MÄLARDALENS HÖGSKOLA
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Veponic

The Quest for the Hydroponic Pepper

Applying Design Research Methodology to Develop Support Tools for Successfully Designing a Post-harvest System for a Plant Factory

Master thesis work
30 credits, Advanced level

Product and process development
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ABSTRACT

The world is facing a food shortage as the world's population increases and arable land decreases. Despite this, the food industry is wasteful, and 30% - 40% of all produced food is lost before reaching the end consumer. Emerging technologies aim to increase the amount of food that can be grown per m^2 or allow the growing of food in climates or on lands previously impossible. Four main farming techniques utilising these emerging technologies are *Controlled Environment Agriculture, Hydroponic Farming, Urban Farming* and *Vertical farming*. When used together, these techniques form the basis for what can be called a *Plant Factory*. Despite the positive effects these technologies have on the production rate, few Plant Factories have managed to achieve profitability. By creating support for developing the post-harvesting system for a plant factory, this thesis aims to aid in the development of profitable plant factories.

The thesis uses Design Research Methodology to achieve this aim in three parts. The first part identifies the underlying factors of the post-harvesting system affecting plant factory profitability. The second presents a set of support components that will aid the developers to improve key factors affecting profitability. The third part is a case study where the support components applicability at targeting the key factors are evaluated, and suggestions for further improvements and testing of the support is suggested.

Further, using Design Research Methodology, the methods used to develop support in this thesis are presented to easily be replicated by other researchers to aid them in developing support for other industries and circumstances.

The suitability of the developed support was tested using the principles of an initial DS-II. The developed support proved very useful for the investigated case, and with its conditions, the application evaluation was considered a partial success. Two key factors were successfully improved and indicated that the intended support is ready for a comprehensive DS-II. A third support component needs more work to provide the intended support fully. Therefore a second PS iteration is recommended before a comprehensive DS-II is done to increase its value.

Keywords: Hydroponic farming, vertical farming, controlled environment agriculture, urban farming, plant factory, post-harvest, design research methodology

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ABBREVIATIONS

CEA	Controlled Environment Agriculture
DRM	Design Research Methodology
RC	Research Clarification
DS I	Descriptive Study I
PS	Prescriptive Study
DS II	Descriptive Study II
HF	Hydroponic Farming
PF	Plant Factory
UF	Urban Farming
VF	Vertical Farming
PHS	Post-harvesting system

1. INTRODUCTION

This section introduces the underlying reason for the existence of this thesis in the background. After the background is established, the challenges of this area are stated in the problem formulation. The project's purpose and desired contributions are then presented in the aim and research question. Lastly, the scope of the thesis is stated.

1.1. Background

According to the Food and Agriculture Organization (2015), the world faces a food shortage problem where around 800 million people do not have enough food to eat. Food shortage is further recognised as one of the United Nations 17 goals for sustainable development. The second of these 17 goals is to ensure nutritious food for all people and end hunger (United Nations, 2015). The problem is twofold; on the one hand, according to Cicullo (2021), 30 – 40% of all produced food is wasted or lost somewhere along the way from its start to the end consumer. These problems put pressure on streamlining production and logistics (Florkowski et al., 2014).

On the other hand, the farmable land of today is a limited resource. The increased global population and urbanisation pose challenges in at least two aspects; a need for more food to feed a growing population and more land to house the people and serve as farmland (Mok et al., 2020). Fedoroff (2015) further underlines this issue by stating that all good agricultural land already is in use.

Several sources threaten this resource. Most pressingly is the rising global temperature, which causes a multitude of different issues for farmlands. According to Fedoroff (2015), roughly 40% of the world landmass is arid dryland, and this land is home to about one-third of the world's population. The amount of global dryland is expected to increase with rising global temperature and increased desertification. On top of that is the depletion of the worlds groundwater reserves (Fedoroff, 2015; United Nations, 2015). The world's arid areas rely on groundwater extraction for their subsistence, and in many of these areas, groundwater replenishes at a slower pace than extracted (Fedoroff, 2015). Rising temperatures also cause rising sea levels and more extreme weather, threatening farmable land and forcing food producers to develop more resilient farming techniques (Mougou et al., 2011; United Nations, 2015).

There are several different techniques and technologies used as a solution to increase efficiency and resilience in farming. Being often used together, the terms, however, are sometimes used interchangeably. Those terms being *Controlled Environment Agriculture (CEA) and Hydroponic (HF), Urban (UF)*, and *Vertical Farming (VF)* (Beacham et al., 2019; Larsson et al., 2016; Martin & Molin, 2019). CEA and HF recycle the used irrigation water and lower losses due to evaporation, reducing the water footprint (Benke & Tomkins, 2017; Martin & Molin, 2019). They also increase yield by CEA optimising light, temperature, humidity, and CO_2 (Beacham et al., 2019; Benke & Tomkins, 2017) and HF optimising irrigation and nutrients (Benke & Tomkins, 2017) all year round. Apart from increasing yield, CEA and HF also protect against pests, extreme weather and other adverse natural influences (Benke & Tomkins, 2017). VF is utilised to multiply the effective agricultural area by growing crops on multiple levels or vertical surfaces, for example, on shelves or in multi-floor building complexes (Beacham et al., 2019; Benke & Tomkins, 2017). UF means growing crops in direct proximity to populated areas (Larsson et al., 2016). By farming in urban areas, the logistics requirements are reduced, which reduces the losses attained during these processes (Benke & Tomkins, 2017; Larsson et al., 2016). It is also possible to utilise urban residual heat and other waste for synergetic effects (Beacham et al., 2019; Martin & Molin, 2019). Another term that is sometimes used for a combination of most or all of these previously mentioned techniques is Plant Factory (PF) (Kozai, Niu, et al., 2015).

Despite these new agricultural technologies' positive attributes, a survey from 2014 showed that only about 25% of PFs in Japan were making a profit (Kozai & Niu, 2015). Much effort has been put into increasing the efficiency of the pre-harvest processes (e.g. Beacham et al., 2019; Benke & Tomkins, 2017; Florkowski et al., 2014; Kozai & Niu, 2015; Martin & Molin, 2019; Rouphael et al., 2018) but the post-harvest system (PHS) have received very little attention. The production development process itself, or the process of designing the production facilities, has also received little attention (Kozai, 2015; Kozai, Shunsuke, et al., 2015). A structured approach to production development is essential to ensure efficiency and effectiveness for any production process (Bellgran & Säfsten, 2005). A PF often relies on local consumption, making them extra susceptible to trends and public opinions, causing rapid changes in demand (Larsson et al., 2016). The complex nature of handling sensitive crops is further increases the importance of flexibility and a structured design process (Bader & Rahimifard, 2020). Another contributing factor for the low profitability has been suggested as a heavy focus on "product-out" and a lack of a "market-in" strategy (Kozai & Niu, 2015). The absence of a structured design process increases the risk of missing contextual information such as market values causing designers to jump at misaligned solutions (Hubka & Eder, 1988).

1.2. Problem formulation

While a large portion of operating and construction costs are related to the pre-harvest systems, PHS:s also requires attention. The PHS affect the facility's total footprint, pushing up costs, especially in urban and suburban areas. The high price of real estate in these areas makes scaling up production to commercial levels challenging for PF:s (Benke & Tomkins, 2017). The complex nature of living crops and the volatility of local markets pose further challenges, and few PF:s have managed to achieve profitability. The absence of a structured development process increases the risk of jumping at misaligned solutions, and this is especially relevant for PF:s due to its complexity and that a lack of "market-in" strategy has been suggested as a contributing factor to its poor profitability. Despite this, little effort has been made to assist in dealing with these challenges by improving the development process.

1.3. Aim and research questions

This study aims to contribute to the development of a profitable PF by supporting the design of its PHS. Two objectives are clarified to reach this goal. The first one is to make it easier for developers to make informed decisions when specifying the requirements of their PHS by closing the gap in the literature regarding the unique conditions put on the PHS by the farming techniques involved in a PF. The second objective of this study is to create a structured way of working when developing a PHS for a PF. The following three research questions were formulated to reach these objectives. This project uses Design Research Methodology (DRM) to ensure the support developed is applicable to other similar cases and that the method used to create the support could be copied to create support for other industries.

Research question 1: *How does the farming techniques of a PF affect the requirements on its PHS as compared to traditional farming?*

Research question 2: *How can production development methodology be applied to design PHS for a PF?*

Research question 3: *How suitable is the application of the developed support for designing a PHS for a PF?*

1.4. Scope

This project investigates the effect modern farming techniques linked to plant factories have on the PHS. The PHS from harvesting to delivery is investigated, including sorting, decontamination, packing and palletising. Other processes, often crop-specific treatments to extend shelf life, have not been considered. Manual and automated alternatives to the investigated processes have been investigated. Experimental solutions have been investigated in the literature, but only commercially available solutions have been considered for the case itself.

The studied case was to develop and evaluate a set of supports for the development of PHS:s of PF:s. The case company was a single-man start-up that wanted to develop a network of plant factories with in-house PHS. The network consists of a relatively large number of smaller-scale facilities. Therefore, the supports developed during the project were selected to be used by a person without previous experience with production development and designed to be general enough to apply to varying conditions of future facilities. No facility existed during the study, and as such, the facility developed during the case was based on a theoretical facility with the basic conditions expected in future facilities.

2. RESEARCH METHOD

This project was performed as the master thesis for Production and Product Design at Mälardalens Högskola. The project started in March 2021 with the collaboration of Veponic AB, a startup fresh food producer located in Västerås, Sweden. This chapter will present the research approach and methods used during the project and the reasoning behind the choices.

2.1. Research approach

The project was intended to explore and create an understanding of how the farming techniques used in a PF affect its PHS and how this knowledge can be used with production development methodologies to design a PHS for a PF. An explorative approach was taken to achieve these goals, and a single case was deemed sufficient. A single case might not be sufficient to establish causal relationships but is useful for exploring ideas and pre-testing hypotheses (Blessing & Chakrabarti, 2009). The project was based on existing literature and aimed to verify if the theories are applicable for a new field using observations. For this, a deductive approach was appropriate (Säfsten & Gustavsson, 2020).

As the aim was to develop and analyse the effect of using a particular method, the empirical data collection had an interventional approach (see Blessing & Chakrabarti, 2009, p. 245). The data was collected using active participation, which means the researchers were taking part in the experiment and continually observing themselves and possibly other participants (Säfsten & Gustavsson, 2020). Having the researchers as observing participants is useful when a designer takes on the temporary role of researcher and can thereby get a real-time and first-person perspective of the situation (Blessing & Chakrabarti, 2009). This approach was chosen for the project as it gives a good balance of practice and theory suitable for a master thesis project.

This study is one of many in the pursuit of understanding and describing knowledge in the field of PHS and PF. As Säfsten & Gustavsson (2020) express, one scientific survey is one of many building blocks that make up the more significant scientific bank of knowledge. Thereby, a single building block of many that together make up a greater area of understanding within any specific field (Säfsten & Gustavsson, 2020).

2.2. Design Research Methodology

DRM is used to support design research, which in turn is used to support product and process development (Säfsten & Gustavsson, 2020). As the goal was to provide support for the design process for a company's PHS, a DRM of type 3 (see Blessing & Chakrabarti, 2009) was chosen as the basis for the project method. A full DRM of type 3 is considered suitable for PhD projects (Blessing & Chakrabarti, 2009), but as the PS was based heavily on existing methodologies, only select parts of the DRM had to be used, and the method was therefore deemed suitable for the scope of this project. The explorative nature of the project also meant some steps could be performed to a lesser extent.

The four main steps of the DRM, Research Clarification (RC), Descriptive Study I (DS I), Prescriptive Study (PS) and, Descriptive Study II (DS II), are designed to lead the researcher through the process of developing support for a design process (Blessing & Chakrabarti, 2009). The steps are designed to clarify the purpose of the study in the RC, develop an understanding of the problem in the DS I, designing the supporting tool or tools during the PS, and then evaluating its usefulness in the DS II (Säfsten & Gustavsson, 2020). Depending on the state of the art of the situation investigated, each of DS I, PS and DS II can either be based purely on reviewing existing literature or through a comprehensive combination of review and empirical studies. RC is generally always purely review-based (Säfsten & Gustavsson, 2020). However, a single research project does not need to include all steps from start to finish (Blessing & Chakrabarti, 2009).

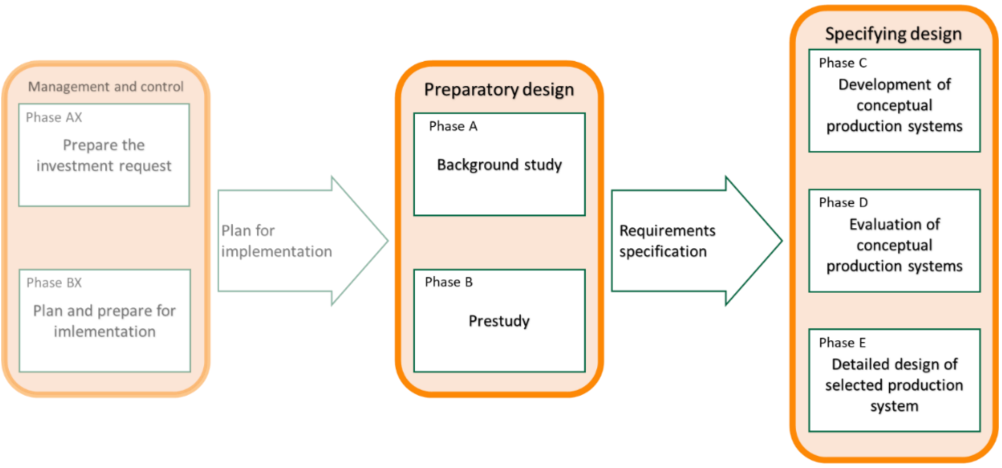

Figure 1 Production development framework by Bellgran & Säfsten (2005), where the last two stages are used as a basis for the support components of this project.

The state of the art of PHS for traditional farming was found to be extensive. Therefore, a review-based DS I was deemed sufficient to synthesise an understanding of what key factors of the development process could be targeted to increase profitability. The PS consisted of creating support and evaluating its ability to target these key factors. The support was based extensively on the two latter stages of the production development framework proposed by Bellgran & Säfsten (2005), displayed in Figure 1. This framework was adapted for the unique conditions of the PHS of a PF using existing literature and communication with the case company and suppliers of production equipment. An initial DS II was then done, where a case study was used to indicate the support's usefulness at designing a theoretical facility. Suggestions were also provided for further research into a more detailed evaluation of the supports applicability for improving the key factors and, in extension, the desired success factor profitability. Throughout this process, the three research questions were answered, as demonstrated in Figure 2.

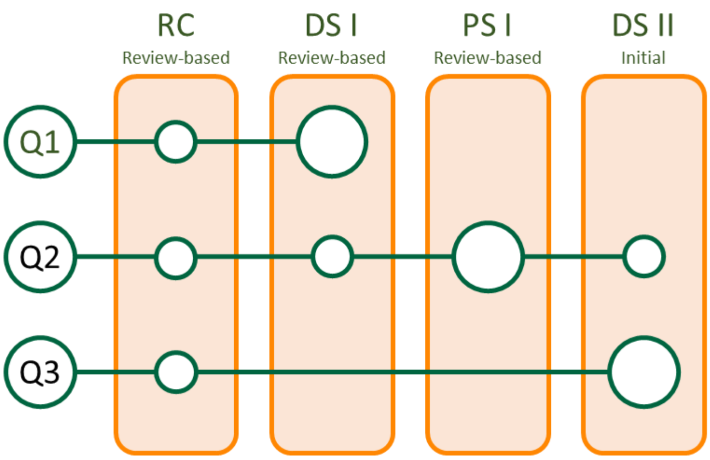

Figure 2 A representation of the four elements of the project and which research questions they are intended to answer. The large circles represent the focus of the section, while the smaller circles are sections supporting in answering the questions.

2.2.1. *Research Clarification*

The first step of the DRM was RC. In this step, the task of the study is clarified and should result in a detailed purpose, goal, and initial plan for the project (Blessing & Chakrabarti, 2009).

An initial interview with the case company's owner and a structured literature review was conducted to describe the situation. The description included what was to be achieved and what criteria were to be used to measure success. These are fundamental first steps, according to Säfsten & Gustavsson (2020). Already at this stage, it is essential to consider all later stages to be performed during the study (Blessing & Chakrabarti, 2009). For example, the measurable success criteria of DS II should already be considered, and as such, an initial case study plan was devised to be suitable for these criteria.

A tool used was a relationship diagram (see Säfsten & Gustavsson, 2020), a graphical representation of how different factors influence each other. Blessing & Chakrabarti (2009) calls these networks *reference* or *impact models* depending on if they represent the current situation or the expected impact of the developed support. See Figure 3 for the initial impact model developed in this project. This model helps visualise the cause-effect relationship between the intended support and the desired results to ensure reasonable and constructive research goals (Blessing & Chakrabarti, 2009).

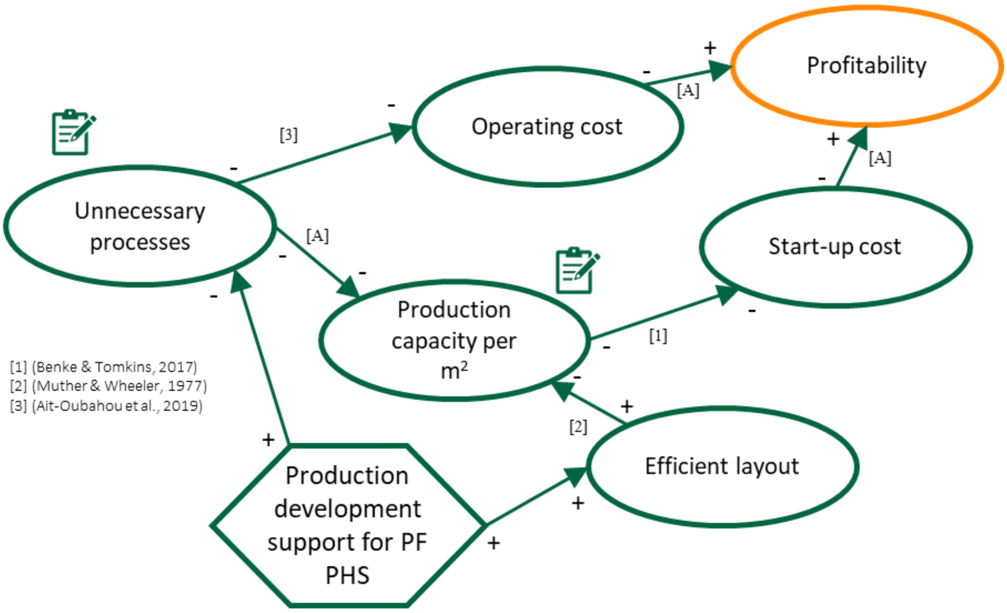

Figure 3 Initial impact model showing key factors and the desired production development support

2.2.2. *Descriptive Study I*

DS I should deliver a complete reference model with success criteria, measurable success criteria, key factors that describe problems with the situation and show the study's relevance (Säfsten & Gustavsson, 2020). The reference model is then used as a basis for an impact model that includes the intended support and its expected effects (Blessing & Chakrabarti, 2009).

