralogistics* or *micrologistics*.

The Extralogs of all households, companies and logistic service providers of the world are subsystems of the global Interlog. The analysis and optimization of the Interlog are subjects of *general logistics* or *macrologistics*.

A closer look shows that each subsystem or element of a logistic network consists of subsystems and elements and so on. This leads to the *logistic systems hierarchy*:

1. The Interlog, i.e. the global logistic network, consists of
2. national and regional logistic networks composed of the
3. Extralogs of households, companies and service providers connecting the
4. Intralogs of consumption, production and logistic sites consisting of
5. handling, storing, commissioning, conveyor and vehicle systems made up by
6. machines and robots which consist of parts, components or modules.

It is not task of logistics to deal with the lowest level of this hierarchy, but of other disciplines, such as materials handling, conveyor engineering, vehicle construction, ship building, aircraft design and road construction. As outlined in *Sect. 3.11*, these technical disciplines focus on the construction and development of the specific equipment, robots and machine systems.

The logistic systems hierarchy is similar to the *packaging hierarchy* of logistic units (see *Sect. 12.1* and *Fig. 12.2*). It reflects the *self-similarity*, which is typical for *complex systems* (Simon 1962). To the hierarchy of the operative logistic system corresponds the *hierarchy of the control system*. For example, *Fig. 18.6* shows the levels of a hierarchical control system for a transport network. By the control system the different functions of the subsystems and elements are released, coordinated and controlled in order to execute the *current orders* and requirements efficiently, correctly and reliable.

The analysis and design of the system hierarchy and its structures, of the subsystems and elements, and of the corresponding control systems are key activities of *strategic network management*. It has to differ between the *horizontal integration* of systems of the same hierarchy level and the *vertical integration* of systems of different hierarchical levels. The orders come from vertically integrated systems of higher levels or from horizontally integrated systems of the same level. The vertically integrated systems of lower levels determine the *limit performances* and *buffer capacities* of a logistic system. They also receive their orders from systems of a higher or the same level.

15.3 System Planning and System Optimization

Central task of *system planning* is to develop a system that is capable to fulfill the *performance demand* at minimal costs and keeps the given constraints. *System optimization* has either to improve the static and dynamic *capacities* or to reduce the *performance costs* of an existing system.

15.3.1 Demand and Capacities

The current or expected demand results from the number and content of orders placed by operators, users or customers:

- The orders specify the *kind*, *quantity* and *quality* of the required performances, products and services and prescribe the *date* and *location* of the delivery.

Orders to a production system are *processing orders*, *manufacturing orders* or *assembling orders*. Orders to logistic systems can be *pick-up orders*, *transport orders*, *storing orders*, *handling orders*, *commissioning orders* or *delivery orders*.

A current or anticipated *order entry rate* λ_O [Ord/PE] with a mean *order content* m_O [LU/Ord], measured in *performance units* [PU] or *logistic units* [LU], leads to the *performance rate, throughput* or *material flow*:

$$\lambda = m_O \cdot \lambda_O \quad [\mathrm{PE/PE\ or\ LU/PE}]. \tag{15.1}$$

A randomly fluctuating order entry causes a *stochastic flow*. If the order entry is time dependent, the throughput or material flow becomes *dynamic*. The order entry rate, throughput, performance rates and material flows constitute the *dynamic demand*.

Stochastically fluctuating dynamic flows can generate *order backlogs* and *material stocks* for which the system has to provide sufficient buffer capacity. Since *order scheduling* has the option to execute orders in advance, the *static demand* for storage and buffer capacities of the system results from the dynamic demand and the *scheduling strategies* for orders and inventory.

Static demand and dynamic demand determine what should be achieved by a system. The demand has to be compared with the *static* and *dynamic capacities*, which measure what a certain system can achieve under given conditions. As outlined in *Chap. 13*, the *dynamic capacity* of a system is determined by the *limit performances* μ_i [LU/PE] of the system elements SE_i and by the *operating strategies*. The *static capacity* of the system depends on the *buffers* and *storage capacities* C_i [LU] of the elements, and on the *scheduling strategies* for the orders and inventories.

