Toward the integrated determination of a strategic production network design, distribution network design, service network design, and transport network design for manufacturers of physical products

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Abstract

The right distribution network design and the right service network design play an important role in strategic decisions about a specific production network design and the location of production sites, especially for physical goods. This paper shows which design possibilities are suitable for distribution networks and service networks for particular markets and product characteristics, depending on the design of the production network. Secondly, the design possibilities for retail networks for decentralized distribution are deduced. Thirdly, the design possibilities for appropriate transport networks are considered. The result is a new method with which the appropriate network designs can be determined using a combination of generic characteristic values and the portfolio approach. The determination is integrative: a combination of designs of the production, distribution, service, and transport networks both suit the product and the targeted customer segment, and fit well together.

Keywords

strategic operations management, supply chain management, supply chain design, location planning, manufacturing network design, strategic production concept, strategic distribution concept, strategic service concept, strategic transportation concept, portfolio approach, decision making.

Preferred citation style

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1 Introduction

Decisions to invest in production sites are strategic for manufacturing companies, owing to both the generally high financial commitment and the long lead time until the facilities enter into production. In [1, 2, 3], centralized and decentralized production network designs are introduced, with a description of their dependencies on market and product characteristics, by using the portfolio approach. Managers in firms like to base their decisions on such simple approaches that provide intuitive transparency and allow assessment of the robustness of the solution. Thereby, the adequate network design may differ for each product family.

In practice, decisions on production network designs also involve – from the very beginning – not only tax aspects (see [13] section 2.1.2) but as well the determination of the suitable distribution network design and the suitable service network design for the products being manufactured. In fact, if the distribution or the service concept was not feasible, the best production concept is of little use. While some authors consider individual aspects of this problem [4, 5] or of its operational manifestations [6, 7], others introduce mathematical models and algorithms for system optimization [8, 9].

In general, authors of qualitative methods limit their discussion on only one type of network design. Thus, the research question arises, whether there is a qualitative method that allows an integrated determination of all the production, the distribution and the service network designs, while still remaining simple, intuitive and robust.

This paper spans a large set of different domains. For the sake of readability, in particular for practitioners, the number of literature references is reduced to the minimum necessary. Synthesis is in the foreground.

The paper builds on established methods for designing production networks in [2] and distribution networks in [10]. It proposes a new generic approach for determining a distribution and a service network design that are related to the production network design. By looking at the properties of the market and the product as generic features, it is possible to combine the values of these features to produce a comprehensive set of design options for distribution networks and service networks that fit the design of the production network. In addition, for decentralized distribution, it is also possible to determine potential retail networks. Similarly, for decentralized service, it is possible to determine potential service and
collection points. In addition, design options for a suitable transport network can be generated by combining the values of additional market, product and service characteristics. This final step also serves to perform a necessary validation of the selected design of the service, distribution and production network. In fact, the analysis must be integrative: a combination of designs of the production, distribution, service and transport networks must both suit the product and the targeted customer segment, and fit well together.

The pattern of each of the following sections is similar. After explaining the basic area of conflict that entail different design options, we firstly find the underlying generic features or decision variables. Secondly, we present the strategic portfolio of design options. Thirdly, we discuss concrete cases of companies that were and are confronted with changing their network design option, in particular when values of the generic features change. Forthly, we note some further correlations that should be considered for an integrated determination of the design options of the different networks.

2 Design Options for Production Networks

For the determination of the production network design, the generic approach is already quite well established. In a first approach it is possible to distinguish two basic types of production networks.

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centralized production</td>
<td>A product is manufactured at only one location or through a chain of single stations, one station per operation at one location.</td>
</tr>
<tr>
<td>Decentralized production</td>
<td>A product or certain operations of a product are manufactured at several locations.</td>
</tr>
</tbody>
</table>

Figure 1 shows a simple example.
Taking a product with four operations (or four production levels) and subsequent distribution, Figure 1 shows centralized production (obviously for the global market) versus decentralized production (more for the local or regional market). Roughly speaking, the advantages of centralized production are obvious: higher quality and higher capacity utilization, thus lower production cost. The advantages of decentralized production are also easy to see: shorter delivery lead times and proximity to the customer.

2.1 Generic Features or Decision Variables

For the decision as to centralized / decentralized there are features (or decision variables) for designing production networks, including:

- **Demand volatility:** Items have continuous demand if it is approximately the same in every observation period. Items have discontinuous demand if many periods with no or very little demand are interrupted by few periods with large demand, for example ten times higher, without recognizable regularity.

- **Supply chain vulnerability:** Disruptions can arise from either the supply chain partners or the macro-economic environment.

- **Necessity for economies of scale,** that is an effect whereby larger production volumes reduce unit cost by distributing fixed costs over a larger quantity; or necessity for economies of scope, that is, when different products can be produced in a changeable factory at lower costs than when each product is produced in its own factory.

- **Demand for consistent process quality:** Can customer needs be satisfied despite differing process quality?
An interesting observation is that these four features are highly correlated: Centralized production is an advantage for high economies of scale or scope and for a high demand for consistent process quality. Decentralized production is an advantage in the case of high demand volatility and in the case of high supply chain vulnerability.

Further important features for designing production networks are:

- **Customer proximity**: To sell a product it can be necessary to locate the value-adding processes close to the customers.
- **Market specificity of products**: Adapting products to the market is necessary for functional requirements, such as voltage, electrical connections, packaging, and documentation. But it also applies for the appearance of products in the broadest sense.
- **Customer tolerance time**: According to [11], the time span the customer will (or can) tolerate from the date of the order release to delivery of the product.
- **Value density**: This is, product value — or item costs — per kilogram or cubic meter: Transport costs are of greater consequence if value density is low than if value density is high.

The above four features are also highly correlated: If customer tolerance time is high enough, there will be a tendency to centralize production, as there is also when value density is high. If high customer proximity is necessary, there will be an advantage in decentralized production, as is also the case if high market specificity is necessary.