The DSI was conducted after a clear goal and focus for the project was established during the RC. A structured literature review, described in sections 2.3 *data collection* and 2.4 *data analysis*, was performed to better understand the current state of the situation. DS I aims to give details on any primary factors and how these factors affect the overall situation (Blessing & Chakrabarti, 2009). A full-scale DS I typically explores an exhaustive range of factors to get as complete a picture of the investigated phenomenon as possible (Säfsten & Gustavsson, 2020). The scope of this study was kept narrow by limiting the review to literature regarding PHS and PF, which confined the factors to those regarded critical specifically for this field. As the PS was based on existing methods with proven merit for other fields, this scope was deemed sufficient to show relevance for the new field.

During the literature review, the factors and links between them were continually added to the reference model leading to the primary success factor: *profitability*. When the reference model was deemed sufficiently complete to give a full picture of the situation, possible measurable success factors were chosen. While the success factor, profitability, is the ultimate goal, it is a factor that requires a long time to calculate. For one thing, production has to be up and running and normalised for some time before stable measurements can be taken. For another, it is affected by other factors outside the scope of this study and requires comparable "before" measures that can be hard to get. The success criteria are often hard to measure because no suitable metrics exist, or it would be impossible to gather data within a reasonable time frame (Blessing & Chakrabarti, 2009). When this is the case, a set of measurable success criteria can be chosen to judge the research outcome. These measurable success criteria should be chosen to serve as good proxies for the actual success criteria and should be as close to it as possible and the links between them as strong as possible (Blessing & Chakrabarti, 2009).

Finally, a plan for how the intended support was desired to affect the situation was devised. This plan is called an impact model and includes the support and the expected desired effects on the values of the reference model's factors (Blessing & Chakrabarti, 2009). The creation of the impact model often requires the introduction of new factors to describe auxiliary effects of the support, and at least a few links commonly have to be based on assumptions (Blessing & Chakrabarti, 2009). See Figure 4 for the deliverables of the DS I.

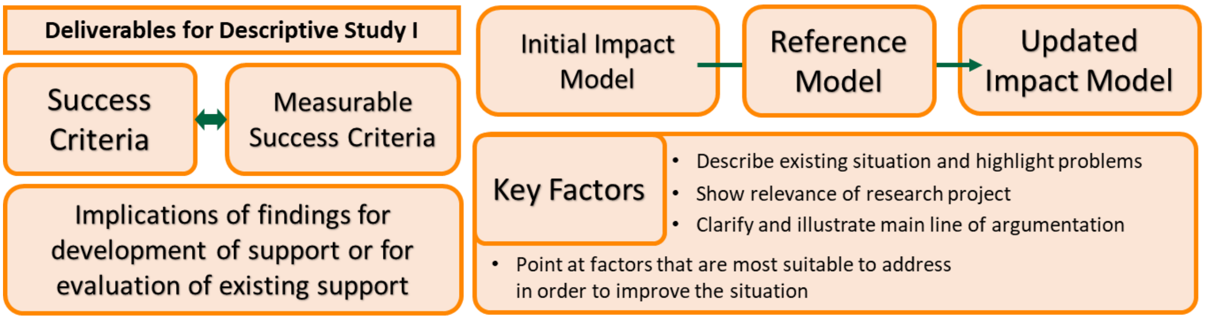

Figure 4 Deliverables for the DS-I Blessing & Chakrabarti (2009)

The DS I was initiated before and made the basis for the PS but was maintained and updated in parallel to the PS. As new knowledge is likely to occur as a project moves along, running these stages in parallel allows this knowledge to be captured and used iteratively, which increases efficiency (Blessing & Chakrabarti, 2009).

2.2.3. *Prescriptive Study*

During the PS phase, the actual support is developed for the investigated field (Blessing & Chakrabarti, 2009; Säfsten & Gustavsson, 2020). Three critical factors were identified as targets for the support during DS I; crop insight, marketing insight and efficient layout. As described by Blessing & Chakrabarti (2009), the deliverables of the PS are divided into two categories, intended and actual support. They describe the intended support as a theoretical description of how the support is intended to affect the critical factors, how it is intended to be used and what pre-requisites it has on the user. For this study, the intended support was based on the framework proposed by Bellgran & Säfsten (2005) studied during the literature review.

The actual support is described by Blessing & Chakrabarti (2009) as a set of workbooks, checklists or software that can be seen as a prototype or demonstration of the intended support. The actual support for this study was partly described in the literature already and partly developed with the case company from the intended support with supplementary data from a systematic literature review and workshops. The part of the support targeting the efficiency of the layout is well described in the literature by Muther & Wheeler (1977), and its continued relevance is corroborated by Bellgran & Säfsten (2005). This support was deemed sufficient for this project with minimal modifications to the instructions to make it more intuitive for PHS:s.

A systematic literature review was conducted to create the actual support targeting crop insight. The idea was centred around the concept of a background study, as described by Bellgran & Säfsten (2005), adapted for the case of not having a previous production system as a basis. The literature review was used to create a compressed guide describing how the farming techniques of a PF affects the PHS. This guide was to be used to help make decisions of what processing steps are required and make a rough description of the production system. The actual support targeting marketing insight was based on pre-study techniques described by Bellgran & Säfsten (2005). Workshops with the case company, aided by the information obtained from the literature review, were used to devise a guide for collecting relevant market information.

A way to calculate capacities and dimension the cells for the chosen processes and appreciated demands was devised to capture the most value from the process and market information. This work was done to connect the market and product-related supports with the process development support. Process planning is a natural bridge between product and production development (Olhager, 2015) and literature regarding it was therefore included in the literature review to create the calculation support.

2.2.4. *Descriptive Study II*

The second descriptive study aims to evaluate the suggested support components' usefulness in improving the situation. This evaluation process focuses on attaining a proof-of-concept for the support as the design is not entirely realised (Blessing & Chakrabarti, 2009; Säfsten & Gustavsson, 2020). The evaluation is divided into two segments, Application and Success evaluation, each targeting fragments of the intended support. Application evaluation addresses whether the support affects the key factors as intended and expected. The success evaluation assesses if the support can improve the calculatable success factors. However, success evaluation is not applicable in an initial DS II as the final result is unavailable (Blessing & Chakrabarti, 2009).

The support components adapted and developed in the PS were applied and evaluated with the case company. The applied test of the support components involved the researchers working with the case company to use the background- and pre-study information to design a layout using the capacity and simplified systematic layout planning components. After utilising the components, the application evaluation was carried out through a reflective questionnaire filled out by the owner of the case company and the researchers. The usage of questionnaires as an evaluation tool is recommended in Blessing & Chakrabarti- (2009) alongside group discussions and interviews. In this case, a reflection questionnaire was deemed a suitable way to gather evaluation data. The questionnaires aimed to evaluate the applicability of the questions used in the pre-study, background study, and specifying design; and evaluate the relevance of the developed component for calculating cycle time and Muther & Wheelers (1977) layout generating tool.

For an initial DS II such as this project, the evaluation focus should be Application evaluation as the full scope of the success of a component may not be realised (Blessing & Chakrabarti, 2009).

The application evaluation is, as stated previously, used to gather insight on the supports effectiveness at affecting key factors. The support was evaluated through questionnaires and discussions with the owner at the case company. The questions were designed to collect data on the intended supports relevance, simplicity, effectiveness, and comprehensiveness. As the subject of the questionnaires differed from each other, they were hence analysed separately. Furthermore, the DS II should deliver suggested improvements for the intended and actual support (Blessing & Chakrabarti, 2009).

A comprehensive DS-II is used to provide a complete evaluation of the suggested support and its impact on the success factors (Blessing & Chakrabarti, 2009). Only an initial DS-II was conducted as part of this study, but measurable success factors are described, and ideas for how a comprehensive DS-II can be performed evaluate them is presented for future research.

2.3. Data collection

Three main methods of data collection were used, a literature review, interviews and workshops. The interviews and workshops were held during the case study, while the literature review was ongoing throughout the project.

2.3.1. *Case study*

A case study is appropriate when more in-depth knowledge is sought after (Säfsten & Gustavsson, 2020). The phenomenon of focus in this study is the PH production system of a PF. A one-shot-case study involves only one case. A one-shot-case study such as this one cannot be used to test or find causal relationships. Therefore, the case studies main goal is to offer specific information about requirements on one particular case (Blessing & Chakrabarti, 2009).

Interviews and workshops

Interviews offer an additional view on subjects and can be more explanatory than literature (Säfsten & Gustavsson, 2020). However, there are drawbacks to this method of data gathering, among them are: that the interviewers might affect the interviewee or other factors which result in misleading results (Williamson, 2002), sampling from wrong respondents might give wrong or misrepresenting answers (Säfsten & Gustavsson, 2020 or, the researcher's interpretation of what is being said may be inaccurate or skewed (Blessing & Chakrabarti, 2009).

The interviews adopted a semi-structured or unstructured approach. The participants of the interviews were the two researchers and the owner of the case company. Three interviews in total were conducted, each focusing on different support tools. First, the pre-study interview was conducted. The purpose of this was to gather general and specific information about the company and market. Before this meeting, an interview form was sent to the participant containing the questions. The choice of a semi-structured approach opened up leeway to further expand on previously unknown details. This interview lasted about three hours.

The second interview was centred on presenting and discussing the requirements specification. The purpose was for the interviewers to present data gathered in the background study and combining it with pre-study data. For this purpose, a semi-structured approach was adopted. General subjects of system overview, functions and target values, dimensioning of workstations, and other properties were discussed. Before the meeting, a rough draft of the requirements specification was provided to the case company—the interview lasted for 1 hour.

According to Blessing & Chakrabarti (2009), a workshop led by the researchers acts as the most effective means of introducing support to the company. Thus, a two-hour workshop was conducted to present the developed support components to the case company.

2.3.2. *Literature review*

A literature review aims to collect information and increase understanding to clarify a problem and ultimately justify developing the support components. The literature review conducted in a review-based DS-I should provide the researchers with enough evidence to support the assumptions. After that, the knowledge gained through this review should be used to develop the support used in the PS. In order to increase the detail of a literature review, other relevant areas of knowledge should also be reviewed. As a tool to present the current state-of-the-art, the literature review provides context and reason about a chosen focus area. The literature review thus provides a contemporary understanding of an area, which can be represented in reference models. With the increased knowledge of a subject, the aims, problems, and assumptions are clarified and can be re-evaluated and further defined. However, the research questions formed in the RC were used as a solid start; however, they should be updated after gaining increased understanding during DS-I. (Blessing & Chakrabarti, 2009)

The source of literature was Scopus, from where both books and papers were gathered. Scopus was the chosen database because it has content from many different publishers and many relevant papers. Throughout the literature review, books sources were used as primary sources in the preliminary stages. Starting with books provided a good overview and starting point for the subsequently more detailed literature searches. A structured literature search was conducted on the subject of post-harvest processes in a mainly traditional setting. The keywords chosen for this preliminary search were *postharvest* or *post-harvest*. The literature study was undertaken to gain a better insight into what is traditionally essential in the post-harvest handling of fruits and vegetables. As a primary sorting mechanism, papers focusing on irrelevant crops were removed. As the number of papers published on this subject each year is large, the initial search only included articles from 2019 and later to ensure the relevance of subjects. Moreover, the language of the used papers was limited to the English language.

Additionally, an unstructured literature review was conducted. The primary database used in finding relevant literature was Scopus, for the same reasons as the structured literature review. The purpose of the unstructured literature review was to gather more in-depth information about subjects of high interest for the study. The review thus focused on gathering extensive information about how the PHS is affected by the farming techniques used in a PF. Hence, the primary keywords used in this search were *hydroponic, vertical, controlled environment agriculture,* and *urban farming*.

2.4. Data analysis

The data gathered for this study was qualitative in nature. A qualitative data approach requires the usage of qualitative data analysis methods. This data analysis could be summed up in four iterative steps, familiarise with the data, find codes, abstract the data, and organise into theories showed in Figure 5 (Blessing & Chakrabarti, 2009; Säfsten & Gustavsson, 2020; Williamson, 2002).

- **1. Familiarise with the data.** Familiarisation with the data is done through thorough reading, data collection, reduction of data, and data display. This procedure was based on a method described by Säfsten & Gustafsson (2020) called qualitative data analysis, which uses data reduction, data display, and conclusion/verification simultaneously and cyclically to analyse qualitative data.
- **2. Finding codes.** In this step, segments from data are coded and can thereby be grouped into categories.
- **3. Abstracting the data.** The coded data is further abstracted and grouped into broader themes.

- **4. Organise into theories.** Theories are broader concepts that are based on themes. These theories are used to answer research questions.
- **(5.) Iterate.** Continue finding theories to answer the research questions.

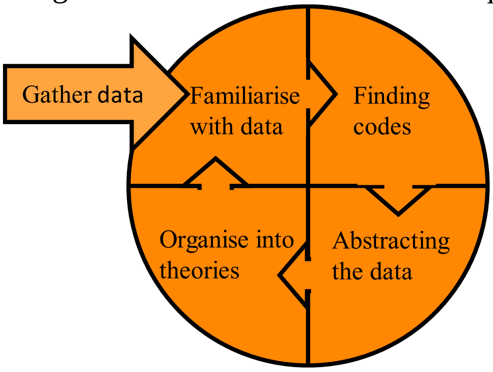

Figure 5 The four + one steps of qualitative data analysis by Säfsten & Gustafsson (2020)

Williamson (2002) offers a nine-step process to analyse qualitative data. As other methods for qualitative data analysis, it is primarily based on interviews and transcribing interviews, of which this study has few. However, subsequent steps are a relevant base for analysing qualitative data. Sharing similarities with methods used in Säfsten & Gustafsson (2020) and Blessing and Chakrabarti (2009). Therein the usage of codes in categorising data, organising categories and forming theories.

Blessing & Chakrabarti (2009) has some outlier ideas of data analysis compared to other sources. The foremost description given of data analysis is to draw interfaces about the observations. There is also an important point stated of avoiding spurious relationships whilst conducting the analysis. Another important point brought up by Blessing & Chakrabari (2009) is to explore all alternative explanations for a phenomenon. They are making an explicit point that a result might be a set of explanations if needed and that the main reason cannot be solely accepted if there are other plausible explanations. Therefore, the definitions given for a contributing project can be described as the set of explanations that is smaller at the end than at the beginning of a project.

2.5. Validity & reliability

Research quality has been ensured through continuous consideration of validity and reliability. Validity is often separated into internal and external validity. External validity considers whether the underlying conditions of the study are valid to gain generalised results and conclusions which are applicable outside the examined case (Säfsten & Gustavsson, 2020). For creative studies, external validity may be challenging to consider; in such cases, transferability might be a more appropriate concept (Bryman & Bell, 2015). Transferability is how well the reader can determine if the results from the study can be used in another application. The rigid structure of DRM aims to create transferability through meticulous documentation, constant questioning of the methods, and transparency of the limitations of the project. The study’s transparency allows the reader to determine how well the results are usable for other applications.

Internal validity considers whether the study method is suitable for gaining the desired result and if the results are useable as a basis for the conclusions drawn (Säfsten & Gustavsson, 2020). Interview protocol and evaluation questions were operationalised to gain the desired internal validity and ensure overlap between the studied concepts and asked questions (Säfsten & Gustavsson, 2020).

Reliability considers the possibilities of replicating the conducted surveys and gaining the same result (Säfsten & Gustavsson, 2020). For qualitative studies under social circumstances, reliability can be challenging to determine. However, through thorough descriptions and documentation of the circumstances, the observations can be replicated (Säfsten & Gustavsson, 2020). Another possible point of view is the inter-rater reliability, which considers the consistency of the implementation and analysis of the study (Säfsten & Gustavsson, 2020).

Ensuring inter-rater reliability required the involvement of both researchers in all practical activities. Inter-rated reliability also needs each researcher to conduct the analysis and conclusion individually before finalising them together. If two researchers draw the same conclusions individually, the internal reliability can be considered good (Säfsten & Gustavsson, 2020).

Moreover, the DS I exists to strengthen the validity of the study. Multiple sources were used, and where it was possible, sources based on multiple surveys were used to strengthen the statistical conclusion validity. The researchers' biases and methods were carefully examined to increase the internal validity of the sources. This examination was conducted by both researchers individually and then discussed together to strengthen the internal validity among the researchers. When the relationships were reversed in the impact model, assumptions indicate that additional research could increase validity.

DS II analyses the performed work and discusses conditions for the results to strengthen external validity. Additionally, proposals for a more rigid survey can be conducted to strengthen external validity through success evaluation.

3. THEORETICAL FRAMEWORK

In this chapter, the thesis' theoretical framework is presented. The areas covered are post-harvest processes, farming techniques of a PF, and systematic production system development methods.

3.1. What is post-harvest

Vegetables and fruit are living organisms that continue to live after harvest (Brosnan & Sun, 2001). The biological activities of the crops cause rapid ageing and degradation of quality unless properly treated (Opara & Mditshwa, 2013). The task of the PHS is to deliver crops from the plant to the consumer while preventing the natural deterioration of value and, in some cases, adding new value through processing (Yahia, 2019).

The PHS is divided into several different stages for the vegetables and fruits to pass through. The requirements on the PHS will change according to factors such as growing method (Yahia, Gardea-Béjar, et al., 2019), location (Elansari, Fenton, et al., 2019), vegetable or plant type (Ait-Oubahou, Brecht, et al., 2019), and cultivar (Prakash & Jesús, 2019).

