agriculture

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Decision Support in Horticultural Supply Chains: A Planning Problem Framework for Small and Medium-Sized Enterprises

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Abstract: This paper investigates and systematizes planning problems along the supply chain of small and medium-sized companies in the horticultural market of ornamental plants, perennials, and cut flowers. The sector faces considerable challenges such as multiple planning uncertainties, product perishability, and considerable lead times. However, decisions in practice are often based on rules of thumb. Data-driven decision support is thus necessary to professionalize supply chain, logistics, and operations planning in the sector. We explore the practical planning problems with the help of expert interviews with people in charge of typical companies active in the market. We structure the planning problems along the supply chain according to their time horizon and highlight the critical elements of the planning tasks and horticultural specifics. We examine the status quo of research on decision support for these planning tasks with the help of a structured literature review, highlight research gaps, and outline promising future research directions. We find that the tactical planning domains of material/product requirement, production, and demand planning are especially critical in practice, and that there is a great need for research to develop practically relevant decision support systems. Such systems are currently available only to a limited extent in literature and are not fully compatible with requirements in the ornamental horticultural sector. By structuring and detailing the relevant decision problems, we contribute to an understanding of planning problems and decision-making in horticultural supply chains, and we provide a first comprehensive overview of planning problems, aligned literature, and research gaps for the horticultural business.

Keywords: supply chain; horticulture; logistics; operations; planning framework; decision support

Citation: Drechsler, M.; Holzapfel, A. Decision Support in Horticultural Supply Chains: A Planning Problem Framework for Small and Medium-Sized Enterprises. *Agriculture* **2022**, *12*, 1922. https://doi.org/10.3390/agriculture12111922

Academic Editor: Dimitre Dimitrov

Received: 27 October 2022
Accepted: 11 November 2022
Published: 15 November 2022

1. Introduction

One of the major parts of the horticultural sector is the market for ornamental plants, i.e., flowers, ornamental plants, and perennials. Ornamental horticulture for example makes EUR 9.4 billion in sales per year, accounting for 19.8% of the overall horticultural market in Germany, which is one of the largest producing markets in Europe [1,2]. Small- and medium-sized companies have a particularly large role in this market with about 5000 producers and 16,500 specialized trade and retail companies in Germany [3]. The companies can be divided into producers, wholesalers, and retailers, with most of the companies undertaking multiple functions [4]. Producers mostly specialize in propagating and cultivating plants into (semi-)finished products. This usually requires long lead times and good storage conditions. Retailers are all enterprises selling horticultural products to final customers, which are florists, specialty retailers, market stands, garden centers, DIY markets, and supermarkets. They typically offer a big assortment, no or short lead times, and can only operate marginal stockpiling to guarantee freshness. Wholesalers are all traders in between the other two roles, such as ex- or importers, auctions, and cash and carry markets, which can cover urgent demand by offering short lead times and often also handle planning and execution of transportation. Given their heterogeneous functions, all these market players face specific supply chain planning problems.

Systematized supply chain and operations planning is important for horticultural companies as the sector exhibits several specific challenges such as product perishability, as well as demand and supply volatility and uncertainties [5]. Product surpluses lead to spoilage and waste and have to be avoided. It is equally important to prevent product deficits and thus stockouts. This is complicated by external and sometimes unpredictable factors such as product decay, pests, traffic, and weather conditions [2,6]. The weather influences the production of plants, as well as the demand of final customers, and it is difficult to predict seasonal trends prior to the first sales data of a season. Lead times of sometimes several months and more also have to be factored in, and reliable information is rare.

However, there has been only limited research on supply chain and operations planning problems in the horticultural context. Existing contributions on supply chain management barely touch the prevalent planning problems or analyze selected planning problems in very specific contexts (see Section 2). In consequence, there is no general and holistic overview of planning problems in the horticultural business [7]. Such an overview could however help to systematize and understand the interaction of the multiple decisions. Additionally, guidance towards the research gaps for practically relevant decision support in ornamental horticulture is missing so far. Such research could further support industry practice to take decisions in a more structured, informed manner based on reliable data. Our study has thus the following objectives: Identifying and systematizing relevant supply planning problems of small and medium-sized companies in ornamental horticulture supply chains considering the different agents introduced above and investigating pertinent literature on the different supply chain planning areas to depict the status quo and to derive the research gaps.

We thereby contribute to horticultural supply chain literature by developing a structured supply chain planning matrix providing an overview of planning problems and representing the interrelations of decisions and their time horizon. By detailing the relevant decision problems, we contribute to an understanding of planning problems and decision-making in horticultural supply chains. Thus, we guide horticultural decision-makers in a structured way through the large bandwidth of planning problems. By reviewing existing scientific contributions in the various planning domains, we further pinpoint under-investigated decision problems in literature, and thus guide researchers in filling the existing gaps. Thereby, we also support the development of data-driven decision support systems that are tailored to the requirements of the horticultural sector. This could enhance existing Enterprise Resource Planning (ERP) systems used in horticulture, as we find that these systems currently miss interfaces for using the available data for decision support in an automated manner.

All results presented are based on exploratory expert interviews with managers involved in supply chain and operations decision-making in the business and on structured literature reviews to identify the research gaps.

The paper is organized as follows. We motivate our research objectives in detail and formulate our research questions based on initial literature research on supply chain planning in horticulture in Section 2. Afterward, we explain our methodological approach for identifying and structuring the relevant planning problems in detail in Section 3. We further introduce a general supply chain planning framework that will be adapted to the situation in ornamental horticulture in the following section. Section 4 identifies and systematizes the practical decisions and reflects on the respective gaps for decision support in the pertinent literature. We summarize and reflect our findings in a discussion in Section 5, and finally conclude our paper with an outlook and further research directions in Section 6.

2. Literature Overview and Research Questions

Overall, literature on supply chain planning problems in ornamental horticulture is relatively scarce. Existing contributions on supply chain management in horticulture often focus on describing characteristics, developments, and needs of very specific market segments, but barely touch the prevalent planning problems [6,8].

Nevertheless, there are some dedicated publications that analyze specific planning problems and provide solution approaches for specific ornamental horticultural planning areas. Examples are the contributions of van der Vorst et al. [9] who present innovative logistics concepts in the floricultural sector, Ossevoort et al. [10] who develop an approach for improving strategic distribution planning in Dutch horticulture, or Tromp et al. [11] who present a model for predicting remaining vase life of cut roses. Therefore, it is worthwhile structuring the existing body of contributions by planning area and time horizon to provide a systematic overview of existing suggestions in the literature, but also highlighting the areas that are still under-researched. Besides this, a major proportion of the still small body of publications that explicitly deal with sector-specific supply chain planning problems focuses on the Dutch horticultural market which is driven by auctions and large companies. These findings however can not always be transferred to non-auction-driven markets dominated by small and medium-sized companies, like Germany. Thus, it is also relevant to analyze which approaches are generic enough to provide guidance for different agents in the heterogeneous horticultural market and which contributions require supplementation of further research.

Based on the results of our literature research, so far only Mir and Padma [7] presents an overview of different decision support systems in a horticultural context. They review multiple plant-specific contributions for general purposes in horticulture and applications for integrated plant protection, nutrient management, and land use. Therewith, Mir and Padma [7] provide a first overview of relevant decision support systems for horticulture, but their findings are limited to the aforementioned topics which exclude the areas of distribution and sales planning as well as some procurement planning problems. These are, however, relevant to investigate when aiming to provide a complete overview of supply chain planning problems and contributions. Thus—to the best of our knowledge—there is no general and holistic overview of planning problems and aligned literature for the horticultural business so far. Such an overview could however help to systematize and understand the interaction of the multiple decisions beyond direct plant treatment. This could further support industry practice in taking decisions in a more structured and informed manner based on reliable data.