However, the two groups of features unfortunately often stand in opposition to one another. There are examples of this:

- **Appliances**: (specialized machining equipment, but adaptation due to voltage, connections, packaging, documentation): high necessity of economies of scale (in favor of centralized production), however also high market specificity of product (in favor of decentralized production)
- **Bakery products**: with a brand promise regarding quality: high demand for consistent process quality (in favor of centralized production), low value density (in favor of decentralized production)
- **High value components**: with various variants (e.g., electronic chips, engines, pumps, injections): high value density (in favor of centralized production), but also high demand volatility and high supply chain vulnerability (in favor of decentralized production)
- Important raw material (such as steel), perishable foodstuffs: low market specificity of product (in favor of centralized production), however also high demand volatility and high supply chain vulnerability (in favor of decentralized production)

Here, a company must make a strategic decision, which sometimes differs for each product family.

2.2 The Strategic Portfolio of Design Options

The portfolio in Figure 2 is based on an idea in [1] and slightly modified from earlier versions as in [2] (see also the adaption in [3]). It shows, in addition to the two classical designs (the two sectors in the one-dimensional space in Figure 1, namely centralized or decentralized production), two possible mixed designs. The four possible designs lie in four sectors in a two-dimensional space, spanned by the dimensions that correspond to the two (conflicting) groups of features.

The sector P1 describes the centralized production for the global market. This option is advantageous where economies of scale or economies of scope are strong and, in addition, when there are advantages to having well-established, always identical partnerships for the added value of the various production levels. In this way, there is a greater possibility to maintain consistent process quality, which is important mainly for validation of production processes (keyword: GMP, Good Manufacturing Practices). Here it is not essential whether added value occurs via a company-internal supply chain or a cross-company supply chain. Distribution takes place from the location that manufactures the last production level, or last operation. Required for this is, in any case, high value density as well as high customer tolerance time and low vulnerability of the (only) supply chain. The products tend to be standard products. Some examples here are electronic components, liquid crystal displays (LCD), consumer electronics, chemicals and pharmaceuticals, fine chemicals, giant aircraft, standard machines and standard facilities.

The opposite sector P4 describes the decentralized production for the local market. This option is advantageous when high proximity to customers is required, when products must be modified for the local market, and when customer tolerance time and value density are very low. What is needed is a supply chain that is not strongly dependent on economies of scale or economies of scope. Qualitative differences, however, will result. Some examples here are household appliances, building materials (gravel,
cement), and products connected with services, e.g. clothing that must be adapted continually to the object during the manufacturing process.

Figure 2: Features of and design options for production networks (slightly modified from [2]).

The intermediate sector P2 describes the in part centralized production for the local market. If semifinished items are produced centrally, and if the last value added steps are performed at decentralized locations, important economies of scale or scope can be exploited while at the same time having proximity to market. Examples here are strategies for local end production for all consumer goods, such as, for example, “late customization” or “postponement“ (see here [13], Section 1.3.3).

The intermediate sector P3 describes the in part decentralized production for the global market. If the same components and/or end products are manufactured at different locations, and if at various production levels they

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**Table: Tendency to centralize vs. decentralize production**

<table>
<thead>
<tr>
<th>Customer proximity / market specificity of products</th>
<th>Demand volatility</th>
<th>Supply chain vulnerability</th>
<th>Necessity for economies of scale and scope</th>
<th>Demand for consistent process quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Low</td>
<td>Low</td>
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<td>High</td>
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<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
</tbody>
</table>
can be moved to different locations and distributed globally, this brings advantages in the case of volatile demand as well as for a supply chain that is vulnerable to disruptions, in that the capacities in the network are utilized more evenly or can even substitute for one another. This makes sense, however, only for standard products with high value density and sufficient customer tolerance with regard to delivery times, such as, for example, for components or end products in the automotive industry, perishable foodstuffs, or important raw materials (such as steel).

There are, of course, mixed forms of production networks that lie between these four main design options. This is particularly the case when the characteristics are not significantly pronounced on the abscissa or ordinate of Figure 2.

2.3 Company Cases

When features for designing production networks change, it is appropriate to consider changing the production networks. However, the financial investments required often quickly set limits to changeability.

For example, the production costs of cement are on the rise today, due to rising costs of both energy and CO$_2$ emissions (see the discussion of the triple bottom line in [13], Section 2.5). As a consequence, value density increases, so that centralized production becomes more and more an option (i.e. option P3 instead of the traditional option P4). But that requires new cement works and additional logistics infrastructure for supply of raw materials and distribution of the cement. Holcim, a Swiss based cement manufacturer opened its new production plant in Ste. Genevieve, Missouri, in 2009, with its own port and loading facilities on the Mississippi. Production cost and thus value density increased, as the new plant is aimed to reduce CO$_2$ emissions significantly. At the same time, the waterway network allows transportation to ten of the twenty largest cities in the US at lower cost than before. Thus, a more centralized production network design became possible.

Increased demand volatility makes it necessary to produce two different engine variants at each of two locations (option P3) instead of producing only one of the variants at each (option P1). Although this entails considerable investments for equipment, the result is much better use of the capacities. As an example, Daimler, a Germany based car manufacturer, produces its four and six cylinder engines in USA as well as in Germany. The benefit of the flexibility to cope with volatile demand is greater than the cost for double toolsets and facilities as well as for transportation of some of the finished engines between USA and Germany.
Increased necessity for economies of scale, due to massive competition, forced Hilti, a Liechtenstein-based manufacturer to centralize the production of drilling machines, despite its “the construction site is the point-of-sales”-driven sales strategy. Today, each drilling machine type is produced at exactly one site (option P1). Here, each site holds specific technology competences. Different fastening consumables, however, continue to be produced in different factories, close to the local markets (option P4). Still, semi-finished items that need expensive or important technologies, are produced centrally (option P2).

3 Design Options for Distribution Networks

In a first approach and in analogy to production networks, it is possible to distinguish two basic types of delivery of a customer’s order.

<table>
<thead>
<tr>
<th>Centralized Distribution</th>
<th>Decentralized Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>A customer order for a given product is fulfilled directly from the production plant or from one or a few of the manufacturer’s central warehouses. In decentralized distribution, the given product is stored in several decentralized warehouses or with (often independent) distributors, from where the customer order is fulfilled.</td>
<td></td>
</tr>
</tbody>
</table>

The advantages of centralized distribution, directly from a central warehouse or the manufacturing plant to the customer, are obvious: a bigger selection of products (which, in part, can also be produced per customer order, that is “assemble-to-order,” “make-to-order,” or even “engineer-to-order”), a greater availability, and lower total costs for inventories, plants, and handling.