All stages of the PHS operations are in some way costly. From harvest (Erkan & Dogan, 2019), pre-cooling and cooling to peripheral systems such as conveyor belts (Elansari, Fenton, et al., 2019) and other ways of transportation (Yahia, Fonseca, et al., 2019). A reduction in the total number of operations results in lower overall costs (Ait-Oubahou, Brecht, et al., 2019). To streamline the processes in the PHS, general knowledge about the wishes of the market and the biological requirements of the crops is essential. Having good knowledge about the market and customer demands enables the designer to ensure essential processes are performed (Ait-Oubahou, Brecht, et al., 2019; Kozai, Niu, et al., 2015) and reduces the risk of over-dimensioning or spending resources solving unimportant or non-existent problems (Kozai, Niu, et al., 2015). Overengineering processes or jumping at solutions to false problems often drain resources when designing technical systems (Hubka & Eder, 1988). Biological requirements can be vastly different for different crops, and if this knowledge is missing, PHS are likely to miss essential processes or have poorly performing ones (Shipman et al., 2021; Yahia, Fonseca, et al., 2019). Missing or poorly performing processes cause loss of produce (Brosnan & Sun, 2001), which reduces profitability and sustainability (Brander et al., 2020; Lenzi et al., 2021). Conversely, having good knowledge decreases the likelihood of having unnecessary or overengineered processes (Ait-Oubahou, Brecht, et al., 2019). This connection is especially true when dealing with multiple crops in the same facility (Benke & Tomkins, 2017). Knowing what is truly valued by customers also prevents wasteful processes by focusing on what is essential and value-adding (Ait-Oubahou, Brecht, et al., 2019)

This section will be divided into the five segments that generally make up the PHS.

- Harvest
- Cooling
- Sorting
- Decontamination
- Packaging

3.1.1. *Harvest*

By definition, the post-harvest process starts at the moment of harvest (Florkowski et al., 2014). During harvest, the main challenge is the risk of causing physical damage to the produce (Erkan & Dogan, 2019). Physical damage of produce might result in quality issues such as softening tissue, colour changes and pigment loss. Physical damage to fresh produce results from not handling, processing, harvesting or packaging the produce using proper methods (Brosnan & Sun, 2001). Bruising damage changes fresh produce' integrity and texture. As a result, they release juices that cause discolouration, affecting taste, visual appeal and quality. Automated systems handling the crop must be appropriately designed to reduce the risk of causing such damage (Bader & Rahimifard, 2020).

Fresh produce is also at risk of microbial attacks, which, in some cases, causes deterioration of the crop quality. Further, fruits and vegetables are at risk of attacks from larger living organisms such as insects, birds, and rodents that inflict physical damage and increase contamination risk (Brosnan & Sun, 2001).

Manual harvesting is the predominant technique for most crops as mechanical harvesters risk causing excessive damage to fruits and vegetables (Erkan & Dogan, 2019). Manual harvesting cause less physical stress on the crops but increases the risk of contamination by human pathogens instead (Miceli & Settanni, 2019). Automated harvesting solutions differ widely for different crops. Wheat, potatoes and other sturdy crops have long been mechanically harvested, but delicate crops require gentle and precise handling, which is challenging to achieve mechanically (Gosset, 2020).

The technique used for harvesting tomatoes, cucumbers, and bell peppers differs widely. Bell pepper is best harvested with the stem left on the fruit by cutting the peduncle (Arad et al., 2020). Experimental solutions where robots identify and grab the fruit exists, but the technology is expensive and working speed has to be improved to be considered commercially (Arad et al., 2020). Cucumbers and tomatoes are generally harvested without the stem and traditionally done by pulling the fruit off the vine whilst holding the stalk in place. The primary problem with automated cucumber harvest is the varied force it takes to pull the fruit off the plant (Jakob & Geyer, 2021). Similar challenges exist for tomatoes, which is easily damaged (Gosset, 2020).

Experimental solutions exist, such as the SCARA-based harvesting robot presented by Gosset (2020), but they are not used commercially, again because of the cost compared to speed. To minimise losses for tomatoes during the harvesting and subsequent processes, they are harvested at a green stage when they are significantly less sensitive to mechanical damage (Kabas et al., 2020).

3.1.2. *Cooling*

Cooling is paramount throughout the PHS, and maintaining the cold chain is one of the most critical factors for maximising the shelf life of produce (Lufu et al., 2020). Proper cooling is further used to maintain quality and nutrition in the harvested products and control food safety (Giorges & Pierson, 2018). Because the harvested crops are living organisms, their natural respiration and metabolism cause them to lose water and age under normal conditions and cooling the crops slows down these functions (Janick, 1986).

Different cooling temperatures are required for different kinds of produce. Fresh produce may be prone to chilling damage in too low temperatures resulting in deteriorating quality and loss (Giorges & Pierson, 2018; Ze et al., 2021). Strawberries and broccoli have vastly different ideal temperatures than squash and tomatoes, where the former requires near-freezing temperatures and the latter would require higher temperatures not to receive chilling damage (Brosnan & Sun, 2001). Ripening is a natural part of ageing for climacteric fruit, and customers often desire an ideal state of ripening for consumption (Janick, 1986). As cooling slows down fruit ripening, it is important to keep in mind when they are to reach retail customers to adjust cooling to match the desired ripening stage by that time (Ait-Oubahou, Brecht, et al., 2019).

Cooling is used in two main ways between harvest and the consumer, pre-cooling and cold storage, and different cooling methods are appropriate depending on the role and the requirements of the crop in question (Elansari, Fenton, et al., 2019). When crops are harvested, they have been exposed to the natural conditions of their fields. These conditions usually include high ambient temperatures and radiated heat from the sun, resulting in high crop temperature called field heat (Brosnan & Sun, 2001). If possible, crops should be harvested during the early morning or cold and cloudy days to minimise the detrimental conditions (Yahia, Fonseca, et al., 2019). Field heat must be removed as quickly as possible as the rate of deterioration increases logarithmically with temperature (Brosnan & Sun, 2001), and as a rule of thumb, every hour that the freshly harvested produce remains uncooled shortens shelf life by one day (Elansari, Fenton, et al., 2019). Pre-cooling is the rapid removal of field heat before further processing or storage and is one of the most critical and cost-effective operations for quality preservation in fresh produce (Brosnan & Sun, 2001).

The alternatives for pre-cooling freshly harvested produce are comprehensive. Room, hydro, forced air, package icing, vacuum, and cryogenic cooling are commonly used techniques (Elansari, Fenton, et al., 2019). Pre-cooling is generally done in either a central cooling facility or a packing house (Brosnan & Sun, 2001). A cooling room is an old and established practice where cold air is dispersed near the ceiling and then passed through the produce, stacked in ventilated containers, before passing out through heat exchangers near the floor (Brosnan & Sun, 2001). Room cooling is simple but can take up to a day, and for crops that require rapid cooling or are harvested in hot conditions, it is often unsuitable (Elansari, Fenton, et al., 2019).

The second role of cooling is cold storage, where the task is to keep the crops cool during prolonged periods of storage before or after processing and during transportation and sales (Elansari, Fenton, et al., 2019). Room cooling is an appropriate technique for cold storage as it is easy to implement in warehouses, trucks, and retailers (Brosnan & Sun, 2001). The metabolism of fresh produce causes metabolic heat, which means that, during storage, heat must not only be kept out of the system but removed (Brosnan & Sun, 2001; Elansari, Fenton, et al., 2019). Therefore, ventilation is vital, and forced air cooling might be necessary to get even cooling throughout large volumes (Elansari, Fenton, et al., 2019).

3.1.3. *Sorting*

Sorting is the operation of separating crops into categories based on their characteristics. The essential steps of grading and sorting crops are based on their size, volume, and weight (Nyalala et al., 2021) but could also be measured by colour and quality (Liu et al., 2019). The type of sorting varies depending on the crop, harvesting conditions, and whether any further processing is to be done, but sorting is usually done in multiple steps.

At an early stage of the PHS, pre-sorting the freshly harvested fruit and vegetables is conducted to remove noticeably low-quality produce and debris from the plant (Ait-Oubahou, Brecht, et al., 2019). At this stage, products with any apparent faults, such as damage, bruising, blemishes, irregular shapes or colours, et cetera, are removed (Yahia, 2019). Some of the discarded products can potentially still be used in, for example, processed foods if the defects are only superficial (Ait-Oubahou, Brecht, et al., 2019). Towards the end of the PHS, it is customary to have some form of grading where crops are sorted into categories based on size, weight, colour, shape, quality, et cetera (Liu et al., 2019). This sorting is done partly to single out any damaged crops that got past the first sorting or that got damaged after it, but also to group the remaining crops into product groups. These product groups might then be packaged differently, sold to different customers and at different price ranges depending on perceived quality (Ait-Oubahou, Brecht, et al., 2019).

The traditional way of sorting fruits and vegetables is to do it manually based on the crop's visual appearance based on the operators' subjective opinion (Ait-Oubahou, Brecht, et al., 2019). The operators' opinion of the produce is, in this case, also dependant on factors such as lighting and surroundings (AmeethaJunaina et al., 2020). Workers need to be perfectly familiar with the characteristics and standards the crop must meet (Ait-Oubahou, Brecht, et al., 2019). Automated solutions are becoming more common and efficient (Yahia, 2019). Automated sorting machines can classify products on their weight, dimensions (Ait-Oubahou, Brecht, et al., 2019) or visual properties (Sun et al., 2021). Sorting by weight and dimensions can be done efficiently mechanically, and there are numerous equipment manufacturers available, for example, Zhengzhou First Industry (n.d.). Automated optical sorting, using visible or invisible light, is also becoming more prevalent (Sun et al., 2021), with graders able to both remove defects by detecting discolouration and shape anomalies while at the same time sorting by size, colour or volume, such as ones by Newtec (n.d.) and Tomra (n.d.). These solutions are more flexible than mechanical sorters and can often handle a small family of similar crops after changeover (Florkowski et al., 2014). Some optical graders are also able to detect qualities outside the range of the human eye. Hyperspectral imaging can detect damaged tomatoes before any bruising visual to the human eye appear, which can be up to 12 hours after impact (Sun et al., 2021).

3.1.1. *Decontamination*

Plants are susceptible to contamination both in pre-harvest and post-harvest stages. In the pre-harvest stages, plants and their crop are at risk of contamination from several different sources, including improper fertilisers, low-quality irrigation water (Hirneisen et al., 2012; Lenzi et al., 2021; Ogunniyi et al., 2021), animals, insects (Hirneisen et al., 2012; Lenzi et al., 2021), the soil in the field, dust or air currents (Hirneisen et al., 2012; Mamphogoro et al., 2020), faeces, manure, biosolids, pesticides and pollutants (Hirneisen et al., 2012). During post-harvest, the contamination risk lies in harvesting equipment, human handling, and transportation means, as well as animals, insects and dust (Hirneisen et al., 2012). These contaminations cause significant losses in the PHS (Brander et al., 2020; Lenzi et al., 2021). Loss of produce is especially detrimental to profitability if they occur in the final stages of the PHS as the product would have gone through several costly operations by then (Yahia, Fonseca, et al., 2019).

Human pathogens such as Salmonella and Escherichia coli (E. Coli) and Shigella and Listeria are on the list of diseases that can contaminate multiple types of produce (Lenzi et al., 2021; Miceli & Settanni, 2019). These pathogens cause no sign of spoilage on the contaminated plants but are harmful to consumers (Lenzi et al., 2021). E. Coli and Salmonella outbreaks can be traced to low-quality irrigation water. If a water source of good quality is unavailable, the produce's disinfection is mandatory to reduce contamination (Ogunniyi et al., 2021).

Dealing with these contaminants is a significant part of most PHS (Lenzi et al., 2021). Washing, brushing and blowing are some of the simplest methods but are only effective against larger contaminants such as soil particles or plant residues (Ait-Oubahou, Brecht, et al., 2019). Heat treatment is a common method for reducing microbial load but can reduce the sensory qualities of some crops and damage others (Pinela & Ferreira, 2017). Using chemicals is another common but controversial method and using chemical decontamination requires extra washing stations afterwards to minimise health risks (Ait-Oubahou, Brecht, et al., 2019). Other less invasive and chemical-free methods of microbial decontamination using such methods as radiation, ultrasound, cold plasma, among others, is being investigated by the industry and are seeing increased usage commercially (Pinela & Ferreira, 2017). Because these methods are either relatively ineffective against microbial contamination or are costly, many producers focus on techniques of preventing pre- and post-harvest contamination in the first place (Lenzi et al., 2021).

3.1.2. *Packaging*

A study by the American Institute of Packaging proposed that proper packaging usage may reduce food waste by 10-15% in stores and a further 20-25% in households (Owoyemi et al., 2021). Apart from ease of handling, foodstuff packages have three main functions; one is to protect the foodstuff from physical damage (Lufu et al., 2020), another is to hinder contamination with other objects, microorganisms or pathogens (Opara & Mditshwa, 2013; Paine & Paine, 1992), and the final one is to optimise storage atmosphere (Dhall et al., 2012; Guo et al., 2019; Owoyemi et al., 2021). All three of these functions serve to extend the time it takes for food to spoil and thereby allow it to be sold and consumed over a longer period (Lufu et al., 2020). Apart from shortening the shelf-life of the food item, contamination by pathogens can also be harmful to consumers, potentially causing sickness or even death (Paine & Paine, 1992). Secondary packaging purposes also include the convenience of handling (Ait-Oubahou, Brecht, et al., 2019) and attractiveness during sales (Opara & Mditshwa, 2013).

Cucumbers' short shelf-life without packaging is due to moisture and weight loss, microbial contamination, mechanical damage, yellowing, and peel disorders (Li et al., 2021; Owoyemi et al., 2021). The shelf-life of tomatoes (Distefano et al., 2020) and bell peppers (Opara & Mditshwa, 2013) are affected by the same drivers but to a lesser degree. Freshly harvested vegetables and fruits produce reactive oxygen species and heat, both of which cause hastened quality degradation among vegetables (Guo et al., 2019). Therefore, the atmosphere inside a package plays a crucial role in keeping fruits and vegetables fresh (Lufu et al., 2020; Owoyemi et al., 2021; Paine & Paine, 1992).

It is imperative for packaging for foodstuff to be appropriately ventilated when packed. Ventilation is required for cold air to remove field- or metabolic-heat from packed crops during pre-cooling or in refrigerators (Opara & Mditshwa, 2013; Paine & Paine, 1992).

For the purpose of this study, packaging types will be divided into two varieties: sales packaging and bulk packaging. Sales packaging includes packaging like plastic punnets, trays or bags that the crops are sold in as a unit, while bulk packaging includes any box, basket or similar used for transportation or bulk sales.

Paper and cardboard are made from wood and plant fibres and are biodegradable, highly recyclable, have a relatively low cost and are therefore the most used packaging materials for horticultural products (Ait-Oubahou, Hanani, et al., 2019; Opara & Mditshwa, 2013). Paper and cardboard are usually used as boxes and trays for transportation and bulk sales and can be equipped with moulded layer separators to keep individual items from damaging each other (Ait-Oubahou, Brecht, et al., 2019; Paine & Paine, 1992). Sales packaging is also typical in the form of small boxes or trays, often in combination with plastic bags (Ait-Oubahou, Hanani, et al., 2019).

The other commonly used material is plastic which can be used for bulk packaging (Opara & Mditshwa, 2013) as baskets or sales packages as prepacked punnets, bags or stretch-wrapped trays (Opara & Mditshwa, 2013; Paine & Paine, 1992). When plastic baskets or crates are used as bulk packaging instead of cardboard boxes, the increased ventilation and reduced insulation reduce loss when tomatoes are stored over multiple weeks (Opara & Mditshwa, 2013). When collapsible or stackable plastic containers are reused by circulating back to producers from retailers, one comparison to corrugated cardboard showed the plastic container requires 39% less energy and produce 29% less greenhouse gas emissions (Ait-Oubahou, Hanani, et al., 2019). They have also been shown to be as cheap or cheaper per kg of transported goods than cardboard boxes or wooden crates when calculated over their expected lifetime (Rapusas & Rolle, 2009).

When used for enclosed sales packaging, plastic has properties that contribute to increased shelf-life and quality as it can be used to modify the atmosphere inside the package (Opara & Mditshwa, 2013; Owoyemi et al., 2021). Different plastics have different permeability of water and gases such as O2, CO2 and ethylene, and by designing bags with proper materials and thickness, the atmosphere inside can be optimised for the crop (Guo et al., 2019). These properties allow cucumbers wrapped in plastic to be stored almost twice as long as unwrapped (Owoyemi et al., 2021). As tomatoes (Distefano et al., 2020) and bell peppers (Opara & Mditshwa, 2013) are less affected by the atmosphere than cucumbers, the positive effects of modified atmosphere packaging are also smaller but still relevant for extended storage periods. Many plastics are non-renewable and considered polluting but can be recycled, and renewable and biodegradable plastics are becoming more prevalent (Opara & Mditshwa, 2013). These biodegradable materials are more expensive than regular plastics (Opara & Mditshwa, 2013), and more research needs to be done for their properties to match traditional plastics (Owoyemi et al., 2021).

Plastic packages have a significant upside as sales packages as they can be made transparent and let the customer see the quality of the product (Opara & Mditshwa, 2013). This feature is considered especially important for vegetables and fruit as consumers are wary of signs of damage and blemishes (Paine & Paine, 1992).

The packing process can be divided into crop and package handling, as the mechanical properties of the subject being handled puts different demands on the process (Bader & Rahimifard, 2020).

Crop handling involves the process of filling sales or bulk packages with crops. This process is most commonly done manually, but automatic methods are increasing, mainly in large-scale operations, such as fixed installations pouring crops into bulk packages (Ait-Oubahou, Brecht, et al., 2019). Several different high-speed container filling machines are also available on the market for pouring smaller crops into sales packages, such as the BBC Technologies' (n.d.) CURO line or Newtec's (2020) HSCF line, but individual models are usually only capable of handling a single or a few similar types of crops with changeover. Flexible solutions for smaller volumes and a wider variety of crops using industrial robots are also increasing rapidly, but uptake remains low because of the complexity and requirement of skilled operators (Bader & Rahimifard, 2020).

An alternative to automatic crop handling that is also becoming more popular is field packing, where crops are packed during or immediately after harvest (Ait-Oubahou, Brecht, et al., 2019). Reducing the number of packing operations will significantly reduce costs, waste, and quality loss but requires skilled workers and good oversight to be performed properly (Ait-Oubahou, Brecht, et al., 2019). Packing out in the field or in closeby packing sheds makes the packing operations more sensitive to temperature and weather, however (Ait-Oubahou, Brecht, et al., 2019).

Package handling involves putting sales packages into bulk packages and palletising bulk packages. These operations are simpler than crop handling as shape, size, and mechanical properties are more consistent than that of the crops and, therefore, more commonly automated and use much the same solutions as other industries (Bader & Rahimifard, 2020). Sales packages are typically handled efficiently with small and fast industrial robots such as cartesian, SCARA or delta robots, while palletising is usually done with larger articulated industrial robots (Bader & Rahimifard, 2020).

3.2. Farming techniques of a Plant Factory

As previously mentioned, many emerging technologies can potentially be used to increase farming efficiency and these technologies are often grouped into farming techniques such as urban or vertical farming. As these technologies are often used together or dependent upon each other, one technique has often come to imply the use of other farming techniques (Martin & Molin, 2019). Therefore, these techniques have come to have many and varying definitions, which can confuse (Beacham et al., 2019). This chapter will briefly present four of these farming techniques, CEA, HF, UF and VF, explain their unique features and then discuss how these unique features affect the post-harvest requirements of the crops. Finally, an explanation of how these techniques can be used together to form a PF will be described.