Our study thus aims at identifying and systematizing the practically relevant planning problems and corresponding decisions along the supply chain of small and medium-sized companies in ornamental horticulture. We further target to identify and systematize existing contributions within the different planning domains and highlight the gaps for future research. We posit the following three research questions to be answered:

1. Which specific decision problems arise in the value chains of ornamental plants, perennials, and cut flowers and how are they correlated?
2. What differences in planning problems can be identified between different positions in the respective supply chain?
3. To what extent have these planning problems already been studied, and what research gaps exist?

3. Methodology

As there is currently no structured overview of supply chain and operations decisions in horticulture, we applied a three-step research approach to identify, systematize and analyze the corresponding planning problems and research gaps. First, we conducted exploratory expert interviews (Section 3.1). Second, we systematized the planning problems identified with the help of a supply chain planning matrix (Section 3.2). Finally, we analyzed pertinent literature in the respective contexts to identify the status and gaps of horticultural supply chain and operations research (Section 3.3).

3.1. Exploratory Expert Interviews

As a first step, we chose an exploratory study design for answering research questions one and two aimed at identifying and portraying the practically relevant planning problems along the supply chain. An exploratory qualitative research study is appropriate for uncovering such unstudied research areas as data from practice enrich the theoretical findings [12]. Exploratory interviews are thereby recommended for use in logistics and supply chain management research [13]. Developing theoretical insights out of empirical data, we followed an approach inspired by grounded theory [14,15].

3.1.1. Data Collection

Our empirical data collection followed the ground theory concept leading to generalizable results [15] and providing a practical perspective on the relevant planning problems in ornamental horticulture. We conducted semi-structured exploratory expert interviews with people in charge of horticultural companies that proved to have a holistic view of all planning activities and processes in their enterprises as recommended in pertinent literature [13,16]. These were (co-)owners or executive managers. We chose an unbiased selected sample of representative average small and medium-sized companies in the German horticultural market of ornamentals, perennials, and cut flowers, following the classification of the European Commission [17]. We focus on the German market to create a unified context and because Germany is one of the largest producing horticultural markets in Europe [1,2]. Furthermore, we limited the study to ten enterprises to keep the investigation to a reasonable scale. The companies are specified in Table 1.

Table 1. Specification of case companies

Company	Size	Assortment	Description
Com 1	Medium	Bed and balcony plants, cut flowers	Cash & carry market wholesaler with their own large production and fleet
Com 2	Small	Pot plants, perennials, cut flowers	Producer with their own retail store, wholesale activities and a limited own fleet
Com 3	Medium	Cut flowers	Online retailer for bouquets, also acting as mediator and wholesaler for cooperating retailers
Com 4	Small	Mediterranean perennials	Specialized importing wholesaler with their own fleet
Com 5	Small	Pot plants, perennials, house plants	Retailer relying on close cooperation with a producer at the same location
Com 6	Small	Herbs, pot plants, bulb plants	Specialized producer expanding their operations by establishing a further modern production facility
Com 7	Medium	Grasses, perennials	Specialized producer with their own fleet serving large customers
Com 8	Small	Cut flowers, pot plants	Specialized producer with their own retail store, also serving other retailers or wholesalers
Com 9	Small	Perennials, blooming plants, herbs	Specialized producer mostly serving retailers with an own fleet and wholesale activities
Com 10	Small	Bed and balcony plants, perennials, house plants	Retailer with a small production operation of their own and mainly wholesaler sourcing

The participating companies cover all major roles in the horticultural supply chain, with some companies taking on multiple functions. Out of the ten companies, we classify seven as producers, six as wholesalers, and five as retailers. We developed an interview guideline and marginally adapted it after conducting the first interview, which also served as a pre-test [14]. The questions targeted the different planning problems in horticulture, their correlations, and circumstances in the sector. A brief overview of the questions' topics was sent to all interview partners prior to the interviews. We used this to make sure that we got insights into current horticultural proceedings and different supply chain roles [12]. All interviews were conducted via video chat by the same two interviewers, who took field notes during the talks and compared and merged them afterward to achieve reliability [18]. The interviews lasted 85 min on average. After conducting the ten interviews there were no important new findings and we stopped the data collection, as we could assume that we had reached theoretical saturation.

3.1.2. Data Analysis

Following the approach of Mayring [19], we coded the interviews freely before merging the codes and structuring them into up to four levels of subcodes. We performed the analysis and evaluation of the interviews with the help of the MAXQDA software and all results of this paper have been validated and confirmed by the interviewees. Thereby we followed the guidelines of Gioia et al. [20] to ensure the trustworthiness of our data analysis. More than 550 codes were recorded and structured for investigating the supply chain and operational decision problems.

3.2. Supply Chain Planning Framework

To structure the planning problems identified, we used the systematization proposed by Fleischmann et al. [21]. They developed a general supply chain planning problem matrix by distinguishing the planning problems according to their time horizon (long-, medium- and short-term) and their position in the supply chain process (procurement, production, distribution, sales) (see Figure 1).

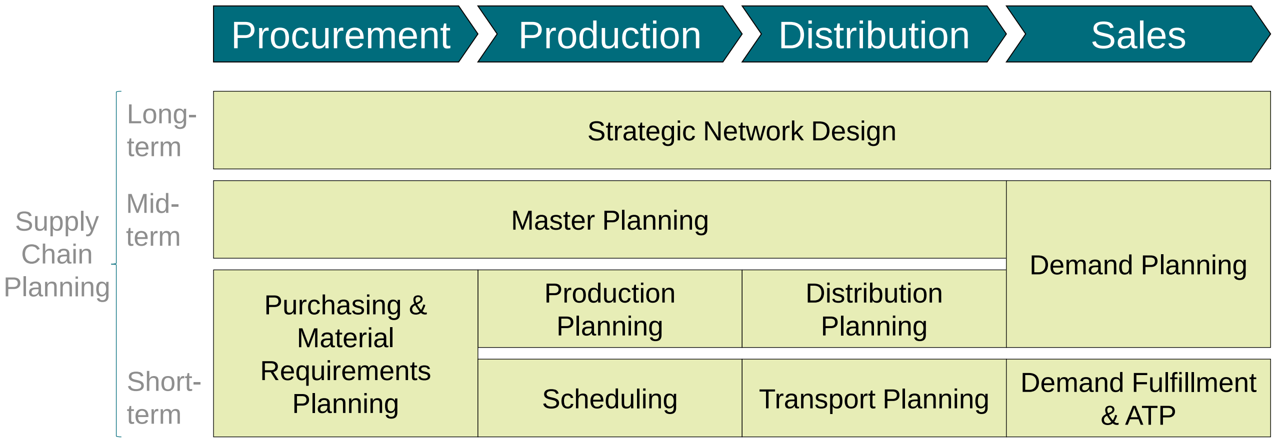

Figure 1. Supply chain planning matrix, own representation based on Fleischmann et al. [21].

Strategic network design covers all long-term planning sections determining the basic supply chain design and the elementary material and product flow between suppliers, producers, wholesalers, retailers, and customers. Master planning coordinates procurement, production, and distribution, which often have to be planned simultaneously, on a tactical level. Demand planning covers mid- to short-term demand estimates. The planning of ordering components and finished products takes place on a mid- and short-term level in the procurement section. Production planning especially covers lot-sizing problems, providing the basis for short-term production scheduling. Product flows are coordinated in distribution planning and subsequent transportation planning, i.e., short-term vehicle routing. The tasks of demand fulfillment and available to promise (ATP) planning cover short-term sales planning [21].

Note that these general supply chain processes and planning tasks usually differ concerning their relevance and context depending on which supply chain functions a company covers. For instance, while horticultural producers naturally face a high variety of production planning tasks, distribution planning is not their main focus. On the other hand, pure wholesalers and retailers have no classic production. Nevertheless, there are similar tasks for these types of companies from a planning perspective in terms of warehousing, which typically substitutes the production step at trading companies [22].