The advantages of decentralized distribution are also easy to see: shorter delivery lead times and a more efficient possibility for product returns (e.g. at the retailer’s site). Besides this, transport costs are somewhat lower: first, the decentralized warehouse, which is located nearer to the customer, can be served at lower cost, e.g. using large transport units and (full) truck-loads ((F)TL); second, a customer order comprising multiple articles can be bundled into a single delivery at the decentralized warehouse. Finally, order tracking is only needed between the decentralized warehouse and the customer; if the order is raised directly in the store, tracking may even prove unnecessary. Combined with the necessary exchange of information between the manufacturer and the decentralized warehouses, the total cost for information systems is generally lower than the costs of real-time order tracking between the manufacturer and customer.
3.1 Generic Features or Decision Variables

The following features (or decision variables) for designing distribution networks relating to customers and products have proved to be important:

- **Demand volatility**, as defined in Section 2
- **Demand variety**: High demand variety means that customers demand many different products. For these products the demand volatility is mostly high as well.
- **Value density**, as defined in Section 2
- **Customer tolerance time**, as defined in Section 2. In the case of global distribution, the delivery lead time also includes the time required by customs procedures, which can disadvantage centralized distribution.

These four features are highly correlated: In general, centralized distribution is advantageous for products with high value density, high demand variety and volatility, and for high customer tolerance time. If the values are the opposite, then decentralized delivery tends to be advantageous.

Two further features for the design of distribution networks, which are not correlated with the above features however, are:

- **Need for efficient returns via the same network**: Is it important that the customer be able to return goods efficiently through the same distribution network and that the network be able to handle these returns efficiently (keyword: reverse logistics)?
- **Degree of customer involvement in picking up**: To what extent are customers willing and able to picking up the product themselves?

For cases where the need for an efficient product returns process using the same distribution network is key, and for customers both willing and able to picking up the product themselves, various designs of decentralized distribution are advantageous.

As in the case of production networks, the two groups of features often stand in opposition to one another. There are examples of this:

- The distribution of many rather cheap items, like heavy or bulky items (e.g. beverages), fresh produce (e.g. flowers), express delivery items (e.g. medicaments) or fast moving items to the point of use in companies (e.g. C items like screws, nuts, bolts etc.): low value density (in favor of decentralized distribution), however
rather low degree of customer involvement in picking up (in favor of centralized distribution)

- The distribution of vehicles or on-line orders: high demand variety or demand volatility (in favor of centralized distribution), however some degree of customer involvement in picking up, as long as the pickup site is close enough (in favor of decentralized distribution)

Again a company must make a strategic decision, which sometimes differs for each product family. In addition, if a company delivers to different customer segments, it will at the same time have to use different routes or channels for distribution. The channels or distribution centers need not necessarily be owned by the manufacturer. An additional required channel generally entails additional costs. Also, existing channels may change over time. For example, postal services may expand the offering of their mail rooms to become local shops, while points of sale may also offer a reduced set of services traditionally provided by a postal service.

3.2 The Strategic Portfolio of Design Options

Based on an idea in [10], the portfolio in Figure 3 shows, in addition to the two classical designs (centralized or decentralized distribution) two possible mixed designs. The four possible designs lie in four sectors in a two-dimensional space, spanned by the dimensions that correspond to the two (conflicting) groups of features.
Sector D1 describes centralized storage near the producer or – in the case of make-to-order – delivery directly from production, with direct shipping to the customer or his unloading point. This option is advantageous for products with high value density and high demand volatility. With this characteristic, customers are mostly willing to tolerate some time to delivery due to the generally long transport routes. This design makes possible a large selection of products, high fill rate and relatively low costs for inventory, installation, and handling. However, transport costs are high, as are costs for possible returns. Also, there are high costs for information systems for transmitting orders from the point of sale and for order tracking during shipments. This is the classic design for distribution of investment goods (such as machines), as well as for drop shipping (i.e. direct delivery from the manufacturer to the customer of the order entering party, e.g. a wholesaler, a spare-parts or online retailer. In the latter case, the order entering party can avoid its carrying cost but must factor in the
cost of integrating its information system with that of the manufacturer and is also unable to monitor the quality of the delivered product).

The opposite sector D4 describes decentralized storage at retailer with customer pickup. This design option is suitable if customers are able and willing to pick up the desired products, also products from different manufacturers. It generally offers a great amount of flexibility in terms of time for this. Beforehand, customers must also do the order picking themselves. This design option is transparent and requires rather simple information systems for tracking orders and delivery, and it also allows returns of products or packaging material. However, as stressed in the figure, it requires an adequate retail network. See here Section 4, particularly Figure 5 and the respective examples.

The intermediate sector D2 describes decentralized storage in distribution center of wholesaler or retailer with shipping to customer or his unloading point. This is the most convenient design option for customers. But it requires rather low demand volatility as well as the customer’s presence at the unloading point. Otherwise, high transport costs, also owing to irregular delivery tours, are the consequences. The problem of optimum routing and scheduling often occurs anyway, especially in respect of efficiency for last mile delivery or same day delivery. Using lockboxes for unloading, similar to post office boxes, the customers’ presence may not be necessary in every case. Storage by the wholesaler copes with smaller stock levels than a corresponding retailer network, but generally does not permit same day delivery. Where the unloading point is set up to handle returns, these can also be processed by this system (e.g. the return of empty bottles on a milk run). However, normally returns must take place via a different network (e.g. via the postal service’s network). This solution is suitable for the delivery of heavy articles such as beverages, of fresh produce such as flowers, of express-delivery items such as medicines, or of fast moving items, e.g. the distribution of ranges of C item goods (screws, nuts and bolts, etc.) to the point of use in companies. In the latter case, stocks may be managed by the customer as vendor-owned inventories (VOI).

The intermediate sector D3 describes delivery directly from production, or centralized storage in distribution center of the wholesaler, with shipping to the pickup site. This design option can be selected if customers are willing and able to pick up the goods and thus profit from considerably lower transport costs. Examples include the shipping of vehicles or online orders (click and collect). But this places higher demands on the accompanying information systems than in the case of shipping to the customer. If the pickup site entails high costs, this solution will, in addition, tend to be not cost effective. For this reason, pickup sites should be able to be combi-
ned with existing distribution centers for other products or service centers (e.g. a car showroom or a supermarket chain such as Coop or 7eleven). In this case, they are also suitable for product returns or return of packaging material. Storage in the distribution center of the wholesaler reduces delivery lead times. But it also either reduces product selection and availability or increases inventory costs. The costs anyhow increase for installation and handling owing to the costs of the distribution center. Distribution centers, including those located directly in the factory, may also act as a pickup site. An example of this is the pickup of cars from the plant.