In addition to the internal influence factors, the capacities of a system are affected by *external factors*, such as size and structure of the orders and the stochastic and dynamic of the order flow. All internal and external influence factors must be known in order to optimize and schedule an existing system or to plan and realize a new system.

15.3.2 Performance Costs

The *performance costs* or *cost rate k* [€/PU or €/LU] are the *operating costs* K(λ) [€/PE] related to the *performance rate* λ:

$$k = \mathrm{K}(\lambda)/\lambda \qquad [€/\mathrm{PU}]. \tag{15.2}$$

If the system produces, processes, handles or transfers several *partial flows* λ_r [PU_r/PE] of logistic or performance units PU_r, the total operating costs can be split up into a sum $K = \Sigma\ K_r(\lambda_r)$ of partial operating costs $K_r(\lambda_r)$ due to the utilization of the system elements. With relations corresponding to (15.2), the *partial performance costs* k_i [PU_i/PE] can be calculated from the partial operating costs. As explained in *Chap. 6*, the operating costs are determined by the depreciations, interests and maintenance costs for buildings, machines and equipment, and by the costs for personnel, material and energy. The operating costs can be split into *fixed costs* $K_{fix}(\mu)$ and *variable costs* $K_{var}(\lambda)$, that depend on the performance rate λ [PU/PE]. The fixed costs are independent of the current performance, but determined by the limit performances μ [PU/PE].

15.3.3 Stepwise Improvement and Iterative Planning

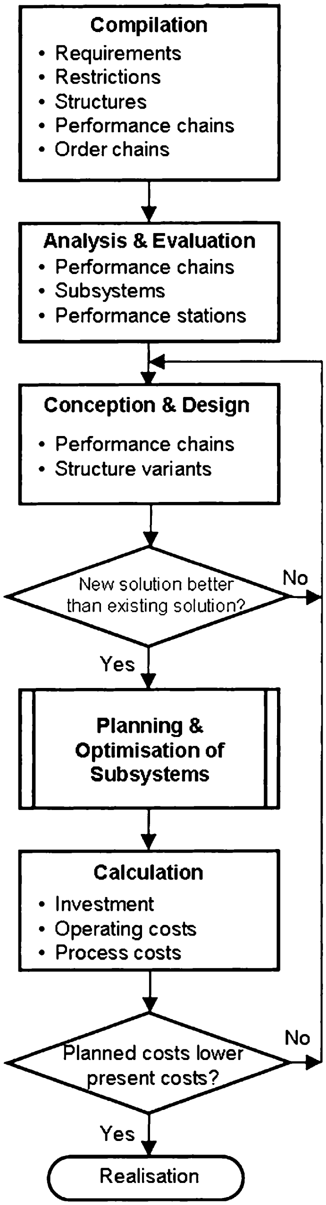
With decreasing *utilization* ρ = λ/μ [%], the performance costs of a system increase due to the remaining fixed costs. Systems with longer lasting underutilization are oversized and generate high costs. In order to avoid this, the system should be planned and optimized in the following steps:

1. Different system solutions are designed, dimensioned and optimized for the expected *mean demand*. Out of these, the most efficient solutions with the lowest inventory and performance costs are selected by the methods described in *Sect. 3.9*.
2. The best of these solutions are adjusted to the expected *dynamic* of the demand. To cope with the demand of the *peak hour* of a regular *peak day*, the operating strategies, limit performances and storage capacities are adapted. The investment, performance costs and return on investment of the adapted systems are recalculated and compared again.
3. The most economic of these solutions is adjusted to the *stochastic* of the demand. By a *function and performance analysis* as described in *Sect. 13.7*, the limit performances, buffer capacities and operating strategies are adjusted to the stochastic demand. The result is the technically and economically *optimal system*.

This *stepwise improvement* in logistics is similar to *perturbation calculation* in physics, by which a problem that has no explicit mathematical solution can be solved to any required accuracy. In the first step, a solution is calculated for the main influence factors disregarding any higher order disturbances. In the next steps, further influence factors are taken into account in the sequence of their relative importance. This is done until a solution with the required accuracy has been reached.