We adapted the general framework proposed by Fleischmann et al. [21] to the planning situation of small and medium-sized horticultural companies by varying the individual contents, highlighting the context specifics and interdependencies that can be found in the horticultural sector. In doing this, we followed a similar procedure to that already taken in literature for other types of business, e.g., for grocery retailing and shipyards [22,23].

3.3. Structured Literature Research

Based on the systematization of planning problems achieved, we performed a structured literature search to investigate the third research question following the approach of Seuring et al. [24]. For each planning problem relevant to horticulture and identified within our study, we conducted a separate literature search focusing on planning problem descriptions and solution approaches to evaluate how intensive research has already been conducted for the practically relevant planning tasks. To do this we first combined keywords regarding the horticultural planning tasks with those of classic decision support system nomenclature in the respective area. In case there were no or only very few publications referring to the context of ornamental horticulture, we extended the perspective to a broader horticultural context, to other industry sectors with similar characteristics or circumstances, or, as a final measure, to generic supply chain and operations planning literature. After this identification step, we completed a qualitative content analysis for portraying the respective contributions [19] and analyzed the gaps comparing the existing literature with the planning problems and necessities identified in the exploratory interviews.

4. Typology of Planning Problems in Horticulture

This section discusses the practical planning along the supply chain of small and medium-sized companies in ornamental horticulture, divided by their respective time horizon. The systematization of planning areas follows the nomenclature of Fleischmann et al. [21] with slight adaptations where necessary due to horticulture specifics. For each planning area, we first detail the most relevant practical planning problems in horticulture, refer to potential supply chain role specifics, and discuss planning interrelations. We then reflect on the current status of pertinent literature regarding the respective planning problems and delineate research gaps and needs for decision support from a practical perspective.

4.1. Strategic Planning

In the long-term strategic planning domain, we can make distinctions according to the supply chain areas between procurement, production, (physical) distribution, and sales planning. We discuss the corresponding strategic planning problems in the following paragraphs.

4.1.1. Strategic Procurement Planning

Planning Problems Identified

Supplier selection and continuous supplier relationship management are key strategic factors for all supply chain roles in the horticultural sector. As the sector is characterized by various uncertainties (e.g., regarding supply and production due to weather extremes or pests) and high perishability of the products, the companies in the sector typically build on long-term cooperations with suppliers to ensure reliable supply and product quality. This means that collaborations over a time span of several decades are common. This highlights the importance of strategic procurement planning decisions. Although long-term relationships and close collaboration are key in ornamental horticulture, this does not mean that the horticultural companies focus exclusively on one supplier per product. Instead, the sector's uncertainties also compel the need to consider suitable alternative suppliers that may also react short term. Screening and contracting suppliers (often wholesalers) that have short-term compensating potential is also very relevant because the horticultural market is characterized by considerable short-term fluctuations in demand due to trends and weather conditions. Overall, supplier selection defines general conditions for product ordering potential, as well as the depth and breadth of the assortment, and lays the framework for make-or-buy decisions.

Pertinent Literature and Gaps

Contributions in literature also highlight cooperation as an important factor for gaining a competitive advantage in horticulture [25,26]. Joint planning as well as risk and reward sharing are postulated as the main drivers for close relationships and information sharing between enterprises [27]. Geerling-Eff et al. [26] additionally outline the importance and potential issues of selecting partners to cooperate with. Matopoulos et al. [27] underline that supplier selection and cooperation are multi-criteria decision problems in horticulture with many factors that are hard to quantify such as reliability, quality, and experience. One of the few quantitative approaches available in the domain of strategic procurement planning in horticulture is the work of de Keizer et al. [28], who model and optimize strategic network decisions for bouquet-making, sourcing cut flowers from auctions. Their approach also takes quality decay into consideration. Outside the domain of ornamental horticulture, there are further models that could be also applicable in the sector. The quality decay of perishable products is for example considered in a source selection model for strawberries [29], and Yazdani et al. [30] present a model for food supplier selection under uncertainty. A holistic supplier selection model reflecting the various specifics of ornamental horticulture has not however been developed so far. This observation is also supported by contributions in horticultural literature that emphasize that especially the consideration of the impact of quality decay and lead times on supply chains of perishables is a research gap in supply chain design and procurement planning [28,29].

4.1.2. Strategic Production Planning

Planning Problems Identified

The strategic production design in horticulture consists of planning acreage and greenhouses as well as the corresponding production systems. These planning tasks are key for producers. Trading companies could also have similar planning issues when deciding about the design of their warehouses [22]. For small and medium-sized horticultural trading companies (wholesalers, retailers), warehouse design, however, plays a minor role due to the fact that the rotation of plants is usually relatively quick. Besides this, wholesalers and retailers often combine their business with the production of their own and thus use the production facilities as warehouses. We, therefore, focus on the planning tasks of producers in the following. The environmental conditions of the production location and the cultivatable land limit potential production and high-impact decisions, on which, plants can be produced. The production system then defines the setup and layout of a production site, which can consist of open crop land, greenhouses, foil tunnels, and roofed indoor areas. Typically, many small and medium-sized horticultural companies grow organically over decades. This often results in fragmented expansion and unfavorable structuring of production sites. A typical strategic production design problem of existing businesses is thus limited by the acreage of multiple in- or outdoor production sites with different levels of automation, conditions, and sizes. The companies in the sector would thus highly benefit from decision support for the suitable reorganization of given production facilities.

Pertinent Literature and Gaps

In literature there are only a few strategic production design models with a dedicated horticultural context. Rath [31] present a model for planning the energy supply of greenhouses for growers, and Vanthoor, et al. [32] develop a model for greenhouse design optimization. Annual financial results are maximized by making optimal choices from alternatives for structure types, covering material, shade screening, whitewash, thermal screens, heating and cooling systems, and CO_2 enrichment. Further research on this topic can be found in the efficient land use planning section presented by Mir and Padma [7]. As shown in our exploratory study, strategic production design requires the consideration of a vast number of additional factors in practice. Implementing a comprehensive optimization model does not appear easy as a result, but there is certainly potential for research on developing decision support systems evaluating alternative production designs that may potentially recur depending on the given infrastructural conditions. This is also supported by Vanthoor et al. [32] who see their optimization model as a first component of a more complex planning system that is still to be developed. Thus, there is considerable improvement potential for the internal organization in horticultural companies, as de Waal and Meingast [33] point out.

4.1.3. Physical Distribution Planning

Planning Problems Identified

As we focus on small and medium-sized enterprises, most of the producers and retailers have no extensive distribution network and often do not even conduct explicit distribution planning. Exceptions are the companies that assume a wholesale function. These often have a wider distribution network and usually assume the responsibility for transportation planning, relying on a fleet of their own. In doing this, they strengthen their market position, especially for cooperation with small producers that are pleased to have the possibility to outsource distribution issues. Nevertheless, in practice, most companies own at least a small truck to handle internal and urgent transportation. However, distribution is often more efficiently operated by larger or specialized partners due to economies of scale. These partners have to make decisions on fleet dimensioning and the definition of transportation links that determine the constraints for tactical distribution planning in terms of transport, packing, storing, and processing capacities. The distribution structure also needs to be set up for fast transportation of fragile and perishable products. Note that direct-to-customer deliveries or customer pick-ups, therefore, dominate in the ornamental horticulture market.

Pertinent Literature and Gaps

There are several contributions in the relevant literature focusing on strategic distribution design in horticulture, especially considering virtual trading networks. In this domain, a trading network for the Dutch horticultural market has been developed that highlights the advantages of direct producer-to-retailer flows focusing not just on cost reduction, but also on the end user´s satisfaction [10]. The concept enables better connections between consumers and producers and does not require a physical presence of the products anymore at intermediate steps. The contributions of van der Vorst et al. [34] and van der Vorst et al. [9] support these benefits of virtual networks that also allow the introduction of virtual auctions for perishable products [35]. Besides this, de Keizer et al. [36] present a mathematical model for logistics network design for perishables, specifically cut flowers, considering quality decay as well as its heterogeneity. Contrary to other planning areas there are thus several suitable contributions to decision support relating to ornamental horticulture's strategic distribution planning providing guidance for the traders involved in transportation. However, models reflecting the distribution conditions and possible particularities outside the Netherlands are missing so far.