3.3 Company Cases

When characteristic features change, it is appropriate to consider changing the distribution network design. In the example of Holcim mentioned in Section 1, not only a more centralized production network design but also a more centralized distribution network design became possible. Still, decentralized storage for basic demand of common products at various so called “terminals” is part of Holcim’s distribution network design in the US-Midwest (i.e. Sector D4 or D2 in Figure 3), right down to the Gulf of Mexico. However, in particular for products with volatile demand, Holcim now uses rather network designs with more centralized storage (Sector D3, where the “terminals” serve as pickup sites, or even Sector D1).

At Hilti, decentralized storage in distribution center of wholesaler or retailer (D2) and subsequent delivery to the production site is executed in order to offer short delivery times to the customer (“last mile”). Although the inventories and respective working capital are high, the availability of the products is more important in order to satisfy the customers’ demand as fast as possible.

3.4 Further Correlations that Should Be Considered for an Integrated Determination of the Design Options

The four design options cannot be selected without considering the design of the production network. For production destined for the global market (sectors P1 and P3 in Figure 2), all four design options for the global distribution network come into question. For production destined for the local market (sectors P2 and P4 in Figure 2) only the design options in the sectors D2 and D4 in Figure 3 come into question from a global perspective, i.e. those corresponding to decentralized storage. Sure, from a local perspective, it is possible to view storage in close proximity to a (local) manufacturer as “central”. In such a case, all four design options can come into question, albeit only for the local distribution network.
4 Design Options for Retail Networks

If a certain degree of decentralization of the distribution network design is chosen, the next thing to be done is to define its structure.

The distribution network structure defines the planned channels of distribution of goods. As the example in Figure 4 indicates, it comprises firstly the number of structure levels or echelons, e.g., a multi-echelon structure with four levels: 1. central warehouse, 2. regional distribution center, 3. wholesaler or distributor, and 4 retailer. Secondly, it comprises the number of warehouses per echelon, thirdly the geographic location of each warehouse, and fourthly the delivery area of each warehouse.

![Diagram](image)

Figure 4 Decentralized distribution – decision variables in the design & planning of the distribution network structure. (following [12], p. 249.)

The result is a geographically ramified distribution network. At every echelon, by a process called break-bulk, (full) truckloads of homogeneous
items can be divided into smaller, more appropriate quantities for use ([11]). For transparency of on-hand balances and transportation inventories throughout the entire network, an information system is required. Today, distances are determined more and more automatically, using distance tables or geographic information systems (GIS), for which in many countries commercial software is available. The lower the customer’s tolerance in terms of lead time, the greater the number of decentralized warehouses and the smaller the delivery area for each warehouse. Points of sale (POS) must be located at convenient locations close to customers. Therefore, the crucial point in the selection of new locations of a retail network is the prediction of the number of potential customers.

In respect of the design of retail networks, in the first approach it is possible to distinguish POS with a smaller volume of goods available on-site, i.e. at the POS, from those with a larger volume. The volume may relate to the number of different items, and/or the quantity per item.

4.1 Generic Features or Decision Variables

For the generic approach, important features for designing retail networks are the following:

- **Available time for shopping and simultaneously capacity of an available means of transport of the customer**: For private consumers (B2C), a car has a high capacity. On foot or by bicycle, the capacity of transport is, in contrast, low. If time is limited, or the car is unavailable at the appropriate time, then the purchase option is restricted to a local outlet and limited size and weight. For commercial purchasers (B2B) – depending on the transaction – a lorry offers high capacity. A small car can then only be used to purchase items of limited size and limited weight.

- **Demand variety**: as defined in Section 3.

- **The required geographical catchment area for the product range on offer**: This characteristic assesses the size of the catchment area in which a “sufficient” number of customers are based, for whom the offered product range represents a good fit in terms of product quality and price. This assessment is carried out in consideration of purchasing power, time available and the choice of means of transport. “Sufficient” means that the frequency of purchases multiplied by the average value of each sale corresponds to a minimum sale value per time unit that is required in order to make the operation of the POS a profitable venture.
4.2 The Strategic Portfolio of Design Options

In dependency of these three features, the portfolio in Figure 5 shows the design options for retail networks with rather smaller or larger volume of goods available on site.

Sector R1 describes the situation with normally no point of sale, since the required geographical catchment area is too large to make it profitable to maintain a POS. Thus, the intended design option of the distribution network design (i.e. Sector D4 in Figure 3) is not realistic and must therefore be abandoned. This, in turn, can entail modifications of the distribution network structure. The customer, if not ceded to a competitor, must place an order that is fulfilled directly from production or delivered from a distribution center, and shipped to a pickup site (e.g. general delivery or poste restante). See the sectors above or to the left in the portfolio in Figure 3. This is the case for most commercial (B2B) purchases.

![Figure 5](image-url)  
*Decentralized distribution: portfolio for designing retail networks.*
The opposite sector R4 describes the shopping mall of large stores. On these expensive sales floors, an extended product range can be offered. This increases the number of customers, so that this higher-value product range moves sufficiently quickly and the volatility of demand remains low. This is the design of the big supermarkets for private consumers, for example, or of cash and carry wholesale for commercial purchases. For the shopping experience, competition by different shops is desired. If such centres have a thematic range of products (e.g. clothes, or furnishing), they try to host as many competitive shops as possible. As automobiles are necessary anyway due to the amount or size of goods to be transported, these shopping malls are outside residential neighborhoods at convenient locations easily reached by car.

The intermediate sector R2 describes the cluster of points of sale or small stores for comprehensive needs, found in low population-density areas. It can only be accessed by most potential customers using a car. In this case multiple specialist points of sale exist largely with no overlap of offering. When considered together, these form an offering that meets the comprehensive needs of the largest possible number of customers who are able to access this cluster of points of sale.