3.2.1. *Controlled Environment Agriculture (CEA)*

CEA means growing crops in a structure where environmental aspects can be partially or fully optimised for the growing conditions of the plants (Rouphael et al., 2018). The most common form of CEA is usually considered to be the use of greenhouses (Kozai, Niu, et al., 2015), although some authors do not include these in the category of CEA (cf. Beacham et al., 2019). Greenhouses can optimise temperature and humidity to increase crop quality and extend the growing season (Andrianto et al., 2020). Artificial lighting and temperature control can increase the effects of greenhouses further by optimising light and temperature to individual crops and their growth stages (Benke & Tomkins, 2017; Rouphael et al., 2018) or enable the growing of crops year-round inside buildings with no or minimal natural lighting (Beacham et al., 2019; Benke & Tomkins, 2017; Larsson et al., 2016). It is also possible to increase crop yield further by enriching the atmosphere inside the construction with, for instance, CO_2 (Benke & Tomkins, 2017; Rouphael et al., 2018).

A large portion of waste in agriculture is due to the crops being spoiled by microbial contamination such as bacteria or fungi (X. Zhang et al., 2020). Other microbial and some virological contaminants can also pose a health risk for consumers (L. Zhang et al., 2021; X. Zhang et al., 2020). Some of these contaminants can be carried by animals or insects who transfer them directly to the plants or contaminate irrigation water (Hirneisen et al., 2012; Miceli & Settanni, 2019). They can also potentially be carried through the air on dust particles or as spores (Miceli & Settanni, 2019). Growing plants indoors, where animals and insects have no access, and the air is filtered, can reduce or even eliminate these pathways (Larsson et al., 2016). These conditions also protect crops against damage caused directly by pests and remove the need for chemical pest and weed control (Larsson et al., 2016).

3.2.2. *Hydroponic Farming (HF)*

HF is usually described as soilless farming (Andrianto et al., 2020; Benke & Tomkins, 2017; Larsson et al., 2016). While it is possible to use HF with soil, the soil is not a prerequisite as HF is characterised by having all nutrients supplied to the plats dissolved in the irrigation water (Larsson et al., 2016). Because of this, there is no need for the living culture in the soil, allowing plants to be grown in an inert material such as rock wool or perlite (Andrianto et al., 2020; Beacham et al., 2019; Benke & Tomkins, 2017; Lenzi et al., 2021) or entirely without growing media where the roots are bathed directly into the nutrient solution and the plants suspended in from a cultivation panel above (Benke & Tomkins, 2017). The nutrient solution is usually mineral-based (Larsson et al., 2016), but by coupling HF with aquaculture, such as fish farming, the waste from the fish farm can supply the hydroponic system with nutrients (Beacham et al., 2019; Larsson et al., 2016; Wirza & Nazir, 2021). This combination is called aquaponics. Hydroponics is usually only used with some form of CEA, and the most common combination is large-scale hydroponic greenhouses (Beacham et al., 2019).

As mentioned in the previous section, microbial and viral contamination are responsible for crop waste and health risks (Rouphael et al., 2018). Contaminated irrigation water, where the contaminants are either already present in the irrigation water or are introduced when the water runs through contaminated soil, is a source of these contaminants (Hirneisen et al., 2012; Miceli & Settanni, 2019). Since hydroponic farming can be done in inert or completely without growing media, the risk of introducing contaminants from the soil can be eliminated (Mamphogoro et al., 2020; Miceli & Settanni, 2019). It is, however, important to thoroughly wash and sterilise any reused material, such as cultivation panels, to prevent an eventual buildup of bacteria or algae (Kozai, Niu, et al., 2015). By circulating the irrigation water through monitoring and decontamination equipment, it is also possible to prevent any buildup therein (Benke & Tomkins, 2017; Miceli & Settanni, 2019).

3.2.3. *Urban Farming (UF)*

UF is more of a set of conditions than a farming technique in itself. UF refers to any type of farming in, or close to, and in some form of symbiosis with urban and suburban areas (Benke & Tomkins, 2017; Larsson et al., 2016). In essence, it is possible to perform UF in very much the same way as traditional farming (Beacham et al., 2019), but one effect the urban environment has on the farm is the land cost, thereby increasing the payback period of start-up and possibly subsequent production scale-ups, which impedes UF profitability (Benke & Tomkins, 2017).

Large connected plots are also scarce, meaning plots are generally smaller and mechanisation is lower (Larsson et al., 2016). The needed footprint of a facility is further affected by the post-harvest processes (Benke & Tomkins, 2017). The land used is often located on the outskirts of urban areas, or plots of land reclaimed from abandoned or derelict industries or housing (Benke & Tomkins, 2017; Larsson et al., 2016). The high cost of real estate and scarcity of large plots of land means it is crucial to maximise the possible output of every square metre of land to prevent crippling payback periods (Benke & Tomkins, 2017). For this reason, CEA and HF are common techniques used together with UF (Benke & Tomkins, 2017; Martin & Molin, 2019). Maximising the production capacity per square metre is also where VF comes in. A large portion of urban farming relies on VF techniques, such as growing on rooftops or inside multi-floor buildings (Beacham et al., 2019; Benke & Tomkins, 2017). VF techniques will be presented in more detail in the next section.

One way the urban environment affects farming is the proximity to people and other services on which they rely. Because of the proximity to people, the pathway to the consumer is usually shorter (Beacham et al., 2019; Larsson et al., 2016). The wider availability and variety of employable people in urban areas also affects UF. This availability increases the farms' possibilities of finding low-wage employees, educated specialists and a wider pool of temporary employees (Larsson et al., 2016). It also enables the UF to work with social outreach programs to offer pleasant employment opportunities to long-term unemployed, work-trails or rehabilitation programs (Larsson et al., 2016).

3.2.4. *Vertical Farming (VF)*

VF is the collective name for any technique used to grow crops away from ground level (Kozai, Niu, et al., 2015; Larsson et al., 2016). There are a few different techniques that are frequently grouped into the term VF; growing stacked horizontal surfaces (Beacham et al., 2019; Benke & Tomkins, 2017; Kozai, Niu, et al., 2015; Larsson et al., 2016; Martin & Molin, 2019), growing on vertical surfaces and growing on top of (Beacham et al., 2019), or even under (Benke & Tomkins, 2017), other structures. This technique is generally only employed commercially in urban areas where the high land cost justifies the added cost of building vertically (Beacham et al., 2019; Benke & Tomkins, 2017; Kozai, Niu, et al., 2015) and therefore shares many of its characteristics.

Growing on stacked levels can either be done with shelves or on separate floors of a building. Both techniques are generally used together with HF and some form of CEA (Beacham et al., 2019; Benke & Tomkins, 2017; Martin & Molin, 2019). Shelves can be placed in greenhouses and designed so that all levels receive adequate natural lightning (Beacham et al., 2019) or where supplemental artificial lighting is given to the lower levels (Fang, 2015). When growing on multiple floors, completely artificial lighting is typical, but some natural light is possible with glass walls (Martin & Molin, 2019). VF on multiple floors of a skyrise gives the theoretical possibility of producing a large volume of crops using a minimal footprint (Beacham et al., 2019; Benke & Tomkins, 2017). Since the floors are separated, it is also possible to adapt each floor to different conditions, allowing a wide variety of crops (Beacham et al., 2019; Benke & Tomkins, 2017; Kozai & Niu, 2015). It is possible to use stacked surfaces without CEA by growing on balconies of existing buildings, but this technique is not very suitable for commercial food production (Beacham et al., 2019).

Growing on vertical surfaces is similar to growing on multiple levels, but crops are grown on vertical growing modules, like cylinders or walls (Beacham et al., 2019). The technique is used together with HF and CEA in similar ways to stacked surfaces and can be used without CEA in the form of façade farming (Beacham et al., 2019).

Growing on or under existing structures is either in the form of rooftop farming (Beacham et al., 2019; Larsson et al., 2016), farming in basements or other underground structures, such as disused mine shafts or runnels (Beacham et al., 2019; Benke & Tomkins, 2017). These techniques are often used together with other VF techniques (Beacham et al., 2019). Growing on rooftops share most characteristics with and is used similarly to the other forms of UF (Beacham et al., 2019) discussed in the previous section. Growing underground also shares characteristics with UF, but the use of HF and CEA is implicit.

3.2.5. *The Plant Factory*

The exact definition of a plant factory varies but always contains elements from these four farming techniques (Kozai & Niu, 2015). The idea of a plant factory is to separate the plants from the outside world's influence so that growing conditions can be controlled similarly to production conditions in any other type of factory (Kozai & Niu, 2015). While any form of HF can be used, cultivation panels where roots are dipped directly in the nutrient solution is the method with the highest control (Benke & Tomkins, 2017). Any form of VF is similarly applicable, and the urban setting is generally considered a prerequisite to increased construction costs of building vertically compared to horizontally. CEA can be done in various ways, but to meet the condition of being independent of conditions of the outside world, any dependence on natural lighting must be removed (Beacham et al., 2019). While natural lighting can be used in a PF, the facility must be equipped with enough artificial light to compensate for seasonal changes or other natural fluctuations. Figure 6 shows a venn diagram of the four farming techniques, and examples of other combined uses.

Together, these farming techniques generally mean a higher production cost (Benke & Tomkins, 2017) which means more money is locked into the products the further down growing and processing they are. Because of this added value, ensuring as much of the crops produced are sold becomes critical. Over 90% of the crops grown and processed in a plant factory has to be sold to make a profit, according to a study presented by Kozai et al. (2015). For this to be achievable, they say that a “market-in” strategy is more appropriate than a “product out” strategy. Apart from dimensioning based on the market, it also includes proper processing according to customer value (Kozai & Niu, 2015). For example, sorting out high-quality crops from lower to sell each to their individual value and ensuring a few damaged crops in a package does not prevent the entire package from being sold.

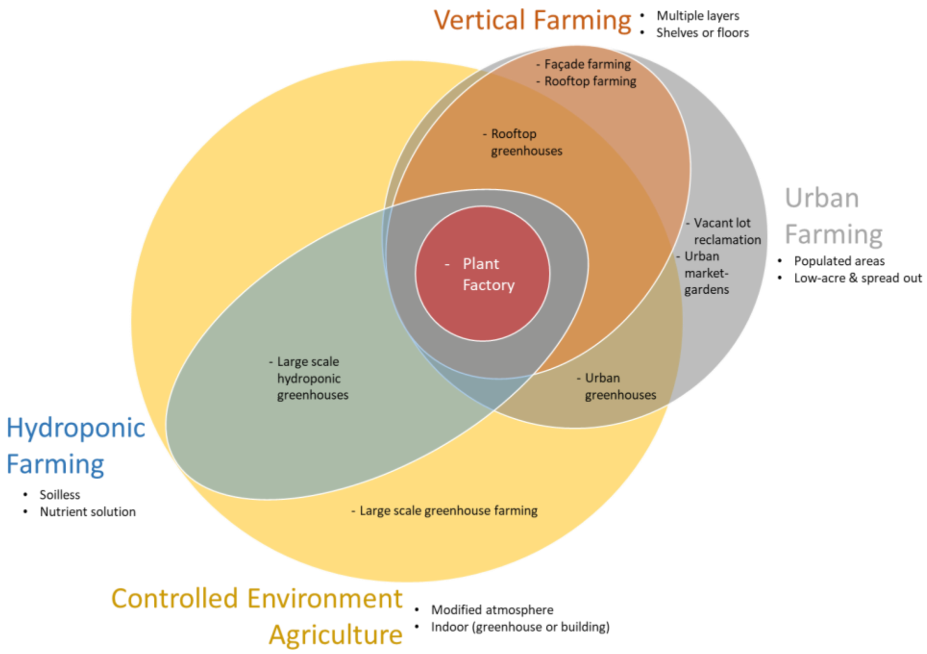

Figure 6 The four farming techniques that make up a plant factory, their unique characteristics, and examples of other combined uses. Larger zones represent more frequently used techniques and combinations.

3.3. Systematic production system development

While the previous sections focused on the products and the underlying production prerequisites, this section directs attention to PHS development processes. A systematic approach to developing a production system is highly recommended in Bellgran & Säfsten (2005). Two methods of systematic PSD are the main points of this section, each tackling different aspects. The methods presented in this section are a framework for developing a production system design and simplified systematic layout planning (Bellgran & Säfsten, 2005). An essential aspect of the importance of a structured design process is presented in Hubka & Eder (1988). The absence of a structured design process increases the risk of missing contextual information such as market values causing designers to jump at misaligned solutions, which will drain resources and increase the payback period (Hubka & Eder, 1988).

3.3.1. *Framework for the development of a production system design*

The following section is, if nothing other is explicitly stated, based on the book Produktionsutveckling (Bellgran & Säfsten, 2005). The book covers the framework for systematic production system development in detail and is thus deemed sufficient on its own as a source for this section.

In this section, the relationship between a company's personnel, economic, and time resources should be sorted out, which are common project management questions. However, four aspects are highlighted as extra influential for production system development, resources for production development and production processes, time, project group cohesion, and creative and analytical abilities (See Table 1).

Table 1 Influential aspects for production system development and their respective critical points

Influential aspects	Critical points
Resources for production development and production processes	• Rationing resources between long term development versus short term gains. • Staff management and competencies. Whether staff can transfer to other functions such as sales, et cetera. • Education level, experience, and competence regarding the development work. • Whether to prioritise solving critical problems or allocating resources for developing long term solutions. • Whether or not to separate the people working on production system development and those who work in production processes.
Time perspectives	• Aspects that affect time to develop a system include complexity, size and scope, automation level, constructor experience and competence, personnel competencies, and decision-making routines. • The perspective is dependant on the system type (manual or automatic) and the development time shifts.

Project group composition	• The project group should consist of people with different competencies to complement and cover as broad an area of disciplines required for a given project. • Whether to use internal, external, or a mixed composition of personnel in the project group.
Creative and analytical abilities	• Analytical thinking is required to develop a requirements specification where data is synthesised to determine relevant factors for a situation. • Creative abilities are helpful in the formulation of new and innovative ideas. The creative aspect is at risk of being hindered by a systematic approach. A method with a defined structure can assist in incorporating creativity in the development. However, a challenge lies in balancing the creative and structured development work.

A structured way of working is an attempt to streamline the production system development process. Bellgran and Säfsten (2005) suggest an eleven-phase process to structure questions, clarifications, and specifications for the development. This study is limited to phases A to E, which includes the preparatory and specifying designs.

The preparatory design aims to deliver a requirements specification created by combining the knowledge gained from phases A and B.

Phase A: Background study involves a thorough and systematic look into previous experiences with production system developments. Where problems, errors, and solutions are highlighted. The main reason for a thorough background study is to find root causes of problems, not to risk only fixing the symptoms but rather the actual problems themselves. An evaluation of existing production systems should be performed, both within and without the organisation. If no comparable production facility exists within the organisation, studying and benchmarking external organisations becomes extra essential. The finished background study should give a complete understanding of the current state of the art of the relevant production system and will work as a frame of reference for decisions made later in the project.

Phase B: Pre-study contrasts the background study by looking forward to the aims and expectations for the production system. During the study, topics such as market, technology, stakeholders and uncertainties are considered. It is crucial to know who the target audience is and understand what they value. Similarly crucial is knowing how the produced products are thought to distinguish themselves from their competitors. The desired level of automation and technological solutions also has to be assessed. Uncertainty in demand is typical and must be considered as it can lead to an increased need for flexibility in the production system, which might affect decisions regarding automation. When possible, the pre-study should involve a multidisciplinary team spanning the relevant departments of the organisation, and the results should reflect the strategic values of the business. The exact topics to include in the pre-study

The background and pre-study are used to form a *requirements specification* for the production system. For this process, the background study will serve as the space of possible solutions, and the pre-study will serve as a guide for choosing the best possible solutions to achieve the strategic and tactical goals of the business. The contents of the requirement specification differ between companies and projects but generally combines technical, commercial, ergonomic, and psychosocial specifications. The specification combines the data gathered from the two studies and the decisions made thereof into one document. The specification will then act as a control document for future decisions and evaluating the production systems solutions. When choosing the technical systems that will make up the production line, a critical aspect is determining the systems' capacities to dimension them. How to make these calculations will be presented in section 3.3.2 capacity calculations.

Specifying design involves developing and evaluating conceptual production systems and a detailed design of a selected production system. Overall, these steps are dictated by the requirements specifications in the conceptual choices of different sub-systems in a production system. The aspects of the specifying design include layout, technical level, material handling, process selection, et cetera.

Phase C: Development of conceptual production systems revolves around the general choices of aspects such as:

1 Flow of material, information, and products.
2 Processes selection and choice of fixed-, functional-, flow-, or line-based layout.
3 Automation- and technical level.
4 Organisational and environmental aspects.

Phase D: Evaluation of conceptual production systems, while formally another phase from the previous, evaluation is conducted simultaneously and iteratively with development. The evaluation can be performed based on the requirements specification. This common approach is also called a goal-based evaluation, which entails assessing how the system reached the goals set in the requirements specification. The counterpart to this is to base the evaluation on the results.

Phase E: Detailed design of selected production system is based on the same concepts as the previous phases in the specified design. This phase goes deeper into the specific details of the chosen system. Descriptions of regulation- and control systems, hardware, and other concepts generated during phases C and D are described in detail. Which ultimately is presented in a detailed layout of the production system.

The completed specifying design results in a *system solution*. As the single most crucial engineering design document. The system solution consists of various documents with technical and organisational solutions and detailed layouts, among other regulatory documents originating from the results of previous phases. The details of these documents are the grounds for implementation. However, the system solutions content and detail level may differ depending on whether the system implementation is conducted internally or externally.

3.3.2. *Capacity calculations*

When considering alternative solutions for a production stage, it is vital to consider their capacities (Bellgran & Säfsten, 2005). The production capacity can be represented by the number of processing hours available over a fixed time period, for example, per day (Olhager, 2015). For example, if an operator or machine is available for work 8 hours per day and two operators or machines are available, that gives a capacity of 16 hours per day (Olhager, 2015).

To find out if a solution has an adequate capacity or to dimension it to reach an adequate capacity, the processing times of the produced products are required. The processing time is the time it takes for one operator or machine to produce one product unit (Olhager, 2015). Approximate processing times are often given in the specification of production equipment or can be estimated by machine manufacturers, but for manual work, or if accurate time is unavailable, a work-study can be performed (Bellgran & Säfsten, 2005). One form of work-study is the time study conducted by measuring the time it takes for an operator or machine to perform an operation repeatedly to get the average processing time (Olhager, 2015). For accurate estimations, the effect of the workers' experience on processing time, called the experience curve, has to be investigated, and the standard deviation of the times has to be estimated so that the number of measurements can be adjusted accordingly (Olhager, 2015).