4.1.4. Strategic Sales Planning

Planning Problems Identified

In the sales domain, sales channels and customer relationship management as well as the product program have to be defined on a strategic level. Strategic sales planning highly impacts the upstream logistics planning areas, and the general conditions regarding lead times, ordering, and production are predefined. Lead times for example can differ from several months for large grocery retailers to immediate supply for final customers. The product program and the respective plants determine specific requirements regarding temperature, humidity, treatment, and more which affects the production planning and materials program. It is typically small and medium-sized producers that continuously specialize to remain competitive in the market in terms of the product program, but for retailers, a certain level of generalization is important to attract final customers. On a wholesaler level, both the generalization and specialization approaches can be promising, and respective examples can be found on the market. While specialization can make sense when importing specific plants from a dedicated region (e.g., Mediterranean plants), small and medium-sized retailers in particular value a broad assortment of wholesalers as this means they do not have to contract too many different suppliers. Wholesalers act per definition in the B2B market, and retailers in the B2C market. Producers may define their preferred sales channel(s) as they have both options. Rising e-commerce in the horticultural domain is thereby an option to widen the customer base without a physical presence. Close cooperations with customers also play an important role in horticulture, especially for producers and wholesalers. Joint sales planning and the organization of advertising and sales campaigns result in valuable information and planning security on a mid-term basis in a generally uncertain market.

Pertinent Literature and Gaps

Explicit strategic sales planning literature with a focus on horticultural products are rare. In terms of strategic marketing planning, White and Uva [37] analyzes multiple cases and discusses different strategies to provide guidance for developing marketing plans in horticulture. Apart from this, the horticultural market is typically not referred to in strategic sales planning literature, and Engelke [38] outlines a research gap in marketing performance and strategic service differentiation in horticultural retail. Nevertheless, there are some contributions in the literature that exhibit elements that could be transferred to a horticultural setting because of their consideration of characteristics like product perishability and the varying product development stages by different customers. Retailers for example demand plants that are at the beginning of their blooming time to be able to provide attractive plants for sale while still ensuring a long blooming time for final customers. Wholesalers in comparison require plants at an earlier developmental level. In literature, there are for example multiple general approaches for optimizing the product portfolio balancing external variety and internal complexity due to product differentiation [39], or considering product quality functions focusing on customer requirements [40]. Besides this Hübner and Kuhn [41] investigate assortment planning models for perishables and non-perishables with limited shelf space, which could be helpful for horticultural retailers. However, most of the models referred to assume modular products and there is no adaptation of assortment planning models explicitly for horticultural products and their specific requirements.

4.2. Tactical Planning

On a mid-term basis, horticultural companies face the planning problems of material or product requirements, production, distribution, and demand. We portray these planning problems in the following.

4.2.1. Material/Product Requirement Planning

Planning Problems Identified

The inherent decision of making or buying makes material and product requirement planning a tactical planning problem for horticultural producers. This task can be seen as more of an operational issue for wholesalers and retailers. However, the typically long lead times in the sector that have to be considered for ensuring the basic availability of products also require mid-term product requirement planning for trading companies.

Producers first have to decide whether to grow plants from seeds or seedlings or to use the cultivation of young plants. These young plants are in turn available at different stages. Some plants such as rose stocks have to be cultivated for years before becoming marketable, which explains the possible long-term aspect of the product requirement decision for producers. Besides the production time, the lead times of seeds and seedlings also have to be considered (which may amount to up to one year). If producers have a B2C channel of their own, they may further decide on whether to grow all the plants or to source additional finished products to supplement their assortment. Generally, self-production may offer higher margins for the producers as well as independence regarding the supply market. However, certain products may be cheaper to source externally from other producers that specialize in these products. Additionally, production of their own may also suffer from uncertainties regarding output. Besides the price, quality aspects are very important in the make-or-buy decision. Self-produced plants offer the possibility of strict quality control in all growing stages. If assortment and order quantity flexibility is prioritized, short-term sourcing via wholesalers is the third basic option for producers to set up their sourcing. Stockouts of seasonal products are just as common as short-term discount offers of overflow products in the sector.

Besides the decision of making or buying products, order decisions also have to be made on a mid-term basis. The earlier horticultural products are ordered or reserved, the higher the available quantities and qualities are. However, production restrictions such as seasonal growing cycles and weather conditions combined with volatile demand and trends can nonetheless result in availability problems in horticulture. The majority of procurement processes in the horticultural sector can therefore be divided into pre- and re-orders or daily spot market sales [42]. A company's main products are mostly sourced in large part via pre-ordered quantities from producing companies. These quantities should cover the basic demand that is forecasted and thus ensure planning security, availability, and quality of the core products. Short-term re-orders can only cover smaller quantities, but provide flexibility to react to fluctuations in demand or unforeseeable supply or production shortages. Wholesalers are typically the main source for re-orders, but producers may also have free quotas for short-term sales. Many companies emphasize that they target coverage of the majority of their demand by pre-orders of large quantities, but that they also want to cover a certain share by re-orders from the same producers or other wholesalers such as cash and carry markets to ensure responsiveness during the high season.

Pertinent Literature and Gaps

While there is literature available on make-or-buy decisions beyond the horticultural context (see e.g., McIvor and Humphreys [43] or van de Water and van Peet [44]), there is so far no specific application in the horticultural domain. Besides this, the prevalent purchasing structure with pre- and re-orders has not so far been covered in horticultural research. This marks a significant opportunity for developing a corresponding decision support system relevant in practice due to the importance of this planning problem emphasized by all participating companies in our exploratory study. Overall, sector-specific expertise is needed for material and product requirement planning to evaluate different materials and sourcing alternatives. This also requires an understanding of the drivers of and barriers to using enterprise resource planning in horticulture. Verdouw et al. [45] examine these to handle the perishability aspects and uncertainties potentially better in horticulture. They outline the importance of improvisation and ad-hoc communication and emphasize the lack of well-structured administrative organization in the sector, which is especially the case for small and medium-sized companies. This further highlights the need for systematic decision support.

Although there is this gap in the literature, specific aspects of tactical material and product requirement planning are covered in horticultural literature. In a recent contribution, Faraudo Pijuan [46] presents an economic order quantity model that considers growing models and dynamic holding costs. The quality aspect also plays a major role in procurement decisions in the supply chain of perishable goods and therefore quality decay in this decision is an important area of research to possibly expand shelf/vase life for the consumers [47,48]. This aspect has not so far been covered in tactical procurement decisions for ornamental horticultural products, but Rijpkema et al. [29] consider costs for quality loss in a source selection decision based on a case study of Egyptian strawberries. Moreover, quality considerations are largely applied in time-temperature distribution approaches for horticultural products (see e.g., Rosset et al. [49], Rijgersberg et al. [50], or Tromp et al. [11]). These approaches could be a starting point when searching for options to include quality aspects in a decision support system for horticultural purchasing.

4.2.2. Production Planning

Planning Problems Identified

Having a production site of one´s own is common in the sector of small and medium-sized horticultural companies. It is therefore not surprising that production planning is—together with the aforementioned product requirement planning—highlighted as a central planning task in our study that impacts all the other planning areas. This involves developing a cultivation plan that makes the most efficient use of available acreage and other capacities. Due to the close cooperation that is typical in the sector, these plans are often developed in close contact with key customers. The producers have to decide which plants to grow in which position at their production sites, coordinating the growing times of multiple products weeks or months ahead. Thus, planning tasks that are usually assumed to be more operational, as for example lot-sizing decisions [21], have to be considered on the tactical level, and an accumulated production plan is not enough. This means the occupancy planning of the acreage has to be performed in a detailed manner. There has to always be enough free acreage when a new product has to be planted for finishing production on time and for fulfilling demand. This can result in tight occupation plans that require a high rotation speed of the plants. High rotation is also needed due to the perishability of the plants and because the plants might otherwise wither or become too big to be marketable. As a result, inventory holding barely plays a role when determining mid-term production volumes. Ultimately, the specific characteristics of the cultivation and occupancy plan greatly depend on the individual plants a producer cultivates.