The intermediate sector R3 describes the small shop “around the corner” for specific needs. As compared to larger stores, this solution offers customers more comfort, but comfort that must be paid for with higher transport costs and often higher installation and handling costs. The product range comprises basic items for specific needs. Among private consumers, these often comprise purchases of food or items for a specific customer group. For commercial purchases they include frequently used spare parts for renowned vehicle models, for example. In the case of food, this may relate to basic daily needs. These are covered by retailers whose shops can be accessed on foot or by bicycle. For this design option, a minimum number on potential customers with the corresponding purchasing power living or working close by the shop is required. This design option can be chosen in some areas of cities or for locations with a high frequency of visits by specific groups of people (e.g. in schools or sports facilities), for example. Stock costs can be kept at a low level by means of an efficient, normally IT-based replenishment system. An example of this is used by chemists or pharmacies, which hold only one unit of certain medicines in stock, the movement of which is then communicated directly to the distribution center by sensors. A fast logistics system ensures that replenishment can be guaranteed within a few hours.
4.3 Company Cases

In the prior example, customers of Holcim operate quite nearby to its “terminals” (Sector R3 in Figure 5). In the cement industry it is advantageous to ceding customers that are far away from such “terminals” (Sector R1) to competing manufacturers.

In some industries, such as food retail, clothing or furniture, big retail chains like Walmart or Swiss based Migros, have points of sale of different sizes and that carry a different range of products. Especially in large conurbations, they use both design options R4 and R3 across one single area, each for a different size of store and different product range. Such retail chains are thereby aware that many potential customers have a choice of transport modes with different ranges and capacity, and can also make a choice depending on available time and personal sentiment.

The aforementioned Hilti company owns its entire distribution structure. Its market organizations are the wholesalers that own one or several warehouses. De facto, the sales representatives on site act as retailers. They are in close contact with potential customers and deliver directly at the construction sites (sector D2 in Figure 3). So there is no need for “Hilti stores” or the partnership with a 3rd-party retail chain. Still, Hilti’s distribution network structure is changing. Actually, a VMI concept should result in a more efficient inventory management at the different echelons.

5 Design Options for Service Networks

A service in the original sense is a process involving a service object, that is an object belonging to the customer that must be transferred to the provider of the service, potentially along with additional customer input.

In many typical cases, the objects are the customers themselves. In other cases, it is technical support, service and maintenance of machines or plants. It can also include operator models (the object is a machine, that the manufacturer not only supplies under contract to the customer, but also operates) and contract work, (the object is a product in the making, on which an external operation is executed). Further examples include services in relation to information products, such as correction of software.

A service in the original sense can also be described as a process with direct contact with the service object. Due to technological development
and industrialization, the following two kinds of (sub)processes of the service as a whole have developed for which contact with the object in the same location is no longer necessary to the same extent. 1.) As process with indirect contact with the object rank services that take reservations or orders, such as in travel agencies, car rental or mail order companies; also services that deliver information and thus support the actual products or services, both before and after sales, e.g. call centers or hot lines. The locations for these services do not have to be located in proximity to the object, in these examples to the customer itself. As the delivery costs of information do not differ greatly for different locations, the locations can in principle be anywhere in the world where the production costs – for the required quality – are minimal. 2.) As process with no object contact often rank sub processes of the service as a whole that bear similarities to classical production and that – for example, due to efficiencies (economies of scale or economies of scope) or difficulty – must be carried out at a centralized location. Some examples of these processes are the “back offices” of banks (for example, in the mortgage or loan business), insurance companies (for example, for policies that cover special risks), or credit card billing companies. In these cases the goods are nonmaterial, so that delivery costs do not play a role as soon as goods can be transmitted digitally; these centers can in principle be located anywhere in the world, as long as quality is assured. Other processes that belong here are also the mere delivery of spare parts, or activities in centralized picking locations, e.g. for catering businesses, or processes along the distribution network structure for material goods; in these cases there are delivery costs in addition to production costs, so that the facilities cannot be sited at just any locations. With this, under certain conditions multi-level service networks will form, in which the individual locations are linked together.

For networks of services in the original sense, it is possible to distinguish, in analogy to production and distribution networks, two fundamental types: In centralized service a specific service is provided directly at one or a few central service centers. In decentralized service, the service is provided at or from several service centers, located, as close to customers as possible.

The advantages and disadvantages of centralized service as compared to decentralized service arise in a similar manner as the advantages and disadvantages of centralized distribution versus decentralized distribution. It is however necessary to assume that the object will be transferred to the service provider, potentially also at the place at which the object is located; this must be the first subprocess of the service and is critical to the effectiveness of service delivery.
5.1 Generic Features or Decision Variables

The important features for designing service networks are in principle the same as those for the distribution networks. However, the meaning of the following features changes:

- The value density of the product becomes the *mobility cost ratio of the service*, i.e. the mobility costs for the service provider (to bring people, equipment and materials such as spare parts to the object), in comparison with the mobility costs of the object. The latter include costs of transporting the object (generally dependent on size and weight) and for preparing the object for transportation at its base location. In the event of a complete overhaul or retrofitting of a machine or piece of equipment, preparations also include the dismounting and subsequent re-mounting. When the object is actually a person, the cost is measured in terms of the subjective value placed on loss of comfort, for example due to a stay away from home in a hospital.

- The degree of customer involvement in picking up becomes the degree of *customer involvement in bringing and picking up*: To what extent are customers willing and able to bringing and picking up the object?

- The need for efficient returns becomes the *need for repeated transfer of the service object*. Some objects must be treated repeatedly by the same service provider, e.g. vehicles at a garage or patients by a general practitioner.

As with production or distribution networks, the two groups of features often stand in opposition to one another. There are examples of this:

- The classical maintenance and repair or operator models on site, insurance services, simple home care, medical services provided by general practitioners in the home, home tutoring: low mobility cost ratio of the service (in favor of decentralized service), however rather low degree of customer involvement in bringing and picking up (in favor of centralized service)

- Major repairs to tools and equipment, the operation of traditional schools with collective transportation schoolchildren, group trips: high mobility cost ratio of the service (in favor of centralized service), however high degree of customer involvement in bringing and picking up, as long as the pickup site is close enough (in favor of decentralized service)
Again a company must make a strategic decision, which sometimes differs for each product family.