With the processing times for each product calculated, a rough capacity plan can be made by first calculating the total processing time. The total processing time can be calculated by multiplying the individual processing times with their estimated demands over the investigated time period. This total processing time has to be lower or equal to the capacity for the solution to be feasible, and the percentage of the capacity being used is a valuable metric when comparing alternative solutions. This capacity plan is rough but serves as an indicator of the viability of the solutions. (Olhager, 2015)

Comparing the capacities of all the processes in the production system is also helpful to prevent balancing issues during production scheduling later on. Expensive or critical resources should be dimensioned to have high utilisation, while their resources should be dimensioned to ensure the critical resource never has to wait for them (Bellgran & Säfsten, 2005). It is also recommended to have the critical resources as early in the production line as possible. Positioning it early in the production line reduces its dependence on other resources and creates a tug through the system, reducing the need for buffers (Olhager, 2015).

3.3.3. *Simplified systematic layout planning.*

Simplified systematic layout planning is a method and tool developed by Muther and Wheeler (1977). This method is a six-step process to generate a layout. This method can be used as a tool in specifying design, starting with listing the general concepts and functions and resulting in a detailed layout. Muther and Wheeler (1977) devised this method as a general, easily understood and straightforward aid for designing production facilities. It is supposed to be detailed enough to help professional layout planners while being comprehensible for those with other principal responsibilities—the second group is, for instance, for smaller businesses without the resources to have dedicated layout planners. Muther and Wheeler (1977) write that it is common to miss auxiliary systems and contextual information when designing a production facility. Aspects like material storage and transport, services such as water and pneumatics, staff spaces, et cetera are easily forgotten and need to be corrected later in the process. By having a structured design process, Muther and Wheeler (1977) shows that these factors will be taken into account earlier, reducing rework and optimising processes to ensure more efficient use of space.

Starting with *step one*, the *connection scheme*. The physical sub-systems and functions are listed and graded based on each functions requirement for proximity to each other functions on the list. The six grades of proximity range from absolute necessity to not desirable. The reason for the given proximity grade is stated for each connection.

Step two, the *functionality requirements list*. In which the different needs on both the functions and the facility are defined. The requirements include factors such as floor area, roof height, pillar divisions, and media connections.

Step three, the *connection diagram*, combines the results from the first two steps to create a sketch of the functional connections. The drawing aims to present the proximity between the functions visually. A node represents each function, lines drawn between the nodes represent their proximity grade, more lines between the nodes equals an increased desire for closeness.

Step four, the *alternative layouts*, progresses the sketch to include scalable and geographical representation. The results from step two now impose a more prominent presence, as functional requirements affect placements of functions in the alternative layouts developed. A couple of different alternative plans should be designed to be compared and valued in the next step.

Step five, the *evaluation chart*, is used to evaluate the alternative plans to determine whichever is subjectively superior. Factors for a production systems success are determined and given a value from 1 to 10. Each alternative plan is then given a value for how well it manages each factor. A summary of all alternative plans points results in the best concept used in the final step. *Step six*, the *detailed layout*, specifies the details of the best concept generated from the previous step. This final layout is used as grounds for implementation. (Bellgran & Säfsten, 2005; Muther & Wheeler, 1977).

4. RESULTS & ANALYSIS

In this chapter, stages DS I, PS, and DS II from DRM are conducted. DS I develops the final reference model from the initial reference model to lastly present an impact model. PS then develops support components for the key factors presented in the impact model. In DS II, the tools are applied to the case company, concluding with evaluating the support components and suggestions for future research

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4.1. DS I

This section contains the analysis of the literature review for the DS I. It will first contain the process and reasoning behind the development of the initial reference model into the final one. After that, the assumptions and justifications made to convert the reference model into the impact model will be presented. Finally, the measurable success factors that were chosen to prepare for a comprehensive DS-II are presented.

4.1.1. *Updated reference model*

The support first envisioned in the RC stage was to target *unnecessary processes*. Ait-Oubahou, Brecht, et al. (2019) emphasises how every operation performed in a PHS increases its operating cost. They say that reducing the number of unnecessary processes, such as packing and repacking or excessive treatments, is essential to limit these costs. The link between *unnecessary processes* and *operating cost* was therefore kept in the improved reference model. The link to *profitability* will also be kept and accepted as an implicit assumption. These links are shown in Figure 7.

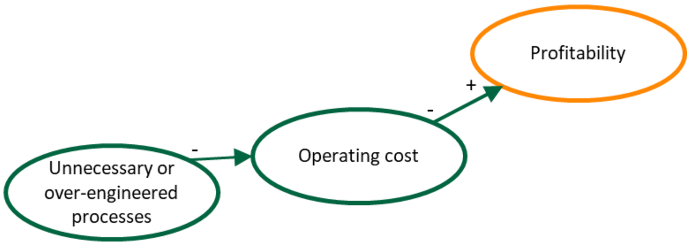

Figure 7 Links between unnecessary or over-engineered processes, operating cost, and profitability

When designing technical systems, it is a common problem to have unnecessarily high start-up costs and subsequently a long payback period by jumping at solutions and overengineering the systems (Hubka & Eder, 1988). This could mean solving imaginary problems or coming up with misaligned solutions. The result, either way, is the inclusion of unnecessary processes in the production system. Many of these excessive processes require large workspaces, expensive equipment or both. For instance, for a PHS, packing crops into containers can be done manually on long packing tables with conveyor belts and multiple operators or using automated packing machines (BBC Technologies, n.d.). Depending on circumstances, these operations could have already been done during harvest with minimal extra cost (Ait-Oubahou, Brecht, et al., 2019). The problem presented by Hubka & Eder (1988) that increasing unnecessary processes will increase the payback period is also a risk for PHS. Furthermore, apart from purchasing and installation costs, these processes will also naturally take up unnecessary space in the production facility, and it can be assumed they will decrease the overall production capacity per m^2 of the system. Therefore, a link between *unnecessary processes* and *payback period* was added based on Hubka & Eder (1988) and another link between *unnecessary processes* and *production capacity per m^2* based on the last assumption as shown in Figure 8.

Processes reliant on a large workforce, such as harvesting, relate to high salary costs (Erkan & Dogan, 2019), while energy-intense processes such as cooling are responsible for a large portion of electricity cost (Elansari, Fenton, et al., 2019). While these operations are necessary and could not be entirely removed, it is clear that their efficiency affects the production system in very much the same way as having an entirely unnecessary process. Cooling is an excellent example of an operation that has improvement potential. Brosnan & Sun (2001) show the importance of cooling and that it has to be done very differently depending on circumstances. For crops being sold locally within a few days, keeping low ambient temperatures in the PHS might be sufficient rather than have forced-air cooling as a separate process. While good cooling increases shelf-life (Lufu et al., 2020), for crops being sold locally within a few days, this increased shelf-life might be unnecessary or even unwanted if it prevents ripening in time. Similarly, delivering crops in individually packed plastic punnets might not add to some customers' perceived value but will add additional operations to the packing line. To include these in the reference model, the factor *unnecessary processes* was changed to *unnecessary or overengineered processes* (see Figure 8).

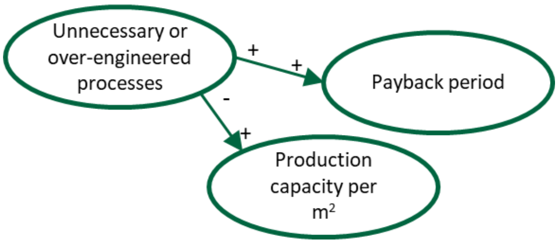

Figure 8 Links between unnecessary or over-engineered processes, and payback period and production capacity per m^2

In the paragraphs above, the expression "depending on circumstances" have come up multiple times. It was clear that to decrease the amount of unnecessary or overengineered processes, these circumstances had to be understood. For the case with cooling mentioned above, Ait-Oubahou, Brecht, et al. (2019) writes about matching the ripening stage desired by the customer by the time the fruit reaches them. This matching requires good knowledge of the market as it is necessary to know who the customers are, when they are likely to order and what they value. Lacking a structured design process is a major reason for lacking contextual information about the market, according to Hubka & Eder (1988), and one of the reasons designers jump at misaligned solutions. For the support to tackle *unnecessary or overengineered processes*, it was apparent that underlying factors needed to be addressed. Therefore, the new factor marketing insight was added to the reference model and linked to *unnecessary or overengineered processes* (see Figure 9).

Kozai et al. (2015) presented more examples of how vital marketing insight is for a PF. They showed that for the PF:s to make a profit, over 90% of produced produce must be sold, and good marketing insight was critical for achieving this. They suggested that a "market-in" strategy had been essential in preventing over-dimensioning expensive processes only to produce waste. A second link was added to the reference model between *marketing insight* and *unnecessary or overengineered processes* to represent this inverted relationship (see Figure 9).

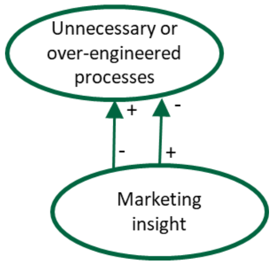

Figure 9 Links between marketing insight and unnecessary or over-engineered processes

Marketing insight is just one side of the challenge. When dealing with sensitive living crops, easily affected by their handling, environment, and storage time, matching customer and market demands also requires knowing the crop requirements. The example of Ait-Oubahou, Brecht, et al. (2019) about matching ripeness with delivery date requires the knowledge of how the fruit ripens under different conditions, such as when cooled. The problem becomes complex if the same facility is to handle multiple crop types. In that case, the importance of knowing crop requirements is further emphasised by Benke & Tomkins (2017). A second factor, *crop requirement insight* was therefore added and linked to *unnecessary or overengineered processes* (see Figure 10).

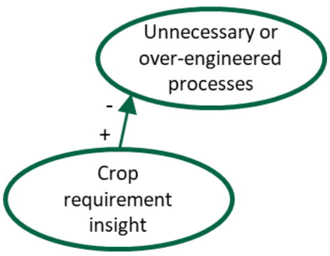

Figure 10 Link between crop requirement insight and unnecessary or over-engineered processes

Overproducing good crops without being able to sell them is a problem already mentioned, but another side of waste in agriculture is damaging crops to the degree that their value is lessened or cannot be sold. Brander et al. (2020) and Lenzi et al. (2021) all emphasise this as a challenge to profitability in agriculture. There are many sources of these losses. Having PHS with poorly implemented essential steps such as temperature control causing chilling damage (Giorges & Pierson, 2018; Miljkovic & Winter-Nelson, 2021) or using too rough handling causing physical damage (Bader & Rahimifard, 2020; Brosnan & Sun, 2001) can lead to significant losses. On the other hand, proper cooling techniques are critical to preventing natural deterioration (Giorges & Pierson, 2018). Packaging technology also has this two-fold challenge of potentially both producing and preventing losses, and improvements in this area have immense potential to prevent losses (Owoyemi et al., 2021). These links between *missing or poorly executed processes*, *losses* and *profitability* are demonstrated in Figure 11.

Figure 11 Links between missing or poorly executed processes, losses and profitability

This brings us back to *crop requirement insight*. The complex mechanical properties of foodstuff and the lack of understanding thereof are contributing factors to the low uptake of flexible packing automation in the food industry (Bader & Rahimifard, 2020). As these same properties are a constant focus of research for the other stages of the PHS (e.g. Brosnan & Sun, 2001; Erkan & Dogan, 2019; Gosset, 2020; Kabas et al., 2020), they can be considered likely factors for slowing the uptake for these stages as well. Other causes for poorly performing or missing processes are other wildly varying biological conditions such as gas and temperature sensitivity (Shipman et al., 2021; Yahia, Fonseca, et al., 2019). While research is required for some of these requirements to be met properly and economically, for example, in harvesting (Erkan & Dogan, 2019) and quality sorting (Sun et al., 2021), the other areas can be improved a lot by simple means if correct temperatures and handling procedures are known and considered by designers (Yahia, Fonseca, et al., 2019). Therefore, a link from *crop requirement insight* to *missing or poorly executed processes* that completes the chain to *profitability* was added to the reference model (see Figure 12).

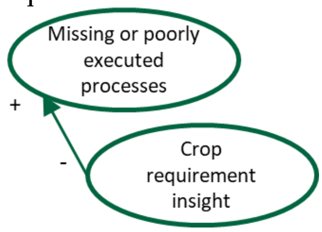

Figure 12 Link between crop requirement insight and missing or poorly executed processes

Another link from *marketing insight* was also discovered with the addition of the *missing or poorly executed processes* factor (see Figure 13). Just as *marketing insight* is important not to over-dimension or overengineer processes, Ait-Oubahou, Brecht, et al. (2019) also writes of its importance to ensure that critical processes are included and done correctly according to customer preferences. They write that proper sorting and packaging should be chosen based on what is desired by the customer to deliver as much value as possible. Being able to fully realise the value of every single crop is something Kozai et al. (2015) also emphasizes. For instance, the sorting out of substandard crops to prevent loss of value to the whole. Ait-Oubahou, Brecht, et al. (2019) goes further and says that having a good knowledge of the market enables the producer to capture opportunities to use substandard crops that would otherwise be thrown away by processing them into juice, jams or similar. That way, by investing in an auxiliary production line, some of the loss created by the waste can be recaptured.

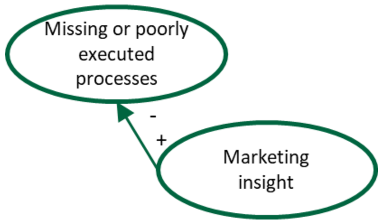

Figure 13 Link between marketing insight and missing or poorly executed processes

The second original target for the support was *efficient layout*. Muther and Wheeler (1977) write that it is common to forget auxiliary systems and contextual information when designing production facilities. They say this results in inefficient use of the available space by requiring unnecessary transportation between process steps or using space saved for expansion to fit staff spaces, conveyors, and auxiliary equipment. This inefficiency means a larger production facility would be required than would otherwise be necessary. By making sure floor space is used as efficiently as possible, the total production per m^2 of the facility could therefore be increased. This link between *efficient layout* and *production capacity per m^2* was kept from the initial model (see Figure 14).

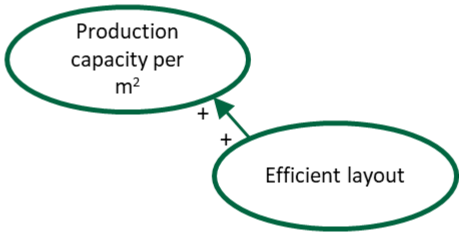

Figure 14 Link between efficient layout and production capacity per m2

The links between *production capacity per m^2*, *payback period cost* and *profitability* are also kept from the initial model (see Figure 15). The correlation between the production capacity per m^2 of a production facility and the payback period is implicit, but whether it is to be considered a key factor deserves attention. The cost of real estate varies greatly depending on the country and if it is in urban to rural areas (Benke & Tomkins, 2017). A PF takes advantage of many of the circumstances that come with urban environments (Larsson et al., 2016; Martin & Molin, 2019), but that also means dealing with its drawbacks. One such drawback is the cost of real estate, which Benke & Tomkins (2017) puts as a critical obstacle for PFs and writes that the size of the facilities dramatically affects the cost of establishing new PF.

While the link between *payback period* and *profitability* could be taken as implicit, Benke & Tomkins (2017) and Martin & Molin (2019) all emphasize the *payback period* as a critical barrier for establishing profitable PF. Because of this, an additional link was added to the reference model to emphasize the relevance of this relationship. With that, the reference model was completed, as shown in Figure 16.

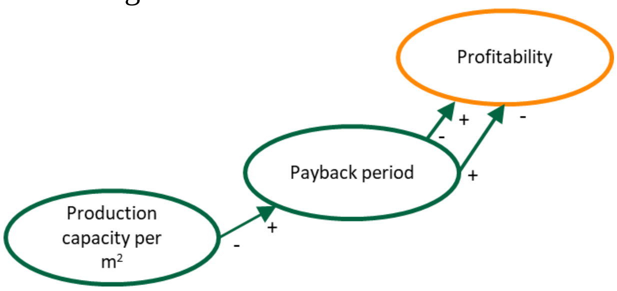

Figure 15 Links between production capacity per m2, payback period and profitability

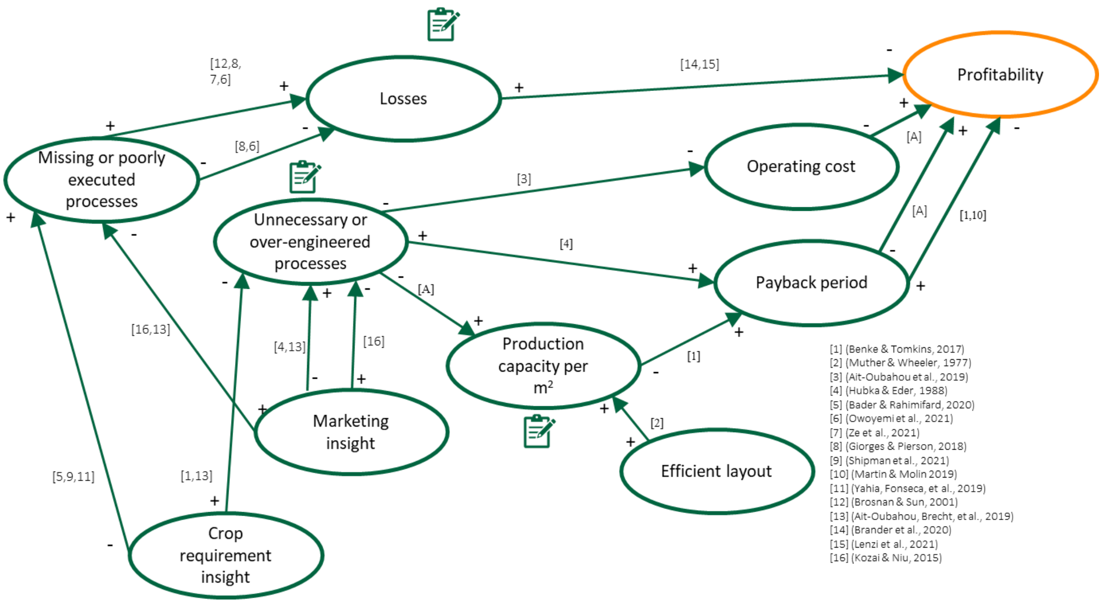

Figure 16 Completed reference model with measurable success factors marked with clipboard symbols

4.1.2. *Impact model*

The impact model demonstrates what factors the support is supposed to affect and the intended impact that will have on the other factors of the reference model (Säfsten & Gustavsson, 2020). The key factors identified in the reference model were *crop requirement insight*, *marketing insight* and *efficient layout*. Each factor was to be targeted by one support component, as shown in Figure 17.