Pertinent Literature and Gaps

While horticultural production planning has received some attention in operations research and decision support systems literature some decades ago, there is a lack of current follow-up studies that close the research gaps that still exist. In 1989 Annevelink [51] presented a production planning model to optimize the batch size and production start of different glasshouse floricultural crops to maximize profit constrained by production and labor capacity as well as maximum sales. Based on that production plan, he worked out a spacing plan in a follow-up study determining the crops' position using a heuristic approach. He thereby considered the lot sizes and space requirements, which change over the production process [52]. In 2000 Darby-Dowman et al. [53] then presented a stochastic programming model resulting in a planting and harvesting plan in a horticultural context. However, there are several aspects that have still not yet been investigated. One example is that demand is often seen as a maximum of possible sales in the literature available, but fulfillment or service level constraints do not play a role. Generally, the assumption of deterministic demand and processing times is a major limitation in production planning models that merits further research efforts [54]. Besides this, the production and ordering structure that we have identified as typical in the ornamental horticultural context with mid-term production and short-term ordering as a compensating option has also not so far been reflected in the pertinent literature. It might thus be worth investigating models dedicated to general perishable products such as the one of Pauls-Worm et al. [55] and trying to adapt and transfer them into an ornamental horticultural context. Apart from this, there are further opportunities to incorporate dynamic space requirements, seasonality aspects, and sector-specific production requirements into general production planning and lot-sizing concepts (using the models presented in Jans and Degraeve [54] or Guzman et al. [56] as a basis, for example).

4.2.3. Distribution Planning

Planning Problems Identified

Demand fulfillment and customer satisfaction are important goals for companies in the horticultural sector, but providing freshness and preventing spoilage does not allow for large safety stocks, long transport distances, or low delivery frequencies [9]. Distribution planning is therefore highly restricted in horticultural companies. As small and medium-sized companies in the ornamental horticultural sector usually only have one central company facility, distribution planning on a tactical level mostly means defining regular base tours and delivery frequencies and weekdays for key customers. It is also important to consider the previously mentioned constraints and the usually very limited transport capacity. The resulting base tours can, however, only be used as a rough framework for operational transport planning due to the several uncertainties in the market, and significant rearrangements are commonly required at short notice. The question of how much inventory should be held is also aligned with distribution planning. An explicit safety stock level planning is mostly only held by trading companies, especially wholesalers. They apply a safety stock calculation, especially for the supply of large retailers that have high priority. Producers are usually bound to contractually fixed amounts of product surplus when serving large customers.

Pertinent Literature and Gaps

Besides the rich literature on general distribution planning, there are also a few contributions in literature focusing on a horticulture-specific context which thus show ways to master this challenging planning task. De Keizer et al. [57] develop a hub network and Ossevoort et al. [58] a metro model for the horticultural sector. They thereby aim to reduce shipment costs and distances by using consolidation effects. De Keizer et al. [5] also present a floricultural distribution network for the Netherlands. All these contributions, however, focus on the Dutch market, which is highly dominated by the auction trade and its specifics. More research in this domain is thus required in non-auction-driven markets. In a broader context, models for the distribution of perishable products show several similarities with the planning conditions in ornamental horticulture. Jiang et al. [59] for example integrate distribution planning with harvesting decisions for perishable agricultural products, and Gaggero and Tonelli [60] present a two-step optimization model for determining relevant figures for the distribution network such as safety stocks, replenishment cycles, and volumes. Focusing on grocery products, Holzapfel et al. [61] present an approach for determining delivery patterns for customer deliveries considering interdependencies along the supply chain, and Frank et al. [62] extend this approach by considering different temperature requirements of products delivered together. These contributions could, however, be extended by a stream of literature focusing on further horticultural distribution specifics. De Keizer et al. [5] and Jiang et al. [59], for example, see research opportunities in integrating horticulture-specific aspects, such as quality control, packaging or bouquet-making, as well as uncertainties.

4.2.4. Demand Planning

Planning Problems Identified

As demand is very volatile and most horticultural products are perishable, one of the main challenges in mid-term planning is to forecast the demand as precisely as possible. The companies investigated to see the weather, holiday effects, and seasonal trends as the most crucial obstacles for generating reliable forecasts. The forecast for key products like cut flowers is difficult, particularly for horticulturally relevant holidays like Valentine's Day. Most small and medium-sized companies estimate forecasts on a product or product group level based on the previous year's demand, known pre-orders, market information, experience, and gut feeling. Quantitative models are, however, not applied. Corresponding with colleagues and partners, for example at fairs or wholesale markets, is therefore key for small and medium-sized companies to collect the necessary market information. Besides the forecast itself, finding an economic balance between demand fulfillment and product overflow that leads to plant wastage is challenging for companies in the horticultural sector. It is particularly the case that short-term demand in the horticultural market has to be fulfilled via plants produced make-to-stock that need to be planned on a mid-term basis, so demand planning has a huge impact on all other tactical planning tasks.

Pertinent Literature and Gaps

In the pertinent literature, multiple external, horticulture-specific factors in demand forecasting that we have identified within our exploratory study are still not sufficiently factored in. The combination of the effects of weather conditions, last-minute assortment changes, product quality development, and promotions makes horticultural demand forecasting a challenging field of research. However, Haselbeck et al. [63] have recently developed a Gaussian process regression for seasonal data that enables event-triggered augmented refitting. The model was successfully tested on real-world horticulture cashier data and proved the ability to handle plants' seasonal demand and several external impacts. Apart from horticulture there are demand management models like that of Dellino et al. [64] that could also help in a horticultural context. They present a modular decision support system for forecasting and order planning for food supply chains. Horticultural supply chains, however, are even more nontransparent compared to the setting assumed and more driven by short-term adaptations. To consider such sudden changes, augmentations are used in literature with time-related functions, such as a forgetting factor or a moving window [65]. Overall, there is still extensive leeway for providing data-driven decision support in demand forecasting in the horticultural market given the current manual practices that we have found in the business and the status of the literature within this domain.

4.3. Operational Planning

Building on the framework set by tactical planning, there have to be solutions for short-term purchasing, production scheduling, transport planning, and demand fulfillment.

4.3.1. Purchasing

Planning Problems Identified

Purchasing is closely connected to tactical material requirement planning and impacts the whole scope of operational transport planning and demand fulfillment. While wholesalers and retailers reserve basic product contingents on a tactical level, these contingents have to be retrieved short-term, but re-orders also have to be placed. Additionally, some product categories are typically sourced entirely on a short-term horizon, such as cut flowers. In this case, wholesalers are the typical short-term source for retailers. This is also true for re-orders that are necessary due to forecasting errors, unforeseeable fluctuations in demand, or because of the flexibility reserve, the companies have calculated on a mid-term basis. Product availability and/or quality can be a problem for these short-term orders as both typically fluctuate in a market of natural products. To complicate things, the majority of products in ornamental horticulture are seasonal and specific plants can be purchased only within a limited time frame of several weeks. Besides wholesalers, producers can also be a short-term source for specific product categories as some companies produce free-for-sale quotas at their own risk. These quotas and sales fluctuations may lead to a product surplus on the part of the producer or wholesaler and result in attractive offers reaching the retailers at short notice. It is usually difficult to anticipate these in mid-term planning, but they may change the short-term assortment and sales planning significantly.