5.2 The Strategic Portfolio of Design Options

The portfolio in Figure 6 shows, in addition to the two classical designs (centralized or decentralized service) two possible mixed designs. The four possible designs lie in four sectors in a two-dimensional space, spanned by the dimensions that correspond to the two (conflicting) groups of features.

The sector S1 describes the option of a centralized service at the manufacturer’s or specific service provider’s location, with the object being picked up and later (that is after the service provision) brought from or to the location by the service provider. It is advantageous where the mobility cost ratio and demand volatility are high. In such cases, customers are usually also prepared to tolerate generally longer transport routes and longer lead times until delivery or execution of the service. This option permits a wide selection of services and a high fill rate as well as relatively low facility and handling costs. Nevertheless, these are countered by high transport costs, often associated with complex preparation and special transport modes. In addition there is a rather higher level of complexity for information systems, in relation to both the transmission of orders from the service point of sale and to order tracking during the service provision. The location of the object before and after the service need not necessarily be the same, and need not necessarily be that of the ordering party (e.g. dealer in second-hand machinery). However, in such cases, even greater complexity must be taken into account for the information systems described above. This is the classical design option for comprehensive refurbishment and modernization of capital goods (normally by the manufacturer, e.g. machinery, aircraft and vehicles), for contract work and for major operations at specialized hospitals in the health sector.
The opposite sector S4 describes the decentralized service in the service center. The object is brought and later (that is after the service provision) picked up by the customer. This design option is suitable where the customer is prepared and able to bring the object to the service center and pick it up again. First, the customer may or must schedule the execution of the service – potentially involving several visits. This design option is transparent, requires much simpler information systems for ordering and order tracking of the service and allows repeated transfer of the same service object. Examples here are simple repairs to items of everyday use, such as vehicles, shoes, devices and simple services delivered to people, such as in the hairdresser’s, at the bank, at the doctor’s surgery or at a kindergarten.
The intermediate sector S2 describes the service provided by the manufacturer / specific service provider or from a local service center, with provision of the service at the location of the object: this is the easiest option for the customer. However, it requires rather low demand volatility and accessibility to the object at the agreed time. If this is not the case, the consequences will be high stand-by costs and transport costs that are even higher than their currently high levels owing to futile journeys. Often, the challenge of optimum routing and scheduling also presents itself. The service is provided from a local center. For rarely executed or difficult services it may be better if a specialist service provider or even the manufacturer is deployed. Examples here are the classical maintenance and repair or operator models on site, as well as insurance services, simple home care, medical services provided by general practitioners in the home, and home tutoring.

The intermediate sector S3 describes the centralized service at the manufacturer’s location or servicing in a major service center. The customer brings to and later (that is after the service provision) picks up the object from a collection point. This design option can be selected if the customer is prepared and able to bring and pick up the object and can thereby benefit from significantly lower transport costs. Examples here are major repairs to tools and equipment or the operation of traditional school (collective transportation of schoolchildren) or group trips. The requirement in terms of accompanying information systems for this is even higher than for option S1. If the collection point incurs significant costs this solution becomes economically unviable. Thus, collection points should be combinable with existing service centers or product distribution centers (e.g. in store). In such a case they permit repeated transfer of the same service object. Collection points in relation to schools or tourism can be combined with a stop on the public transport network, for example. Provision of the service in service centers instead of the producer reduces the transport times. In turn, either the selection of services and their availability reduce, or stand-by costs rise. The costs for plant and handling rise further anyway, due to the costs of the service center. This solution is suitable if the objects accumulate in specific regions. Larger service centers and the specific service provider may also act as collection centers. An example of this would be accident and emergency in a hospital.

Similarly to the network structure for decentralized distribution, and to the design options for retail networks, decentralized service network designs (sectors S2, S3 and S4) require a suitable “multi-echelon” structure and a network of service providers, service centers, and collection points. The
degree of similarity to the shapes of retail networks shown in Figure 5 is high.

5.3 Company Cases

In the prior example, Hilti owns local service and repair centers as part of the different sales organizations. The customer tolerance time is very low, as is the degree of customer involvement in bringing and picking up. Due to the direct delivery concept, the sales representatives are close to the customer. In case of a defect, e.g. of a drilling machine, Hilti’s fleet management quickly delivers replacement, taking back at the same time the defective equipment. Thus S2 is the preferred design option.

For the equipment they previously sold, the aforementioned big retail chains like Walmart or Swiss based Migros offer collection points right at their larger points of sale. Sometimes, there also is an on-site service shop (option S4). More commonly, they use the transportation network that delivers products via the different echelons of their distribution network structure for transporting the defective part to a larger service center or to the manufacturer (option S3).

5.4 Further Correlations that Should Be Considered for an Integrated Determination of the Design Options

Through skillful redesign of a complex service, parts of the service can possibly take on a more decentralized character. For example, extensive revision of a machine at the manufacturer’s site can be more carried out as a sequence of simplified service variants at the operator’s site, without missing the desired goal of the revision. Prior to the performing of these simpler services, the necessary repair parts can be delivered via the distribution network. Furthermore, the degree of decentralization of services is, in general, at least as high as the degree of decentralization of the distribution. Actually, it would not make sense to the customer, why she or he should accept a longer way for maintenance and repair than for delivery. So a point of sale can often be used as a collection point, sometimes even as a local service center.

For a service that is related to a previously manufactured product (e.g. the classical maintenance and repair of installed appliances) the four design options cannot be selected without considering the design of the production network. For production destined for the global market (sectors P1 and P3 in Figure 2), all four design options for the global service network come into question. For production destined for the local market (sectors P2 and P4 in Figure 2) only the design options in the sectors S2
Design Options for Transport Networks

Production as well as distribution networks for physical products must generally be designed in careful consideration of the possibilities for transporting the goods. For each means of transport, e.g. lorry, railway wagon, ship or aircraft, the infrastructure must be available in terms of the corresponding mode of transport, i.e. road, rail, water or air; this means a network of transport channels with the necessary interchanges, i.e. loading yards, railway stations, harbors or airports.