The stepwise improvement is central part of the *iterative planning and optimization* of logistic networks, systems and subsystems which is shown in *Fig. 15.3*. After

Fig. 15.3 Iterative planning and optimization of logistic networks and systems



gathering the static and dynamic demand and the constraints, the next step is an analysis and evaluation of the available order and performance chains and of the existing systems. The further steps depend on the hierarchical position of the system.

If at the end of *network planning* no solution results, which fulfils the demand at significantly lower costs than the current state, the subsystems, which initially have been assumed as fixed, are analyzed, optimized and if necessary redesigned. For the planning and optimization of a subsystem, the same procedure as on the higher level can be applied.

15.3.4 System Planning and Design Principles

The following *system planning principles* help to reach with adequate effort in quite short time the optimal solution:

- *Structure follows processes*: Before the structure of the network is planned the performance processes and logistic chains have to be designed.
- *Data flow follows material flow and performance processes*: The necessary material flows through the network and the required performance processes determine the design of the order processes and information flows.
- *Informatics follows logistics*: The logistic chains through the network and systems and the necessary operating and scheduling strategies determine the IT-systems, such as APS, ERP, PPS and MIS, and not vice versa.

The logistic functionalities of standard software are generally limited. In order to exhaust the potentials of logistics, the operation and scheduling strategies and other logistical IT-requirements must be specified in a manual before the architecture of the IT-system is designed and the software is selected or programmed.

Complex systems with many closely connected subsystems and elements are difficult to control and trouble prone. Even the most accurate calculations and highly sophisticated simulations cannot significantly improve a complex system. A reduction of the *complexity* of large networks and systems is achievable by the basic *principles of system design* (Gudehus 1975/II; Simon 1962):

- *Simplicity principle*: In many cases, the simplest solution with the shortest supply, delivery and performance chains, the smallest number of parallel elements and subsystems, and the lowest automation is the best solution. In any case it is *benchmark* for higher sophisticated solutions.
- *Decoupling principle*: If the total system is outlined and dimensioned in a way, that under normal conditions backlogs and feedbacks of the subsystems are improbable, the decoupled subsystems can be designed, optimized and scheduled separately.
- *Approximation principle*: The formulas and calculations for dimensioning, optimization and scheduling must not be more accurate than the planning data, input values and demand figures.

Two further design principles for logistic networks and systems result from the fact that transport, storing and handling of physical goods are far more expensive than transfer, storing and processing of data and information. These are:

- *Dominance of material flow*: In Intralogistics, the flows of physical goods and material, not the data flows, determine the optimal logistic system.
- *Dominance of logistic chains*: In Extralogistics, the operative supply, performance and delivery chains, not the order flows and administrative processes, determine the optimal logistic network of a company.

As shown in *Fig. 8.1*, an order flow ends after passing a chain of administrative stations in an operative station, where the order execution starts. Here the order chain is linked with the performance or delivery chain. The *decoupling station* is the interface between the anonymous section and the order specific section of the supply chain (see *Sect. 8.6*).

15.3.5 System Optimization and Greenfield Solution

Principally, there exist two extreme options to optimize and redesign the logistic network of a company:

- *System optimization*: Keeping the existing structures and systems as far as possible, the capacities are adapted to the changing demand and the performance costs are reduced primarily by organizational efforts, optimization of processes and better strategies. Investments are kept as low as possible.
- *Greenfield solution*: After thorough redesign of the processes and structures, optimal systems are planned and new operations are built on the green field at optimal locations using modern technology without restrictions.

The greenfield solution should always be compared with the optimized state, not only with the existing state. Quite often, the optimization of the existing processes and systems reduces the costs to a satisfying level and can cope with the changing demand. If the resulting performance costs of the improved system are only slightly higher, the greenfield solution is not attractive.

Quite often, the difference of the fixed costs for the Greenfield solution and the existing system is higher than the achievable reduction of the variable costs. This happens, e.g., if the existing buildings, plants and machines are written off completely but can still be used. In such cases, the greenfield solution can be realized if at all only stepwise. Even if the greenfield solution is not realized, it is a reference for the development of the company logistics. The capacities and costs of the optimal solution are *analytical benchmarks* for the existing systems.

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