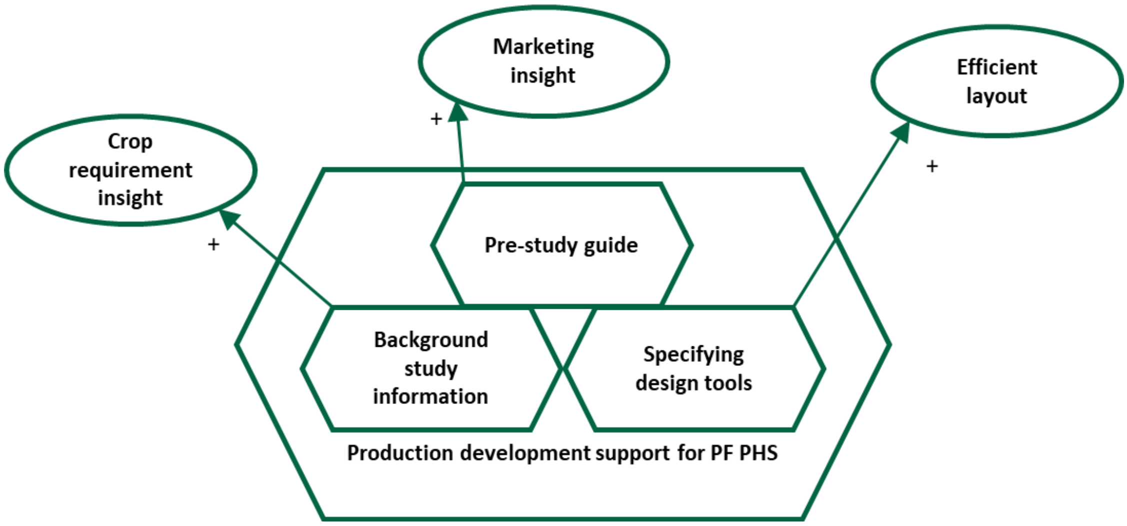

Figure 17 Support components and their intended targeted key-factors

The most significant differences between the models are the values of the links. If the support positively affects a factor, the link leaving the factor should also start with a positive (Blessing & Chakrabarti, 2009). There were four links whose values did not follow a matching chain from support to the success factors.

The link between low *crop requirement insight* and an increase of *missing or poorly executed processes* was had multiple sources referencing the increased risk when knowledge was missing, but few sources explicitly referenced the opposite. However, many sources assumed that increased knowledge decreases the risk of missing or poorly executed processes as an argument for their efforts to increase knowledge. The books used in the project (Florkowski et al., 2014; Kozai, Shunsuke, et al., 2015; Paine & Paine, 1992; Yahia, Fonseca, et al., 2019) were all based on this assumption, and the sources for the original link (Bader & Rahimifard, 2020; Shipman et al., 2021; Yahia, Fonseca, et al., 2019) suggested increased knowledge as a possible solution to the problem. While none of the sources showed any proof of causality, the fact that many credible sources assumed a link between increased knowledge and reduced risk for poor processes, this assumption was also made for this project.

The assumptions regarding the inverses of the links to *payback period* were deemed self-evident. However, other auxiliary factors could be affected by the factors linked to payback period, which in turn would affect it. For instance, the use of expensive equipment to increase *production capacity per* m^2 would naturally also affect the payback period negatively. However, these auxiliary effects were not deemed significant enough to prevent the original assumption to hold.

The last assumption was the link between reduced *losses* to increased *profitability*. Similarly to *payback period*, there are likely auxiliary factors that can affect these two linked factors, but on the whole, the main link between them was assumed to take precedence. The complete impact model is shown in Figure 18, with the explained assumptions shown with yellow links.

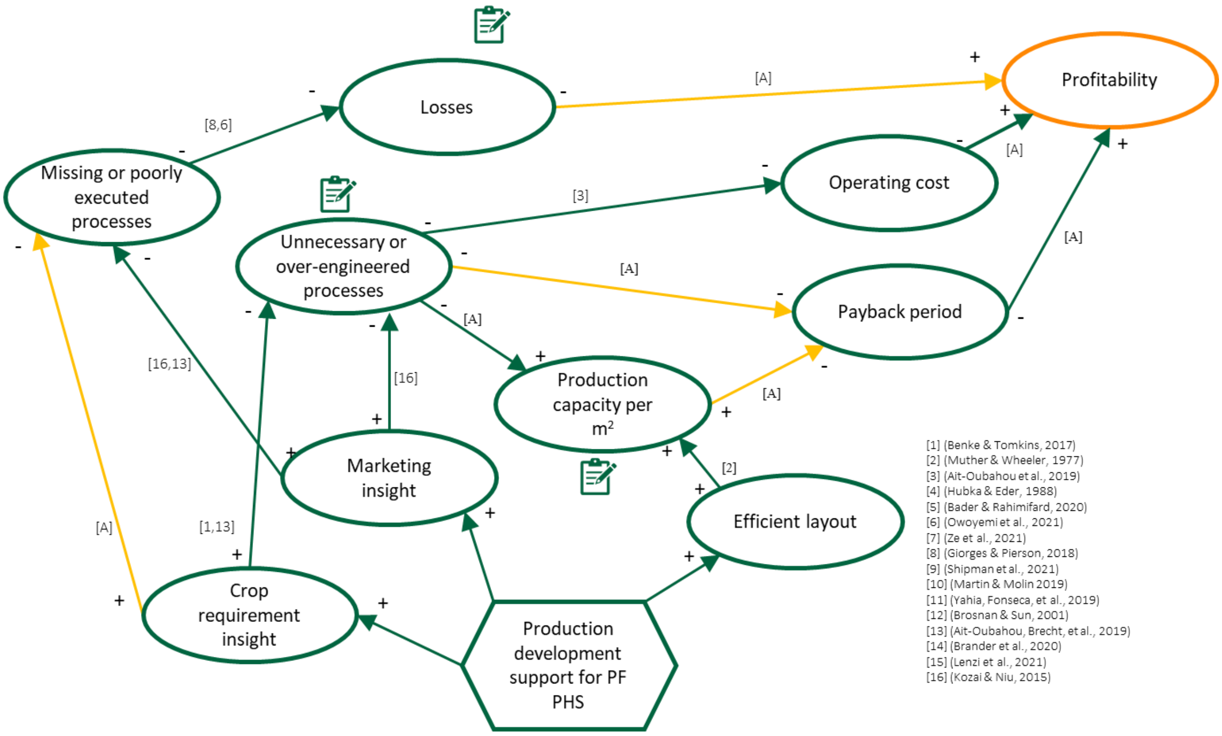

Figure 18 Impact model with assumed links marked with yellow

4.1.3. *Measurable success factors*

The main success factor was profitability, but as this was a factor that was not possible to measure within a reasonable timeframe, a number of measurable success factors had to be found as proxies. Two other factors were similarly difficult to measure for the same reasons, *operating cost* and *payback period*. The factors linked to these three could, however, possibly be measured.

Production capacity per m2 is easy to assign measure and put conditions on as its metrics are self-evident, but just as with the previous factors, a facility in active production would be necessary to get exact values. However, this factor is much easier to evaluate than *profitability* that is affected by factors outside this project's scope, such as market factors. An approximate capacity could be obtained through simulations without the need for hard to estimate factors or existing facilities. Two alternative facility plans could be developed, one with the help of the support suggested by this study and one without, and through simulations, an indication of the success of the supports could be obtained.

Metrics for *Unnecessary or over-engineered processes* is similarly also measurable using two facility plans without the need for either being constructed. However, these metrics involves estimations and appraisals, and a way to obtain measurable values is necessary to compare the two facilities. For this, an evaluation chart like the one used in the support itself for evaluating layout alternatives. A panel should be appointed to determine how well the two facility alternatives uphold the desired properties of the facilities relative to the resources necessary to establish and run them.

Losses is another factor that would be hard to measure without a facility in active production. However, it would be possible to measure it without the need for a separate comparable facility. Like the other two measurable success factors, an alternative facility plan could be devised during the planning, but only the facility designed with the help of the developed support is constructed. This factor relies on how the positive effect of using additional or better processes affects losses, which means it would be possible to estimate the decreased losses by running the facility for a trial period without these additions and improvements implemented. Running the facility without these improvements would simulate having a control facility without the exuberant costs of constructing an additional facility.

4.2. PS

This section develops the support components targeting the key factors. The section describes what knowledge is needed about the products and how those factors are affected by applying PF circumstances. Additionally, the section explains what information is required from a marketing perspective, capacity requirements, and the usefulness of the simplified systematic layout planning tool.

4.2.1. *Crop insight*

The PF affect how the crops are to be handled after harvest. This section describes how each element of the post-harvest processes are affected by the farming techniques of a PF. By following the products throughout the PHS and continually referring to how PF affects the crops, this section explains how harvested crops are affected by the farming techniques. What can be noted in the upcoming section is a lack of discussions on VF. The use of VF is a means to make the PF more profitable, as the elements of a PF are inherently more expensive than traditional farming, such as the technology used in CEA and HF and the location cost of UF. VF is needed to make the PF more profitable by multiplying the crops production area.

Harvest

The common causes of physical damage on produce stem from poor crop handling during harvest, packaging, or transport (Brosnan & Sun, 2001). During harvest, the usage of mechanical harvesters is the leading cause of excessive damage to produce (Erkan & Dogan, 2019). Improved automatic harvesting technology, as described by (Gosset, 2020; Jakob & Geyer, 2021), is a solution to reduce damage to the product during harvest to specific crops. However, fully automated solutions for the harvest of delicate crops are currently not commercially available (Gosset, 2020). On the other hand, manual harvesting increases the risk of spreading human pathogens (Miceli & Settanni, 2019), and the results of manual harvesting are highly dependent on the competence of the workers (Ait-Oubahou, Hanani, et al., 2019).

The continuous growing of crops throughout the year, which CEA enables (Benke & Tomkins, 2017; Rouphael et al., 2018), evens the load on the harvesting systems. This is an advantage for better use of automated harvesting solutions as this gives a higher and more even utilisation and shorter payback periods. A CEA pre-harvest system also allows for a wide variety of crops grown in the same facility (Beacham et al., 2019). To take advantage of this possibility, the PHS should also be able to handle that variety. This flexibility is much easier to achieve with manual harvesting as different crops have very different harvesting requirements.

Many forms of HF uses mobile cultivation panels for growing plants (Benke & Tomkins, 2017). As CEA and UF allow the PHS and pre-harvest system to be in the same facility (Beacham et al., 2019; Martin & Molin, 2019), these panels can be moved with the plants still alive, allowing the plats to come to the harvesters instead of the harvesters coming to the plants. This could be taken advantage of for both manual and automated harvesting as plants could be moved to an area with optimal lighting, equipment and conveyors. Depending on decontamination and packaging solutions discussed later, it would also be possible to harvest crops directly into their sales packages.

To summarise, adequate automated solutions are not available commercially. Experimental solutions exist and are likely to enter the market eventually and would come with several benefits. The even production rate is a significant enabler for automation, and it could be worthwhile working with equipment manufacturers to develop flexible solutions for harvesting a variety of crops. Otherwise, the status of automated harvesting should be continually screened. Manual harvesting is very suitable for harvesting a wide variety of crops and is easy to scale with demand. Taking advantage of possibilities such as movable cultivation panels should be considered.

Cooling

The primary function of cooling is to increase the shelf life of the crops by slowing down their biological functions causing natural ageing and quality degradation (Lufu et al., 2020). Cooling is used in two ways, pre-cooling and cold storage. Pre-cooling is the quick removal of excessive heat, usually caused by warm and sunny growing conditions and then called field heat, before further processing or storage (Brosnan & Sun, 2001). Cold storage is the continuous removal of metabolic heat during prolonged periods of storage or transportation (Zoellner et al., 2018). Cooling has to be done with care as most crops are susceptible to chilling damage at too low temperatures, and these temperatures vary between crops (Brosnan & Sun, 2001).

In traditional agriculture, field heat can be a big problem. This is especially true in hot and sunny climates where every hour delay between harvest and cooling can shorten shelf life by up to a day (Elansari, Fenton, et al., 2019). While pre-cooling is a cost-effective way of prolonging shelf life (Brosnan & Sun, 2001), it still consumes a lot of power and some forms, such as vacuum and forced air cooling, require specialised equipment (Elansari, Fenton, et al., 2019). Their advantage is that they can rapidly remove field heat within an hour or two instead of up to a day for the much simpler room cooling (Elansari, Fenton, et al., 2019), which is the standard form of cold storage (Elansari, Yahia, et al., 2019). Because of this, it is common to harvest during the colder hours of the day and when possible during colder weather (Yahia, Fonseca, et al., 2019). Using CEA, it is possible to control temperature and light (Benke & Tomkins, 2017; Rouphael et al., 2018). Simulating a very cold night for the plants ready for harvest could potentially lower the temperature of the crops to temperatures enough to remove the urgency of cooling. When using HF with movable cultivation panels, as Benke & Tomkins (2017) describes, it would be possible to take advantage of this by moving entire plants ready for harvest into a colder section of the facility to allow even colder harvesting conditions. Together these methods are likely to lessen the need for pre-cooling considerably and if the PF is to take advantage of the shorter logistics chains possible for UF, the extra days of shelf life are unlikely to outweigh the cost.

Keeping the crops cool is still vital, and cold storage of some form is still required. Again, however, the shortened logistics chain possible with UF can reduce the demands on the cooling. While all crops have optimal storage temperatures for maximum shelf life, the deterioration rate increases logarithmically with increasing temperature (Brosnan & Sun, 2001). This means that just keeping the crops relatively cool has a significant effect and an ambient temperature of around 15℃ throughout the PHS during the short lead time between harvesting and delivery is likely to be sufficient.

Sorting

Sorting can be separated into two categories, pre-sorting, and grading (Ait-Oubahou, Brecht, et al., 2019; Nyalala et al., 2021). Pre-sorting is done as early as possible in the PHS, and its primary function is to remove low-quality crops (Ait-Oubahou, Brecht, et al., 2019) such as those damaged by animals, insects or contamination by dust, soil, or low-quality irrigation water (Hirneisen et al., 2012). Using CEA makes it possible to completely prevent animals and insects from gaining access to the plants and removing that source of damage (Larsson et al., 2016). Unfavourable growing conditions, such as temperature, irrigation, or extreme weather, are other sources of damage that CEA can reduce (Andrianto et al., 2020). HF further removes the risk of damage from contaminated irrigation water (Mamphogoro et al., 2020; Miceli & Settanni, 2019). These factors significantly reduce the amount of crops to be sorted out. As the volume of bad crops is much lower, including the pre-sorting function as a secondary function to another function, such as harvesting, becomes more manageable. Depending on the number of processing steps and their utilisation before grading, it could also be feasible to skip pre-sorting entirely and rely on grading instead.

During grading, the crops are traditionally sorted by metrics such as quality, colour, weight, size, and volume (Liu et al., 2019; Nyalala et al., 2021). As the use of HF and CEA evens out the quality of the crops (Andrianto et al., 2020), the need for multiple quality grades becomes lower, but on the other hand, these techniques increase production cost (Benke & Tomkins, 2017), which increases the importance of being able to sell each crop at its optimal price. This means that while most crops will be of the highest grade, accuracy is important so as not to let one bad crop ruin a whole sales package, or not to sort out too many costly high-grade crops by mistake. The high production cost also increases the value of capturing the value of lower grade crops by using them for processed foods or similar.

Sorting is traditionally done manually; however, this method has apparent biases, such as being subjective to the operators' competence (AmeethaJunaina et al., 2020). Grading by mechanical properties such as weight or shape are common, but machines are usually inflexible and optimised for a single crop (Ait-Oubahou, Brecht, et al., 2019). These types of machines are incapable of sorting out damaged crops and will have to be complemented with manual pre-sorting or other optical graders (Ait-Oubahou, Brecht, et al., 2019). Optical graders are capable of both pre-sorting and grading functions and handling multiple similar crops with some reconfiguration (Florkowski et al., 2014). Furthermore, optical sorters can be equipped with hyperspectral imaging, allowing the machine to see damage or blemishes that a human eye cannot see (Sun et al., 2021).

In summary, both manual and automated sorting is viable. The load on the sorting will be low, making manual sorting more economical, but high accuracy is critical, and manual sorting relies on the competence of workers and their attention during long hours of monotonous work. Optical sorters are the most appropriate form of automated sorting because of their flexibility and multifunctionality, critical for a PF.

Decontamination

Three main forms of contamination must be considered for decontamination during the PHS, foreign objects and particles, chemicals, and microorganisms and viruses. Foreign objects such as crop residue, dust or soil particles can attach themselves to the crops before harvest or be included by mistake during harvest or subsequent processing (Ait-Oubahou, Brecht, et al., 2019). Microorganisms and viruses naturally exist in nature and can contaminate plants through the soil, irrigation water, animals and airborne particles (see Hirneisen et al., 2012; Lenzi et al., 2021; Mamphogoro et al., 2020; Ogunleye et al., 2021). Chemicals include accidental contamination by pollutants in nature or from equipment but also the application of pest-, fung- and herbicides (Ait-Oubahou, Brecht, et al., 2019; Hirneisen et al., 2012).

CEA means separating the crops from most of the natural sources of these contaminants. Larger animals can easily be kept out, and with filtered ventilation, insects and airborne spores and other particles (Larsson et al., 2016). With enough control during planting and germination, HF can eliminate the last natural microbial and viral contamination sources by removing the dependence on soil and soil culture. Delivering all nutrition through the heavily controlled nutrient solution allows either growing on cultivation panels or in inert material (Mamphogoro et al., 2020). Human pathogens spread by workers (Miceli & Settanni, 2019) or contaminated equipment (Hirneisen et al., 2012) are still risks, but proper hygiene practices can mitigate them. In addition to standard employee hygiene standards when handling food, one critical action that needs to be taken in the PHS is the cleaning and decontamination of equipment and especially cultivation panels if these are reused.

Apart from reducing the need for microbial decontamination in the PHS, the reduced microbial load and absence of pests and weeds during the growing phase has other positive effects. This absence eliminates the need for chemical pest-, fung- and herbicides to protect the crops from damage (Larsson et al., 2016) and thus any further decontamination to remove the chemicals afterwards.

Contamination by particles and larger objects can still occur in CEA and HF environments, but the amount is significantly lower. As already discussed, CEA in completely enclosed spaces removes any natural airborne particles, and HF with cultivation panels removes particles of soil or growing media. Some particle contamination is still possible, and plant matter can still get collected by mistake during harvest, but larger contaminants are easily removed during sorting, and any particle contamination would be inert and would not pose any health risk.