Depending on costs and availability of a company’s own means of transport, independent carriers may be used in the transportation network. A third-party logistics (3PL) provider provides product delivery services. It may provide added supply chain expertise ([11]). Such services comprise classical services such as transport, reloading and storage, but also secondary packaging, the insertion of an information sheet, simpler assembly or repair work, acceptance of returned products.\(^1\)

Again, in a first approach, it is possible to distinguish two fundamental types of transport network.

| In the case of **direct transport** the transport between two sites takes place without changing the **primary means of transport**, i.e. the means of transport into which the load unit was directly loaded. In cases where a lorry drives independently onto a train (known as a „**rolling motorway**“) or a ferry in the form of a secondary means of transport, this still counts as direct transport, i.e. there is no change in the mode of transport. |

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\(^1\) *First-party logistics (1PL) providers* are internal departments of producing businesses or local transporters. A *second-party logistics (2PL) provider* takes over functions such as transport, reloading and storage as an external provider for producing businesses. A *fourth-party logistics (4PL) provider* is a 3PL-provider that does not have its own infrastructure, but has competence for integration of 3PL tasks throughout the entire supply chain.
In the case of *indirect transport* the transport between two sites uses more than one *primary means of transport*. Therefore it is possible to exploit the individual strengths of different means of transport for the individual transport segments, and thereby increase their utilization levels. At the same time, however, the cost and time for reloading the load units from one means of transport to another (possibly also involving a change in mode of transport) at *transshipment centers*, i.e. distribution centers the purpose of which is solely to reload goods – must be factored in.

### 6.1 Generic Features or Decision Variables

The following *features* (or decision variables) for designing transportation networks have proved to be important:

- **Size or weight of the delivery** in kilograms or cubic meters: How do the suitable means of transport match up to this?
- **Possibility of using an existing transport network**: Can the delivery specify a means of transport that is already carrying deliveries between the point of dispatch and the recipient and that is not yet at full capacity? This calculation could include means of transport that have a known timetable.

Observation of activity in the field shows that these two characteristics correlate highly with each other: Large dimensions/high weight or a high possibility of using an existing transport network tend mainly to be served best by direct transport. In the opposite case, indirect transport is more advantageous. Both apply irrespective of the value density. For example, foam packaging and gravel are better transported directly, owing to their volume and weight, respectively. Diamonds, on the other hand, are better suited to indirect transport owing to their low volume and weight, by plane if greater distances are involved.

Two further characteristics for the design of transport networks that correlate with each other, but not with the previous pair, are:

- **Need for merged transport**: To which extent delivery will be made together with products from another manufacturer or with service objects from another service provider? In the case of returns, to what extent must several products or parts thereof be sent back to a number of manufacturers at the same time? To what extent must several service objects or parts thereof be transferred to multiple service providers at the same time?
- **Customer tolerance time**, as defined in Section 2.
If the need for merged transport is on the high side, or there is greater customer tolerance time, different forms of indirect transport are advantageous.

As with production, distribution or service networks, the two groups of features often stand in opposition to one another. Examples are

- The transportation of very high-value goods (e.g. money, precious gems or precious metals), or express transportation (e.g. for spare parts): low size or weight of delivery (in favor of decentralized service), however low customer tolerance time (in favor of centralized service)

- Regular deliveries to points of sale by a large wholesaler, on-line orders that are delivered to pickup sites, or regular transport of groups of people to events at specific locations: high size or weight of delivery (in favor of centralized service), however high need for merged transport (in favor of decentralized service)

Again a company must make a strategic decision, which sometimes differs for each product family.

6.2 The Strategic Portfolio of Design Options

The portfolio in Figure 7 shows, in addition to the two classical designs (direct or indirect transport) two possible mixed designs for the transport between two locations L1 and L2. The four possible designs lie in four sectors in a two-dimensional space, spanned by the dimensions that correspond to the two (conflicting) groups of features.
The sector T1 describes the design option direct transport between two locations. It is beneficial if a (full) truckload lot – i.e. a single delivery of minimum size or minimum weight that is sufficient for the rate for a full load by the selected means of transport – is to be transported between two locations (e.g. the manufacturer’s warehouse and a pickup site). This can result in lower transportation costs. The means of transport can be provided from the dispatcher’s own fleet, or by (full) truckload (TL or FTL) carriers – i.e. transportation companies that bill for the full utilization of the means of transport. Last mile delivery represents a challenge. In this case the distributor supplies products itself to a range of customers on a route, instead of using a package delivery company. As the delivery vehicles used on at least part of the route are equivalent to „LTL carriers“ (less than truckload) the transportation costs are correspondingly higher. Providing the distance between the distributor’s depot and the customer is short and the routing and scheduling are effective, this is countered by a very short delivery lead time that generally cannot be matched by a package carrier company. Examples here are delivery of daily provisions and the supply of medicines to pharmacies. When the
service is provided at the location of the object the service provider must resolve a similar problem in terms of optimum route planning. Examples here are maintenance and repair of installed appliances.

The opposite sector T4 describes the transportation between two locations by a package carrier via a special distribution center: Third-party logistics (3PL) providers in particular may possess distribution centers that offer a service infrastructure that extends beyond traditional transportation services, for example for in-transit merge, or merging products from several manufacturers. Instead of receiving multiple deliveries, customers need only receive one shipment, which reduces their costs for transport, handling goods in and putting the orders together themselves. However, this is offset by the longer duration owing to the special distribution center, where additional costs are also incurred for the work involved in combining the products. An example of this is the delivery of computers that are merged from components from a range of manufacturers (e.g. processor from brand x and screen from brand y).

The intermediate sector T2 describes the transportation between two sites by a package carrier. This option is selected if the size or weight of the delivery is too small or low to justify ordering transport specifically for this delivery. The package carrier helps in collecting additional shippers and therefore spreading the burden of costs for the full transport over a broader customer base. Such package carriers can also access their own network of transshipment centers, about which the customer need have no knowledge. Depending on the type of goods and specific transportation requirements, there may also be specialized carriers such as those that carry very high-value goods (e.g. money, precious gems or precious metals) or those that specialize in express transportation where the customers’ tolerance time is short (e.g. for spare parts).

The intermediate sector T3 describes the transport between two locations via transshipment centers. This option may be selected if an order comprises several products from different manufacturers and must be delivered without interim storage, or if an order is to be supplied by a given transportation that is approaching the destination location anyway. Cross-docking principles, which are designed for fast transfer through a transshipment center are therefore vital from the customer’s viewpoint. This design possibility leads to better utilization of LTL carriers along the whole route. However, it is even possible to use TL carriers. The pros are offset by a normally longer lead time owing to the diversion via the transshipment center and complex planning for load building and cross-docking operations. Examples here include regular deliveries to individual
points of sale by a large wholesaler, or online orders that are delivered to pickup sites, or regular transport of groups of people to events at specific locations.