Pertinent Literature and Gaps

To the best of our knowledge, a dedicated optimization model for short-term ordering in horticulture does not yet exist. The planning situation, however, is similar to that assumed in a newsvendor setting, and various newsvendor approaches might therefore be adaptable for purchasing in ornamental horticulture, such as that presented by Matsuyama [66]. We refer to Khouja [67] and Qin et al. [68] for comprehensive literature reviews of newsvendor models. Apart from a newsvendor setting, other models that are dedicated to the ordering and inventory management of perishables might also suit the horticultural context. We, therefore, refer to Goyal and Giri [69] who present a literature review on perishable inventory systems and Broekmeulen and van Donselaar [70] who outline the advantages of considering age distribution for the replenishment of perishables.

4.3.2. Production Scheduling

Planning Problems Identified

Short-term production planning comprises scheduling the activities of planting, plant care, and shop floor control. The tactical cultivation and occupancy plan has to be executed and new production has to be started. Production scheduling also means handling delays or reacting to unexpected circumstances, which are common in horticulture due to the dependence on weather and other uncertainties. Plant care comprises all activities to optimize the plant's growing conditions. These can be watering, adding fertilizer or substrate, plant treatments like cuttings or removing older leaves, re-potting, pest control, and much more. These are tasks that are not exclusive to producers, but basic plant care at the very least is also required at the wholesale and retail stage. The extent of and workload attributed to these tasks, however, differs between the different supply chain roles. Producers usually have a comparatively small assortment, which makes it possible to standardize plant care and limits the heterogeneity of tasks. However, these tasks are then executed intensively. Wholesalers and retailers mostly do not have the capacity for intensive plant care. Re-potting for example is too much effort for most retailers, who usually prefer to take discounts instead of providing additional treatment to the plants. The larger assortments of wholesalers and retailers which would cause an enormous heterogeneity of different treatments enhance the effects of avoiding treatment whenever possible. This of course excludes necessary basic treatments like watering to maintain a plant's quality and to prevent withering. An important task for all supply chain roles is also the continuous evaluation of the plants in production or stock. In practice, companies check their plants frequently to detect deviations from the expected production/storage time and quality early. This allows for possible adjustments in sales, procurement or production planning, or the scheduling of additional treatments. All activities mentioned are usually labor intensive and therefore also require suitable workforce management, and thus are highly interconnected with tactical and operational personnel planning.

Pertinent Literature and Gaps

Some decision support contributions regarding selected aspects of short-term production scheduling can be identified in the relevant literature. Chalabi et al. [71] present a model for optimizing greenhouse heating, minimizing energy consumption while satisfying temperature constraints for the requirements of tomato crops. Besides this, Magarey et al. [72] develop a decision support system for pest management, and Damos and Karabatakis [73] model the population dynamics of orchards and the dissemination of pests. However, there are still numerous necessary plant treatments that have not yet been investigated that exhibit cost and quality trade-offs in ornamental horticulture. Beyond the ornamental horticultural market, there are models for irrigation decisions in agriculture, such as for maize [74] or avocados [75], as well as for harvesting apples [76], oranges [77], sugar [78], and grapes [79]. Elia and Conversa [80] also presents a model for managing the fertigation of open-field vegetable crops as well as optimizing the water and nitrogen supply for plant development. Further research on these topics can be found in the integrated plant protection and nutrient management sections presented by Mir and Padma [7]. These studies are focused on individual crops and support the hypothesis that decision support for horticultural production scheduling offers numerous research and practical optimization opportunities. However, several aspects of ornamental horticulture are still unexplored, and a comprehensive approach that combines the heterogeneous requirements of the individual plants reflecting the characteristic uncertainties is lacking so far. Additionally, pertinent literature claims for more elaborate methods for crop estimation, which implies also further plant-specific research [76].

4.3.3. Transport Planning

Planning Problems Identified

While small and medium-sized retailers in the horticultural sector have typically outsourced their transportation requirements, short-term transport planning is a relevant task for producers with a fleet of their own and wholesalers. While the producers mostly have to serve a limited set of customers, transport planning can be complex, especially for wholesalers who provide transportation for a wide range of customers. Delivery tour planning at horticultural companies is characterized by high volatility, demand fluctuation, and supply insecurity. The operative transport planning has to be very flexible as a result. Fast turnover, short storage times, and cross-dock-like processing are required to achieve operational excellence because of the plants' quality loss and perishability.

Pertinent Literature and Gaps

Vehicle routing problems have been widely studied in the literature (see Vidal et al. [81] and Braekers et al. [82] for an overview) and thus there are numerous extensions and adaptations that may fit the circumstances of delivery tour planning for ornamental horticultural products. For example, Gong and Fu [83] present a model for perishable food products that considers delivery time windows, while Buelvas Padilla et al. [84] focus on the quality loss aspect, and Wu and Wu [85] present a green vehicle routing model within this domain. Some models have already been applied in a horticultural domain. Ginantaka [86] present a route selection model for horticultural transportation that takes into account road and traffic impacts, and Soysal et al. [87] consider the perishability of tomatoes in a similar problem scenario. Given the ambitious freshness requirements for deliveries, an interesting path of research in a horticultural domain might also be the integration of production scheduling and transport planning. We refer to Kuhn et al. [88] for a general overview of models that consider the corresponding interdependencies. In the horticultural domain, Widodo et al. [89] present a model to maximize customer satisfaction by jointly optimizing harvesting patterns and deliveries for fresh products. Further contributions with an explicit application in horticulture are lacking, however. This shows the potential for research on integrative production and transport planning considering the specifics of ornamental horticulture, such as a many-to-many supply chain structure [87].

4.3.4. Demand Fulfillment

Planning Problems Identified

The main objective in short-term demand fulfillment is to match current supply and demand to avoid stock-outs and product surplus. The significance of stock-outs, however, varies across horticultural products, companies, and market situations. Generally, the possibilities for substitution are comparatively high for many horticultural products. A stock-out of one specific product can often be compensated by similar products with different colors, or closely related plants with a similar look or usage. This helps in terms of demand fulfillment especially in the retail sector as it is very hard to guarantee availability on a product level due to the highly fluctuating demand, limited shelf/vase life, limited production and sales seasons, and possibly unavailable short-term supply options. The lack of extensive storage options and the perishability of the plants further lead to limited inventory holding and thus lower on-shelf availability. Freshness and a large welcoming assortment with multiple options for product substitution are typically prioritized instead by horticultural retailers. While stock-outs are a minor issue, active demand control is necessary to prevent product surplus and waste at the end of the sales season. Typical measures applied by retailers are marketing campaigns, promotions, discounts, and active store layout adaptations. High-stock items are therefore positioned prominently in the store, advertised in leaflets, or significantly discounted. The latter measure is especially applied at the end of the sales season. Granting discounts is also the dominant demand control element for wholesalers, who can use this to overcome product overflow and quality deficits. Producers typically use so-called availability lists to steer customer demand. These lists are regularly published and contain the current marketable products. This enables the producers to manage their seasonality in production and avoid information deficits and supply uncertainty among their customers. The producers aim to sell out most of their products during the regular sales season because of higher profit margins. The remaining product surplus is then typically sold at short notice to wholesalers or auction houses at reduced prices. This highlights the interconnections between short-term demand fulfillment and tactical sales, production, and procurement planning, while having to consider the notable consequences of planned procurement, production, and sales quantities on the profits than can be achieved.