In summary, it is possible to eliminate all natural sources of microbial, viral, and chemical contamination using properly applied PF techniques. When possible, using preventive methods to remove sources of contaminants are generally preferable to separate decontamination, even for traditional farming (Lenzi et al., 2021). As the discussion above shows, this is simpler in a PF, and this approach would likely be the most suitable. However, it relies on the certainty that high hygienic conditions can be maintained throughout the planting, growing and PHS, and if these conditions cannot be maintained, some form of decontamination could be necessary. In either case, quality control is essential.

Packaging

There are many options for packaging crops, from simple baskets manually filled with loose fruit to individually packaged fruit mechanically stacked in sturdy boxes. This section will distinguish between sales packages sold to the end consumer as complete units and *bulk packages*, which are primarily used for transportation and possibly for presentation at stores. An example of a sales package would be a plastic punnet for cherry tomatoes, and a typical bulk package is the large cardboard box commonly used for regular tomatoes.

Both forms of packaging have three essential functions to consider; protection (Dhall et al., 2012; Guo et al., 2019; Lufu et al., 2020; Opara & Mditshwa, 2013; Owoyemi et al., 2021; Paine & Paine, 1992), ease of handling (Ait-Oubahou, Brecht, et al., 2019) and attractiveness to customers (Opara & Mditshwa, 2013). There are three dangers that packaging needs to protect against, physical damage (Lufu et al., 2020), contamination by foreign objects, microorganisms and pathogens (Opara & Mditshwa, 2013; Paine & Paine, 1992), and harmful atmosphere (Dhall et al., 2012; Guo et al., 2019). Protection is a critical factor, and it is estimated that proper packaging could reduce waste in stores by 10-15% and even more at home (Owoyemi et al., 2021).

The choices that need to be considered are what packaging types to use, their material and how the packing operations are performed. Sales packaging are usually made of plastic wrap, foil, punnets or bags (Opara & Mditshwa, 2013; Paine & Paine, 1992), but cardboard boxes are not uncommon but then usually combined with plastic bags (Ait-Oubahou, Hanani, et al., 2019). Plastic has the advantage of displaying product quality (Opara & Mditshwa, 2013), which is important to consumers (Paine & Paine, 1992). Enclosed plastic packaging also has the advantage of efficiently modifying the atmosphere inside and can be designed to optimise the conditions for the crops (Guo et al., 2019), which can extend shelf life considerably for sensitive crops such as cucumbers (Owoyemi et al., 2021). With the shorter logistics chains made possible with UF (Beacham et al., 2019; Larsson et al., 2016) and the shorter lead times of an in-house PHS of a PF, this effect on the shelf life is less significant but should still be considered. Plastic has a negative environmental connotation to many consumers but is recyclable and renewable, and biodegradable alternatives are becoming more prevalent (Opara & Mditshwa, 2013).

For bulk packaging, cardboard is the most prevalent material because of its availability, low cost and ease of disposal and recycling (Ait-Oubahou, Hanani, et al., 2019; Opara & Mditshwa, 2013). Plastic baskets are also typical and come with the advantages of better ventilation and lower insulation (Opara & Mditshwa, 2013) which makes cold storage more efficient. Plastic is also more durable and can be made collapsible or efficiently stackable, enabling them to be transported back to producers from retailers to be reused. When used in this manner, their greenhouse gas emission is lower than that of single-use cardboard (Ait-Oubahou, Hanani, et al., 2019) and cheaper than both cardboard and wooden alternatives (Rapusas & Rolle, 2009). Whenever material is being reused for food items, hygiene must be considered, and the plastic containers would have to be cleaned between uses to prevent cross-contamination. However, if the containers are used with sales packaging, they will never be in direct contact with the crops, which would remove this need. The shorter logistic chains possible with UF (Beacham et al., 2019; Larsson et al., 2016) also simplify return logistics, giving reusable plastic bulk packaging an advantage over single-use cardboard.

Overall, the choice of material is not vastly affected by the farming techniques of a PF. The higher production cost associated with these techniques means durability is essential, giving hard and enclosed plastic sales packages like clamshell punnets an advantage. On the other hand, shorter logistics chains of UF reduces the package's exposure lessening this advantage. The same is true for plastics atmosphere modifying abilities. However, reusable plastic crates as bulk packages have a clear advantage due to the positive effects on return logistics offered by UF.

The packaging operations are the other options to considered and is in this report divided into crop handling and package handling depending on if the machines or workers are handling individual crops or packages of them. Manual packaging is the most common form for crop handling, but automation is becoming common in larger operations and usually works by pouring crops into bulk packages (Ait-Oubahou, Brecht, et al., 2019). Similar solutions exist for filling smaller crops into sales packages (e.g. BBC Technologies, n.d.; Newtec, 2020), but different models are usually required for different crops, and they are expensive at low volumes (Bader & Rahimifard, 2020). CEA enables the growing of multiple crops in the same facility (Benke & Tomkins, 2017; Rouphael et al., 2018), and if this is taken advantage of, the inflexibility can become a limiting factor and needs to be taken into consideration. Flexible automation is an option using industrial robots for packing individual crops, but the complexity of handling delicate crops and the requirement of skilled operators make these solutions expensive, and the uptake is low (Bader & Rahimifard, 2020). A practice that has become more common lately is to combine harvesting, sorting and packing into a single operation, called field packing (Ait-Oubahou, Brecht, et al., 2019). This form of packing can significantly reduce costs, waste, and quality loss but is very reliant on the harvesting conditions and proficiency of the harvesters (Ait-Oubahou, Brecht, et al., 2019). Field packing could be used very efficiently in a PF. HF with movable cultivation panels enables the plants to be moved to proper packaging stations instead of having mobile packaging stations.

Package handling is very similar in a PHS as in any other industry and is commonly automated (Bader & Rahimifard, 2020), even if manual handling is still the most used method (Ait-Oubahou, Brecht, et al., 2019). Small packages like sales packages are commonly handled with small and fast robots such as cartesian, SCARA or delta robots, while larger articulated robots are commonly used to move larger bulk packages and palletising (Bader & Rahimifard, 2020).

Overall, the options for a PF are similar to any larger PHS for traditional farming. However, CEA enables the production to be evened out over the year rather than being dictated by growing seasons (Beacham et al., 2019; Larsson et al., 2016). This even production pace is a big enabled for any form of automation as it gives an even utilization. However, the inflexibility of fixed automation must be overcome to utilize the advantage of growing multiple crops in the same facility given by CEA.

4.2.2. *Marketing insight*

In developing a new post-harvest production system, insight into the demands and expectations of the market is required to maintain competitiveness (Bellgran & Säfsten, 2005). The main points of the pre-study, as described by Bellgran & Säfsten (2005), were the company's strategic and tactical values related to the market, products, people and technology (Bellgran & Säfsten, 2005). According to Bellgran & Säfsten (2005), a pre-study aims to clarify certain aspects to strengthen competitiveness. In essence, this boils down to creating customer value, differentiate from competitors, and prepare for the opportunity to introduce new products on the market (Bellgran & Säfsten, 2005).

Marketing Insight was gathered through a pre-study consisting of interviews and workshops with the case company. In this section, the background and reasoning of the relevance of the pre-study question are established. Bellgran & Säfsten (2005) was used as a basis for formulating the pre-study interview questions to gather marketing insight. However, Bellgran & Säfstens (2005) questions required adaptation and modification to the specific case. To create a more general pre-study question document, a guide was instead created. The guide's purpose is to instruct the user on what knowledge should be revealed during the pre-study, along with suggested key questions. The questions and answers from the company are seen in Appendix 4.

By gathering insight on the current state of the market and forecasts on the market's future demand, an understanding of the ideal market can be achieved. A complete understanding of the market also requires information about the external stakeholders. For the company to position itself on the perfect market, knowledge about its internal mechanisms is needed. That knowledge includes the product design, the production systems technology level, and what competencies are required.

Market

Understanding the market is one of the pinnacle aspects of being able to make strategic and tactical decisions. A continuous focus on customers values is a cornerstone to successful marketing. To get this, the company needs to identify and understand its customers. Furthermore, it is essential to get to know the other actors on the market and differentiate from them.

It is imperative to be able to identify the key customers and what signifies those from the rest. Essential aspects of customer values are required to become and remain competitive (Bellgran & Säfsten, 2005). Knowledge about who the key customers are is further defined through learning about the customers' demands on the products (Ait-Oubahou, Brecht, et al., 2019). It is anticipated that the direct customer and the end customer have differentiating requests; therefore, information is required on both parties. The customers' demands upon the production system is an additional vital aspect to consider in marketing (Ait-Oubahou, Brecht, et al., 2019; Kozai, Niu, et al., 2015). Furthermore, it is of high value to gather benchmarking information about competitors and differentiate from those by identifying their weaknesses or strengths (Bellgran & Säfsten, 2005).

Product

Questions surrounding the products focus on defining the best possible deliverable products. These descriptions' purpose is to guide decisions on the questions affecting the product. It is important to reconnect the answers to market aspects to ensure product competitiveness and a focus on customer values. The choice of products affects the PHS requirements as different crops require a specific set of processes going through the production system (Ait-Oubahou, Brecht, et al., 2019; Yahia, Gardea-Béjar, et al., 2019). Therefore, it is essential to know the planned product range, how it can change over time, and how large a portion of production each product is expected to entail. Lastly, the packaging design choice is needed, as it affects several of the products quality criteria (Lufu et al., 2020; Opara & Mditshwa, 2013; Paine & Paine, 1992).

Leadtime is the longest allowed time for a product to go from harvest or order to the customer. When choosing the production systems capacity, equipment, logistic system, and layout, the lead time is vital to consider. Competitive advantage is the reason for a customer to choose one company's products above its competitors. These advantages should be developed with the market's values in mind and the companies' internal competencies.

Risk

Generally, the market demand varies over time and is difficult to predict (Bellgran & Säfsten, 2005). The forecasts regarding the market and product are to be reviewed, and any uncertainties should be disclosed. It is crucial to adapt the production to be able to handle reasonable uncertainties. The answers in this section should lead to the choice of equipment based on the desired level of flexibility in volume and product variation. Knowledge about changes in volume and product mix over time is essential to optimise the production systems volume capacity (Bellgran & Säfsten, 2005).

Technology

The desired technical level is to be defined. Values regarding automation, manual labour, modularity, etcetera are to be reviewed. When answering these, the answers to previous questions have to be kept in mind to affirm the focus on customer values, competitiveness, and risk management. The role of technology in a PHS is a heavy influence on the overall payback period (Benke & Tomkins, 2017). A central point in adapting the technology level is knowing whether to specialise or generalise facilities (Bellgran & Säfsten, 2005). A higher level of automation often leads to lower levels of flexibility and vice versa for lower levels of automation (Ait-Oubahou, Brecht, et al., 2019; Bader & Rahimifard, 2020). This ties in with the risk management of product mix changes and volume variations. There is a further need to know both the currently planned level of automation and the future plans of the automation level.

Personnel

The personnel, their competence and their combined knowledge level is an essential resource for the company. It is necessary to know what competencies will be needed to produce according to the previously stated goals. Competencies might involve machine operators, maintenance, process and product design, and constructors (Bellgran & Säfsten, 2005). Training time can be time-consuming, but it could become a factor to consider depending on the required competence level (Erkan & Dogan, 2019).

Stakeholders

Customers and competitors are not the only stakeholders that can affect production. Other stakeholders who can be considered should be examined. These stakeholders are anyone who, for some reason, have reason to care what happens in the company, for example, employees, unions, owners, authorities, etcetera. The tool should disclose both the expected or known external and internal stakeholders (Bellgran & Säfsten, 2005). Further, it should become known how the company affects the stakeholder and how it affects the company, either by laws or directives or by sustainability and work environment.

4.2.3. *Capacity calculations*

The crop insight gained from the background study and the marketing insight gained from the pre-study gave material for choosing solutions for the different production stages of the PHS. The capacity of these solutions had to be compared to each other (Bellgran & Säfsten, 2005; Olhager, 2015) and dimensioned to meet the required capacity of the whole system (Olhager, 2015). Support in the form of an excel workbook was devised that, given the correct information, would return the number of operators or machines required for each stage of the PHS. This workbook is shown in Appendix 5.

When making a rough capacity plan, the estimated demand over a fixed time period is required (Olhager, 2015). The estimated demands given as kilograms of crops per day should be gathered during the pre-study, but as the product units change over the course of the production system, these demands had to be given in the different units. The units used were kilograms, punnets, SRS-boxes and pallets, and the first step of the support was to convert the estimated demands to each of these units. This is done by feeding in demand in kilograms, the weight of a filled punnet, number of punnets in a box and number of boxes on a pallet. The units themselves are not critical, only the quantity of the previous unit that will be counted as one unit in the next step.

To get the total processing time, which will be the value to compare to the capacity of the system, an estimation of the processing time it takes for one resource to process one unit of a product has to be gathered (Olhager, 2015). If accurate processing time is unavailable from machine manufacturers or if manual work is to be done, a time study is an appropriate method (Bellgran & Säfsten, 2005). When these values are inserted into the workbook, the total processing time will be calculated. The final thing that will have to be given is how many hours the resources will be available per day. The daily capacity of a production stage is the number of hours a resource is available during a day multiplied by the number of that resources available (Olhager, 2015). Given the production hours per day, the workbook will calculate the number of each resource required for the capacity to exceed the total processing time.

Apart from dimensioning the processing steps, the support was designed to use the given data to calculate other useful information. When possible, critical resources and possible bottlenecks should be placed early in the production system (Bellgran & Säfsten, 2005; Olhager, 2015). Having machines with lower utilisation downstream will create a tug in the system and reduce the need of using buffers to level out production (Olhager, 2015). By comparing the total processing time of each product individually and summed with the capacity after dimensioning, the utilisation of the processing step can be calculated. The workbook was designed to give the cycle times after dimensioning, the utilisation of each step and product, and each stage's total utilisation. At a glance, it is, therefore, possible to see if any downstream processing step will lag behind and possibly require the earlier steps to slow down or if a buffer is required between.

Finally, the functionality to manually set the number of resources at each step, and the percentage of the production time dedicated to each product, was added. This allows the user to experiment with different constellations and find a solution where utilisation is constantly decreasing downstream to remove the need for buffers altogether. This was added to find a solution with minimal lead time between harvest and delivery.

4.2.4. *Efficient layout*

The layout generating method from Muther & Wheeler (1977) was applied to develop the specifying design. The method is primarily based on background- and pre-study data, which were pre-requisites to complete this method. However, requiring further engagement from the case company in later stages of the method increases its accuracy.

Step one of the tool is establishing a connection scheme; this step lays the groundwork for each subsequent step in the process. The operations that needed to be close by each other were established, and the reason for proximity is stated. In step two, each operation was further defined in its media and footprint requirements. Steps three and four were the first preliminary layout sketches. In these steps, multiple different layout proposals were drawn, each with its benefits and drawbacks. The proposed layout sketches were thereafter used as a basis to determine the objectively best one. In this step, the involvement of the case company proved vital, as different aspects of a production system were to be defined and given a value of importance (Muther &

Wheeler, 1977). Examples of factors that were given values are *Expansion opportunity, manual material flow,* and *conveyor belt flow*. Based on these values and how well each layout reached each aspect, an objectively best layout was generated. The chosen best design was then drawn in greater detail as the last step.

The tool from Muther & Wheeler (1977) could be divided into actual support and intended support, based on the method presented in Blessing & Chakrabarti (2009). The intended support spanned all of the steps proposed by Muther & Wheeler (1977), but what proved helpful and applicable to the case did not include parts of step two and most of step four. Since the actual building dimensions are unknown, the more practical aspects of the Muther & Wheeler (1977) method could not be applied. Therefore, those parts are completed as intended support. Steps one through five were, for the most part, applicable. The issue for this case was a lack of confirmed dimensions for the facility. Steps four, six, and partially five could therefore not be completed as actual support. Steps four and six involve designing the layout, which requires dimensions. Step five uses the proposed layout designs from step four to evaluate their functionality. While the base evaluation score is helpful for future versions of the layout, the final score to choose the best layout is unapplicable as the layout is theoretical.

4.3. DS II

In DS II, the case company and the case are presented. After that, the empirical results of implementing the developed support for the case and the evaluation questionnaires are presented. Finally, the results of the case and the evaluation is analysed to determine if the developed support is applicable to improve the targeted key factors and whether it is ready for a comprehensive DS-II with success evaluation.

4.3.1. *Case company description*

The case company is a one-person start-up fresh vegetable and fruit producer in Sweden. The company consists of one employee and a small testing facility. The small size of the company causes challenges in designing the production facility. Additionally, a lack of experience and specialised training creates a need for tools to fill in the gaps. The company, however, has significant prospects of being a well-established producer and distributor of fresh produce both locally and globally. One of the company's main goals is to have continuous year-round production of fresh produce, which is possible through the PF usage of a controlled environment.

Another aim of the company is to have small facilities spread out through cities. These smaller facilities should support areas of about 100km radius. The facilities can potentially be located in larger schools, hospitals, apartment complexes, and workplaces, thereby providing proximity to customers. The proximity aspect is twofold, both reducing transport, which in and of itself has many benefits, and being closer to workers, thus creating simple work for socially vulnerable people. Having shorter transportation routes is beneficial for aspects such as environmental, product freshness, and product quality.

4.3.2. *Case description*

The focus of this study is the PHS of the case company's hypothetical PF. In the PHS, fresh produce goes through a few different but straightforward steps or stages on its way to the consumer. The start-up company plans its first facility on the outskirts of one of the mid-Sweden urban areas. In this facility, two phases are scheduled to get started. In phase one, the planned volumes going through the PHS are 3000kg per day. In the primary phases of this facility, three products are scheduled to be produced, tomatoes, which make up the most significant volumes, cucumbers, and bell peppers. For phase two, the amount of fresh produce is increased to 8000kg per day.

Currently, no physical facility is available. However, approximate and desired dimensions of the facility are known and are used for this project. Because of the inherent uncertainty of the hypothetical facility, there is a potential for unpredictable challenges to occur. These unforeseen factors might include irregularities in pillar division, roof height, or floor properties which may vary. Some certainties can, however, be stated for the facility. The ground floor will split down the short side of the facility, making two narrower partitions. One side is dedicated to the PHS, the other for seed planting, germination, and transplanting. The ceiling height of this room will be three meters, and each short wall is dedicated to an elevator that connects the ground floor to the growing room above. The elevators function like a cartesian robot transporting the cultivation panels between the growing room and the PHS and take up the entire walls. The dock is located at one of the facility's short sides, and on the same side as the dock, the elevator transports newly planted cultivation panels up to the growing room. The elevator transports the cultivation panels down from the growing room to the PHS along the opposite short wall. One of the possible facilities investigated by the company as a potential site was used as a basis for the theoretical site used to test the tools developed during the PS. For a more comprehensive DS II, a physical facility would need to be evaluated, discussed further in the future research section.