6.3 Company Cases

In the prior example, Hilti prefers option T3 for transport between plant and the warehouses in the local market. This is due to the possibility for using an existing transport network, as the weight of the delivery is high. If the delivery volume of one production plant for one market is high enough and accordingly the need for merged transport of products from different production plants is low, also the direct transport between production plant and local market (option T1) takes place. Direct transport by Hilti’s well-known red station wagons is used for transport from the local warehouse to the construction site (option T1).

De facto, the available transport network design options validate the selected design of the distribution and production network. This means that should the transportation network from the last production or storage location to the customer fail to enable an efficient design for which the delivery lead time can be kept shorter than or equal to the customer’s tolerance time, a competing solution could clearly better serve the customer’s needs. If the provider still wishes to serve the customer, there is a need to redesign the distribution network, and possibly even the production network. Holcim, for example, deliberately cedes a customer to competitors as soon as it has no chance to meet the customer’s tolerance time with its actual production, distribution and transportation network. However, as the example of the new plant in Ste. Genevieve (Missouri) shows, long-term investments in transportation infrastructure can change this situation. As soon as the Panama Canal extension and – in particular – the new Nicaragua Canal will be available for transportation, Holcim will consider whether or not to distribute cement to the large cities of the West Coast of the US as well from this plant. Similarly, with the availability of the new Gotthard railroad base tunnel in the near future, Holcim will consider to distributing cement to Northern Italy from its plants in northern Switzerland instead of producing locally, as soon as an existing quarry will be exploited, and instead of looking for a new quarry in northern Italy.

In addition, certain activities along the supply chain cannot always be clearly identified as part of production, distribution or service. In principle, some activities such as secondary packaging, adding information leaflets or affixing a local sticker to electrical appliances, can be carried out both in the factory and in a suitable distribution center. Services such as clean-
Design Options for Transport Networks

6.4 Further Correlations that Should Be Considered for an Integrated Determination of the Design Options

The four design options for the transport network in Figure 7 can, in principle, be selected for each of the four design options of production networks in Figure 2 to transport between two operations. The same holds for distribution networks in Figure 3 to deliver from a warehouse or directly from the production line to a customer or the customer’s unloading point or a pickup site. The same holds both for product returns and when the transport is not carried out to the end-customer, i.e. the consumer, but “only” to the depot at the next echelon of the distribution network structure, e.g. from the manufacturer to the wholesaler’s distribution center, or from a central distribution center to a retailer’s warehouse – see also Section 4. And the same also holds for service networks in Figure 6 for the transfer of the service object or parts thereof to multiple manufacturers or service providers, or for delivery of the object or parts thereof back to the location after provision of the service, as well as for the transport of the service provider and its infrastructure closer to the object.

As the customer tolerance time is a characteristic for the design of both transport networks (see Figure 7) and production, distribution and service networks (see Figure 2, Figure 3, and Figure 6), there are naturally close combinations when it comes to integrating the networks. This is the case when the customer tolerance time is low in both portfolios, or high in both portfolios. In the case of the distribution network (Figure 3), this means 1.) Decentralized distribution is the preferred combination for direct transport, with the aim of reducing delivery lead time to a minimum; and 2.) Centralized distribution is the preferred combination with indirect transport – i.e. via transshipment centers – since a short delivery lead time is not the priority and it is preferable to ensure that the means of transport is operating at better capacity utilization levels across the route to achieve lower transportation costs.
However, the other combinations are nevertheless possible. 1.) If the combination of centralized distribution and direct transport is advantageous, demand is highly varied and/or volatile. The reduced storage costs obtained from centralized warehousing thereby outweigh the disadvantage of a lengthier delivery lead time. If value density of the product is high, it is anyway possible to select a means of transport that is fast enough. 2.) If the combination of decentralized distribution with indirect transport is advantageous, the ability to reduce transportation costs or increase simplicity of a merged transport (the aforementioned “in-transit merge” where the customer receives just one complete delivery) outweigh the disadvantages of a longer delivery lead time from the customer’s perspective.

7 Conclusion and Research Agenda

Considering the generally high financial commitment and the long lead time until the facilities enter into production, decisions to invest in production sites are strategic for manufacturing companies. Such decisions have to involve the determination of the suitable distribution, service and transport network design. In addition to existing methods and techniques that generally focus but on one type of network design, there is a need for a method or a technique that allows an integrated determination of the production network design, the distribution network design, the service network design and the transport network design.

This paper presented a possible solution method to this need. The new method is based on a generic approach and comprises a framework with which the appropriate distribution network design and service network design can be determined using a combination of generic characteristic values in an integrated fashion. Using the definition of typical market and product characteristics, and depending on the design of the production network, potential design options for distribution networks were established by following a generic approach. In addition, the design possibilities for retail networks for decentralized distribution (or for networks of service and collection points for decentralized service) were deduced. Finally, the design possibilities for appropriate transport networks were considered. The new approach is integrative: a combination of designs of the production, distribution, service and transport networks must both suit the product and the targeted customer segment, and fit well together.
There are a number of possible research questions that could now be taken up. First of all, the portfolios with the design options for the distribution, service and transportation network are new, in contrast to the portfolio with the design options for the production network which is already quite well established. Therefore, despite the number of examples that were mentioned for the four sectors of each portfolio, more research on the usefulness in practice of each of these portfolios is certainly welcome and also necessary. Second, there is not a lot of knowledge around whether and to which degree companies actually practice the integrated determination of the different network designs. And if they do, did they do it proactively, that is from the very beginning of the strategic decision process? Third, as companies normally manufacture several product lines or product families that can entail various production, distribution, and service network designs, how do the network designs that are actually used influence the strategic decision on whether and how to develop a new product that presumably will need still other network designs compared to those actually in use? Forth, as customer needs and available transportation infrastructure changes in time, how do companies practically move from one sector of a portfolio to another sector? In addition, there might be a need for changing some of the network designs simultaneously, e.g. the distribution and the service network design.
References