Pertinent Literature and Gaps

The practical planning situation in demand fulfillment, which we have found in our exploratory study, highlights its stochastic components and the need for dynamic decision support systems. The contribution of Ludwig [90] reflects this, presenting a stochastic model with a Gaussian distributed demand for potted plants that can incorporate decision makers' risk attitudes. Apart from this, distinct models for demand fulfillment in a horticultural context are lacking. In the agricultural domain, Widodo et al. [89] integrate demand fulfillment into a model for harvesting decisions that highlight possible future research directions in horticultural research, combining short-term demand fulfillment with production scheduling issues. Further contributions focus on demand management via price setting. Matos et al. [91] present a computational decision support system for determining the optimal price for specific fruits during their shelf life that considers quantity and quality deterioration, which could be adapted to ornamental plants as well. Pina et al. [92] develop a similar decision support system for vegetables based on microbiological growth models used for estimating the products´ remaining shelf life. Supporting decisions in terms of what, where, and what quantity of plants to position in a retail outlet, the various assortment and shelf space allocation models reviewed by Hübner and Kuhn [41] can be a starting point for versions that are adapted to the ornamental horticulture setting.

5. Discussion

Our systematization based on the supply chain planning framework of Fleischmann et al. [21] offers guidance regarding the most relevant planning tasks and systematizes the planning problems according to the supply chain area (procurement, production, distribution, sales) and the time horizon (strategic, tactical, operational). We find that most planning problems in horticultural supply chains can be mapped within this matrix analogous to the generic proposal of Fleischmann et al. [21]. However, some planning tasks that are generally seen as more relevant on an operational level such as purchasing and lot-sizing decisions have to be considered on a mid-term basis in ornamental horticulture due to the long production time of most of the plants and the need to establish at least a certain level of planning security in an uncertain market environment. These planning tasks together with tactical demand planning are also identified as the most critical ones for small and medium-sized companies, with a considerable impact on their short-term profitability and operational capacity to act.

In contrast, our structured literature review shows that contributions for decision support within a horticultural domain have so far often focused on strategic decisions and distribution issues. Both aspects, however, play a minor role for small and medium-sized companies in the ornamental horticulture sector. The strategic framework is often predetermined for these companies or does not change for a very long time horizon as the companies have only limited investment resources and supplier and customer relationships often last for decades. Distribution planning is identified as an important topic for wholesalers with a larger set of suppliers and customers, while retailers and producers often outsource distribution tasks or have to serve only a limited set of customers or a single outlet. Overall, although interconnections with generic planning models can be identified and models developed for other sectors, there is still a huge gap in the literature regarding decision support systems that reflect the planning characteristics and specifics in ornamental horticulture. This is especially true for the most relevant previously mentioned planning tasks in practice and underlines the need for future research efforts in the supply chain, logistics, and operations planning in horticulture. Tables 2–4 summarize the relevant contributions in literature for each planning area and highlight the main gaps in the strategic (Table 2), tactical (Table 3), and operational (Table 4) supply chain planning horizon.

Table 2. Literature on strategic supply chain planning in horticulture or aligned sectors.

Planning Area	Literature (Q:Qualitative; M:Model-Based)	Focus and Methodology	Gaps
Strategic Procurement Planning	van der Broek and Smulders [25] (Q)	Cross-border barriers for innovation on the example of international cooperations in horticulture (case study/ interviews)	Development of generic supplier selection models reflecting specifics in horticulture
	Geerling-Eff et al. [26] (Q)	National cooperation between different agents in Dutch horticulture (secondary analysis of publications)	
	Matopoulos et al. [27] (Q)	Collaboration in agri-food grower-processor supply chains of small and medium-sized companies (case study/interviews)	
	de Keizer et al. [28] (M)	Logistics network design considering the quality of perishable (horticultural) products (modeling and optimization)	
	Rijpkema et al. [29] (M)	Sourcing strategies for international perishable product supply chains considering shelf life decay of perishables (modeling and simulation)	
	Yazdani et al. [30] (M)	Multi-tier supplier selection for food supply chains considering uncertainty (modeling)	
Strategic Production Planning	Rath [31] (M)	Energy supply for greenhouse production (modeling)	Consideration of additional relevant factors for horticultural practice
	Vanthoor et al. [32] (M)	Greenhouse design (modeling and optimization)	
Physical Distribution Planning	van der Vorst et al. [34] (Q)	Dutch horticultural network, sector developments, bottlenecks and improvement potentials (qualitative study)	Investigation of distribution conditions and particularities outside the Netherlands
	van der Vorst et al. [9] (Q)	Dutch floricultural sector developments, bottlenecks, and opportunities (qualitative study)	
	Ossevoort et al. [10] (M)	Logistics hub network for Dutch floricultural logistics (scenario analysis)	
	Cheng et al. [35] (M)	Cloud-based auction tower for trading perishable products and information sharing in Dutch horticulture (platform development)	
	de Keizer et al. [36] (M)	Network design considering heterogeneous quality decay of perishables and application to the horticultural sector (modeling and optimization)	
Strategic Sales Planning	White and Uva [37] (Q)	Marketing plan development for horticultural companies (guideline development)	Adaptation of generic assortment planning models for horticultural products and their requirements

Table 3. Literature on tactical supply chain planning in horticulture or aligned sectors

Planning Area	Literature (Q:Qualitative; M:Model-Based)	Focus and Methodology	Gaps
Material/ Product Requirement Planning	Verdouw et al. [45] (Q)	Drivers and barriers of ERP systems in Dutch horticulture (case study/interviews)	Horticultural focus; consideration of quality decay and pre- and re-order distinction
	Faraudo Pijuan [46] (M)	Economic order quantity and price determination for agricultural and livestock industries (modeling and optimization)	
	van der Vorst et al. [47] (Q)	Quality-controlled fresh food distribution and inventory management (qualitative framework)	
	Verdouw et al. [48] (Q)	Information distribution in virtual logistic networks in Dutch horticulture (case study)	
	Rijpkema et al. [29] (M)	Sourcing strategies for international perishable product supply chains considering shelf life decay (modeling and simulation)	
	Tromp et al. [11] (M)	Prediction of remaining vase life of cut roses based on time-temperature sum (modeling)	
Production Planning	Annevelink [51] (M)	Production planning for glasshouse floriculture (modeling and optimization)	Consideration of stochastic demand, service levels, and horticulture-specific production and ordering structure
	Annevelink [52] (M)	Spacing and allocation plan with dynamic space requirements for floricultural glasshouse production (modeling and optimization)	
	Darby-Dowman et al. [53] (M)	Planting and harvest planning considering risk aversion in agriculture (modeling and optimization)	
Distribution Planning	de Keizer et al. [57] (M)	Hub network in a Dutch potted plant supply chain considering logistics costs, working times, and emissions (modeling and simulation)	Investigation of non-auction-dominated markets, considering horticulture specifics
	Ossevoort et al. [58] (M)	Distribution planning for Dutch horticulture using consolidation effects (modeling and simulation)	
	de Keizer et al. [5] (Q)	Control and design of floricultural supply chain networks and market developments (case study/ interviews and literature review)	
	Jiang et al. [59] (M)	Distribution scheduling with integrated harvest planning of perishable products and time windows in an agricultural context (modeling and optimization)	
	Gaggero and Tonelli [60] (M)	Distribution planning for perishable products considering replenishment cycles, safety stocks, and product volumes (modeling, optimization, and simulation)	
Demand Planning	Haselbeck et al. [63] (M)	Demand forecasting using machine learning for horticulture (modeling and forecasting)	Considering horticulture-specific factors in demand forecasting
	Dellino et al. [64] (M)	Sales forecasting for perishable products and order plan selection (modeling and forecasting)	

Table 4. Literature on operational supply chain planning in horticulture or aligned sectors

Planning Area	Literature (Q:Qualitative; M:Model-Based)	Focus and Methodology	Gaps
Purchasing	Matsuyama [66] (M)	Multi-period newsvendor problem for ordering perishables (modeling and optimization)	Horticultural focus and specifics
	Broekmeulen and van Donselaar [70] (M)	Ordering perishables considering age distributions (modeling and optimization)	
Production Scheduling	Chalabi et al. [71] (M)	Control of greenhouse heating considering weather data, forecasts, and set points (modeling and optimization)	Comprehensive approach combining the heterogeneous requirements of different plants; consideration of further plant treatments and uncertainty
	Magarey et al. [72] (Q)	Management of plant diseases with decision support systems in an agricultural context (case study)	
	Damos and Karabatakis [73] (M)	Web-based integrated pest management in an agricultural context (modeling and forecasting)	
	Bergez et al. [74] (M)	Effective water use in irrigated agriculture (modeling, simulation, and optimization)	
	Gurovich et al. [75] (M)	Irrigation scheduling strategies based on phytomonitoring techniques (modeling)	
	Gonzalez-Araya et al. [76] (M)	Harvest planning and labor distribution for apple orchards (modeling and optimization)	
	Caixeta-Filho [77] (M)	Harvest planning of oranges considering chemical, biological, and logistical restrictions (modeling and optimization)	
	Higgins and Laredo [78] (M)	Harvesting and transport planning for sugar supply chains (modeling and optimization)	
	Ferrer et al. [79] (M)	Scheduling wine grape harvest considering cost and quality objectives (modeling and optimization)	
	Elia and Conversa [80] (M)	Real-time irrigation and nitrogen fertilization management (modeling, optimization, and simulation)	
Transport Planning	Gong and Fu [83] (M)	Vehicle routing problem with time windows considering the quality loss of perishable products (modeling and optimization)	Horticultural focus; integrated production and transportation planning considering horticultural specifics
	Buelvas Padilla et al. [84] (M)	Vehicle routing problem considering perishable food damage caused by road conditions (modeling and optimization)	
	Wu and Wu [85] (M)	Vehicle routing problem considering time-dependent split deliveries, time windows, and customer satisfaction (modeling and optimization)	
	Ginantaka [86] (M)	Vehicle routing problem for horticultural products considering road conditions and traffic (modeling and optimization)	
	Soysal et al. [87] (M)	Inventory routing problem considering perishability and shelf life in food supply chains (modeling and simulation)	
Demand Fulfillment	Widodo et al. [89] (M)	Harvest planning considering plant growth and loss of fresh agricultural products to maximize demand satisfaction (modeling and optimization)	Investigating multiple possibilities for demand control in an ornamental horticultural context
	Ludwig [90] (M)	Production planning considering the effects of risks on demand fulfillment (modeling and optimization)	

Table 4. *Cont.*

Planning Area	Literature (Q:Qualitative; M:Model-Based)	Focus and Methodology	Gaps
	Matos et al. [91] (M)	Discounts of fresh horticultural products based on quality decay (modeling and optimization)	
	Pina et al. [92] (M)	Dynamic pricing of horticultural food products considering remaining shelf life (modeling and optimization)	

All in all, a huge number of planning problems have to be resolved in practice and claims for structured decision support. However, up to now, many decisions have been taken based on experience and rules of thumb in practice without data-driven support and recognition of the actual position in hierarchical planning. Examples of this missing professionalization and systematization of supply chain planning can be found throughout all of our case companies. Com 9 for example solves a classic vehicle routing problem for their basic tour plan by hand and on an aggregated level once a year. Every change to the resulting standard tours is then resolved ad-hoc on the respective delivery day. Equal situations are found for example for physical distribution planning at company Com 10 and production scheduling at Com 8. This shows a large gap between current state-of-the-art research and problem-solving in practice. Many companies are even not aware of which decisions they make unconsciously. We find that managers in the sector are not aware of many planning problems in physical distribution planning or demand fulfillment, especially demand control. This again outlines the practical relevance and need for a comprehensive and structured planning problem overview with current research and solution approaches, which we provide.

One approach to handle the large number of planning problems identified in practice could be the introduction of capable ERP systems, which are widely used in many other industries such as manufacturing. Standard ERP systems, however, do not fit the circumstances in horticulture because dealing with "living products" requires sector-specific solutions. The existing sector-specific systems, however, can be characterized as island automation [93]. Our study confirms this observation of Verloop et al. [93]. We find that information systems are mostly used for the communication or control of specific procedures such as ordering or operational distribution planning for certain customers. However, they do not really serve as a basis for comprehensive data-driven decision support and lack interfaces to respective standard software tools. So the systems can be characterized as closed ones. In line with the key limitations for effective usage of ERP systems identified by Akkermans et al. [94] and the obstacles in horticulture identified by Verdouw et al. [45], we find that there is a lack of functionality beyond managing transactions. Uncertainties and sudden changes facing high dynamics in planning limit the development of ERP systems for companies in the horticultural supply chains [93]. These conditions lead to a situation in which enhanced, sector-tailored ERP systems are not only necessary for small and medium-sized companies, but also larger enterprises, that typically implement more comprehensive ERP systems [45], which could benefit from such a development. So similar to agricultural supply chains there is a need for further action to improve the ERP implementation in horticultural practice [95]. Our systematization of planning problems can thereby help to define suitable modules for such systems.

6. Conclusions

Within this study, we have explored and systematized the planning problems in ornamental horticultural supply chains. Our exploratory investigation emphasizes the need for structured decision support in this sector. Up to now many decisions have been taken based on experience and rules of thumb, and necessary data is not recorded appropriately. The interviewees who are people in charge of companies in the sector, however, have already recognized this obstacle and highlighted their willingness to advance digitization and professionalization. Research on decision support systems for the various planning problems along the supply chain that reflects the practically relevant aspects and specifics of ornamental horticultural supply chains is thus highly appreciated. Our reviews of pertinent literature in the various planning areas, however, emphasize that there are still numerous gaps in the literature that need to be filled. Besides that, our systematization and characterization of planning problems can also support the development of data-driven decision-support systems that are tailored to the requirements of the horticultural sector. So far, existing systems lack suitable data-driven decision support modules, interfaces to standard software and data analytic tools, as well as comprehensive planning support.

Limitations

Not all planning problems identified are equally relevant for every supply chain role in the sector, i.e., producers, wholesalers, and retailers. Our systematization thus presents more of a comprehensive overview rather than a dedicated systematization for specific companies. However, as vertical integration is common in the sector, the companies will typically face large parts of the planning tasks outlined within our study. Nevertheless, our contribution is not without limitations. As we have relied on expert interviews with selected managers of companies in the sector, our results cannot be seen as representative in a quantitative sense. However, by following the guidelines of Mayring [19] and reaching theoretical saturation, we believe that our presentation of planning problems represents the typical challenges that small and medium-sized companies face in ornamental horticulture. Furthermore, our findings are derived from interviewees with companies operating in the German market. This was necessary to create a unified context and to limit our data collection to a reasonable scale. As Germany is one of the largest producing horticultural markets in Europe [1,2] and has similarities with several other non-auction-driven markets, we believe that our planning matrix is also applicable to companies in other regions worldwide. Future research could, however, compare our systematization derived from the German markets to other markets. A special interest could be a comparison of auction-driven with non-auction-driven markets, or a comparison of the situation on different continents, as horticulture is very dependent on the ecological environment.

Author Contributions: Conceptualization, A.H.; methodology, M.D. and A.H.; validation, M.D. and A.H.; formal analysis, M.D.; investigation, M.D.; data curation, M.D.; writing—original draft preparation, M.D. and A.H.; writing—review and editing, M.D. and A.H.; visualization, M.D.; supervision, A.H.; project administration, A.H.; funding acquisition, A.H. All authors have read and agreed to the published version of the manuscript.

Funding: This research is part of a project called PlantGrid. The project is supported by funds from the Federal Ministry of Food and Agriculture (BMEL) based on a decision of the Parliament of the Federal Republic of Germany via the Federal Office for Agriculture and Food (BLE) within the aegis of the Innovation Support Program. The APC was funded as part of this project as well.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Not applicable.

Acknowledgments: We thank all participating experts for sharing their information and providing valuable sector-specific insights. We also thank the anonymous reviewers for their constructive suggestions for improving the manuscript.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study, in the collection, analyses, or interpretation of data, in the writing of the manuscript, or in the decision to publish the results.

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