4.3.3. *Implementation*

The approach for developing the PHS was based on the framework proposed by Bellgran & Säfsten (2005, p. 234). The framework's preparatory and specifying design portions were used for the studied case, and the support developed during the PS was designed to target its five phases. The background study is considered complete as it is entirely based on literature from the PS. However, the remaining steps: pre-study, requirements specialisation and specifying design, are left to conduct. The pre-study was conducted via the questionnaire created to gather marketing insight. From the crop insight tool that constitutes the background study and the data collected in the pre-study, decisions were made which forms a conceptual system and a preliminary requirements specification. With assistance from the capacity calculator tool, the requirements specification could be finalised. The completed requirement specification was used as a basis for the specifying design. As the final step, the design tool was utilised to develop alternative layout designs. The alternatives were evaluated, and the best one was chosen.

Prestudy

The pre-study was conducted with the case company in an interactive interview with the researchers as active participants. The information collected from the interview is based on data previously gathered by the case company. After the meeting, data was continually added through discussions with the case company to complete missing information.

To hone in on some of the specific results of the pre-study. Two types of customers are identified, end- and direct customers. The desired direct customer was easier to identify than the desired end customer, stated to be the *ordinary* person. Issues with knowledge about the end customer stemmed from the ambiguity of who the *ordinary* person is. In order to assist in the end customer identification, their marketing demands on the products are identified. The main point driven by the case company is that the products are not to be sold or marketed as premium products. Additionally, the predicted demands from the ordinary person are, in this order: low price, good visual impression, eco-labelling, and brand.

Consequentially, when marketing to the ordinary person, all other producers of the same crop become competitors. Thus competitive advantages are essential to identify for both the competitors and the case company. Three different clusters of competitors are identified, traditional agriculture, organic agriculture, and local agriculture. Through this knowledge, the strengths and weaknesses of the competitors can be roughly determined. Traditional agriculture, for example, utilises large volumes to decrease costs but sacrifices flexibility, quality, and environmental friendliness.

A question that sprung immense interest was the choice between specialised or generalised equipment. This topic served as an essential part of opening up the discussion on the desired technological level within the facility. Although automation is associated with a high investment cost, the facility's goal is to be wholly automated for phase two. For phase one, some level of manual labour is accepted whilst scaling up operations.

Results from personnel-related questions were challenging to gain as there are no existing systems to support decisions. Hence any specific answers as to what competencies or roles are difficult to determine. The benchmark for personnel competence requirement is relatively low, no higher education is required for harvesters, but competence is needed for machine operators and maintenance personnel. Minimal training time is overall desired.

The discussion on stakeholders proved difficult. The case company did not possess a complete picture of this subject; hence, no clear answers could be provided. However, it was a crucial subject to discuss as a lack of knowledge was revealed to the case company.

Requirement specification

The next step involved applying the information gained from the background- and pre-study to form the requirements specification. The workgroup used to create the requirements specification consisted of the two researchers and the owner of the case company. The step was conducted in two stages, and the first stage combined the strategies and values from the pre-study with the technical knowledge collected in the background study. The combined understanding was used as the basis to decide technical solutions for the PHS. From that, a conceptual system, shown in Figure 19, was developed to display the general idea of the system.

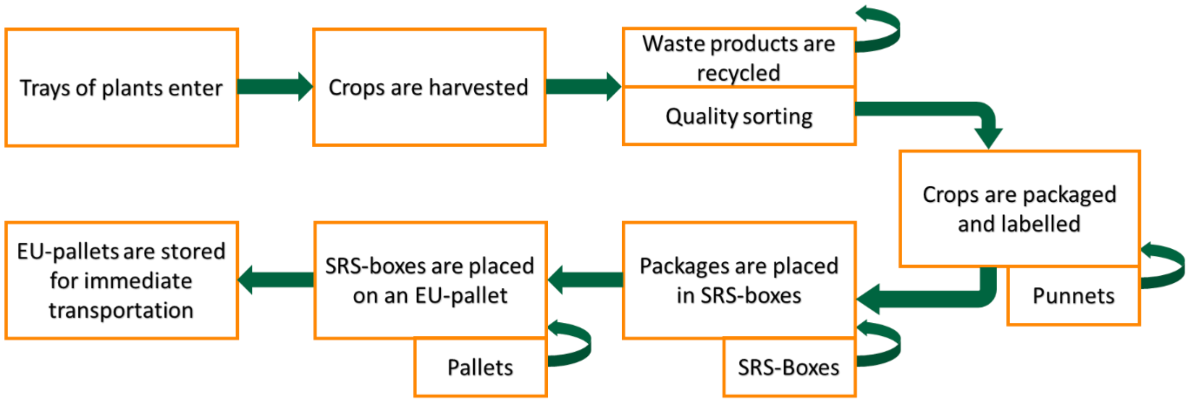

Figure 19 A conceptual system demonstrating the general idea of the post-harvesting system

The system is fully automated in the ideal case, but other manual solutions are explored because of the lack of commercially available solutions for harvest. Harvest is capable of being done manually combined with both packing and sorting in one workstation. Manual harvest could also be combined with a combination of static and flexible automation for sorting and packing. Solutions for this station is further discussed in the next step. Regardless of the selected solution, clamshell punnets were the chosen sales packaging for all crops, based on their positive attributes presented in the background study. The packaged produce then requires weighing and labelling, for which automated solutions are cheap, faster than manual work, and widely commercially available. An automated station for weighing and labelling is thus seen as the best alternative overall.

Based on information in the background study, opportunities to entirely disregard decontamination operations for the crops were explored. From the pre-study, it was clear that a high level of technology was desired within the facility. Furthermore, it was acknowledged that the high technical requirements on the pre-harvest system to remove the risk of contamination was valued higher than adding a step later to handle sanitation issues. Hence it was decided that decontamination of the crops would not be needed. Instead, heightened demands on general sanitation and frequent equipment cleaning are required to avoid cross-contamination within the facility. With this premise, the crops would not require decontamination operations after harvest.

For bulk packaging, reusable plastic boxes were the most beneficial alternative, according to the background study. Plastic SRS-boxes were decided as the chosen solution. With these decisions, a picture of the main production line and the still investigated options was established and visualised in Figure 20.

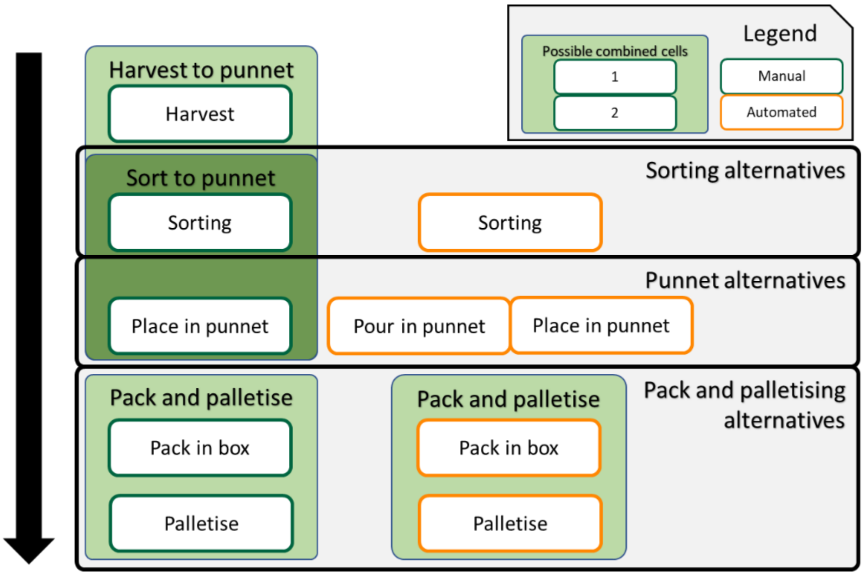

Figure 20 The options considered for the main production line

The sizes of the clamshell punnets were designed to fit the chosen size of the SRS-box most efficiently for each crop. As the green SRS-box was selected, the dimensions of the clamshell punnets listed in Table 2 were chosen best to fit the SRS-box and the dimensions of the different punnets. Additionally, the boxes are easily stacked on a pallet. An automated robot cell to handle the packing of boxes and the palletisation is further explored in the next stage. Overall, an automated solution for this station is deemed suitable and economically viable.

Table 2 Punnet dimensions for the various crops and dimensions of the selected SRS-boxes

	Width (mm)	Length (mm)	Height (mm)
Tomato punnet	100	130	70
Cucumber punnet	100	170	70
Bell pepper punnet	100	260	130
Green SRS-box	348,6	545,1	140

Additional auxiliary operations such as waste management, expedition, and storage require handling. Waste has to be handled, mainly consisting of the remains of harvested plants and low-quality crops and, to a lesser degree, debris, garbage, and damaged cultivation panels. Space also needs to be dedicated to product expedition and material storage. For these areas, rough estimates of space requirements were made. The expedition was dimensioned to have enough space to house three trucks worth of pallets. Storage was primarily allocated a minimum size area to facilitate a few days of production, but its size was considered flexible and could be expanded to larger areas to ease logistics if the opportunity arises. However, this extra space was not seen as crucial.

In the next step, the workstations were developed in detail, and the last alternative solutions were chosen and dimensioned. To extensively examine the possibilities of developing customised solutions for the supposed crops and quantities, manufacturers of sorting and packaging machines were contacted. However, catalogue solutions for these operations were instead used in the system's conceptual design due to low interest from the manufacturers. Automated packaging solutions for cherry tomatoes and mini cucumbers are available on the market and could be packaged by the same machine. However, automated solutions for bell peppers would require another method of packing. The background study suggests smaller industrial robots as the best suited automated solution for bell peppers. However, with the low volumes planned for bell peppers, the investment cost of an industrial robot with very low utilisation is not justifiable. As was shown in the background study, sorting and packing are easily done during manual harvesting with minimal extra effort for the harvester. This information led to the conclusion that investing in automated sorting solutions before harvesting had been automated would not be economically justifiable. A combined workstation with harvest-sorting-packing was therefore decided as the best alternative. However, this workstation must be easily upgradeable for full automation when automated solutions are found for harvesting operations and increasing production pace.

The station for packing and palletising SRS-boxes was developed based on smaller industrial robots of SCARA, Delta, or cartesian variety for packing punnets into SRS-boxes. An articulated industrial robot would then palletise the filled SRS-boxes. Based on conceptual systems presented by ABB and FANUC, a rough sketch of a robot cell could be drawn and is shown in Figure 21. The cell was equipped with pallet and SRS-box dispensers to minimise the need for upkeep. These dispensers are widely available on the market, and approximate characteristics were chosen as benchmarks for dimensions and capacity.

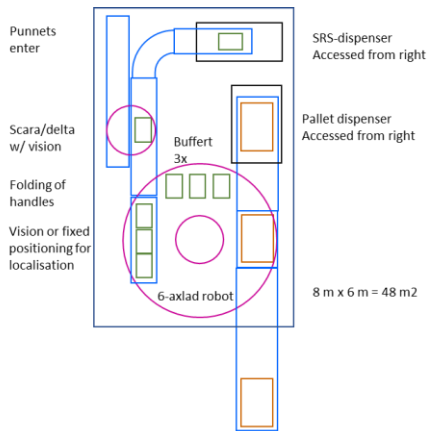

Figure 21 Rough sketch of the pack-palletise cell

To dimension the stations, the developed capacity calculator tool was utilised. As a first step, the cycle times for each activity needed to be estimated. For the manual stations, a simple time study as depicted in Olhager (2015) was done. The time study was conducted by placing cherry tomatoes in a simulated bush and measuring the time to fill a punnet. The process involved picking an empty punnet, picking the tomatoes, and sorting out products with signs of low quality. The time study did not consider the worker's experience or standard deviation of product quality. The time study aimed to gain a rough estimate of harvest-sorting-packaging times. For the packing-palletising cell, commercially available information from the robot manufacturers was used as a basis for a conceptual system cycle time.

The number of operators needed for each workstation was estimated with the capacity calculator tool. For phase one, eight operators were assessed to be needed in the harvest-sorting-packaging station and based on information from manufacturers, a sketch of the workstation could be drawn up, shown in Figure 22. For phase two, the harvest operation is expected to be automated, as are sorting and packaging. In phase two, packaging the SRS-boxes requires another Delta robot to handle the increased production rate. The cell was therefore suited for this expected expansion. Moreover, the articulated industrial robot is expected to have a low relatively utilisation level throughout both phases.

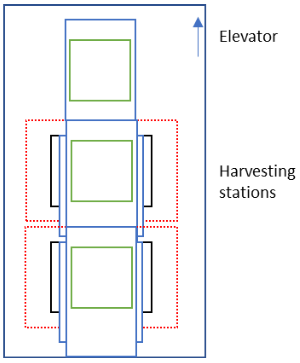

Figure 22 Sketch of the harvest-sort-pack workstation

With this constellation of the PHS, the first station will have the highest utilisation level; from there on, the utilisation level will decrease with each station. This setup creates a pull throughout the system, which alleviates production planning and removes the need for buffers. Another crucial aspect of decreasing utilisation in the later stations is faster lead times, which is vital when handling fresh produce.

Specifying design

The efficient layout tool used for the specifying design was, for the most part, done collaboratively by the researchers and the case company. The steps followed the six stages originally created by Muther and Wheeler (1977). Step one of the layout tools required input from the case company on which functions are necessary for the PHS. Auxiliary and adjacent functions such as storage, planting and initial growing room were also disclosed. Each of these was listed in the relationship chart. With all the functions in the facility known, the researchers filled in the proximity value each function has with all other functions.

The crop flow is the most important relationship, especially when handling the cultivation panels, as these require broad and delicate conveyors, and SRS-boxes and pallets, as these require frequent handling. The second most crucial type of relationship involves the material flow. The material flow consists of transporting material required for production, such as empty panels, punnets, et cetera. The results are shown in Appendix 1.

Step two required data on the planned facility's and function's dimensions and requirements taken from the specification document. The results are shown in Appendix 2. The researchers completed the first draft of steps three and four without the case company, as the data required for these steps were already readably available. A relationship diagram was first drawn, as shown in Figure 23, including all functions and their respective relations. From this diagram, four rough versions of a layout are designed using the dimensions of the facility and the rough drawing of each function from step two. The results are shown in Appendix 3. The diagram and alternative designs were then reviewed and complemented in a meeting with the case company.

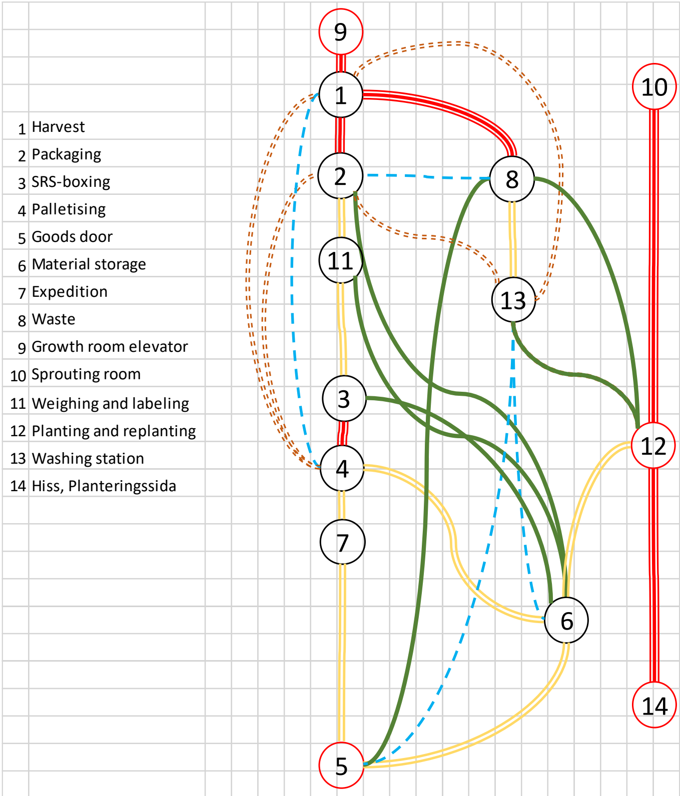

Figure 23 Relationship diagram

Step five highly involved the case company in creating and deciding the evaluation points for the PHS facility layout. Deciding on the evaluation factors for the alternative designs involved multiple iterations collected through a meeting and continuous correspondence with the case company. Once the factors were decided, they were given values of importance ranging from ten to one. The most important factor was decided to be *readiness for phase two*, and it was given ten as a value as described by Muther & Wheeler (1977). The remainder of the factors were then given a value relating to its importance compared to *readiness for phase two*. Each alternative layout design is evaluated after that based on how well it handles each evaluation factor.

This step showed that alternative C possessed the highest ranking after multiplying each factor's value with the alternatives handling score. Alternative C was then brought into step six. In this step, the rough layout was given greater detail, as shown in Figure 24. Little effort was put into the finalised drawing as the project was based on a theoretical facility and little insight was to be gained from more work.

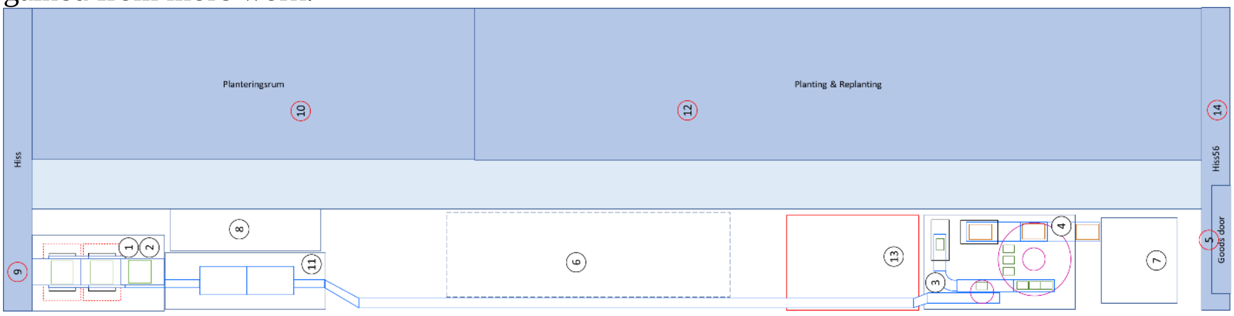

Figure 24 The highest-ranking Layout, alternative C, drawn up in more detail.

4.3.4. *Support evaluation*

The evaluation of the support tools was conducted as the final step of this study. Each of the support tools is evaluated through a reflection questionnaire, where each support tool had a similar set of questions. The support evaluation form can be seen in detail in Appendix 6. Because of the difference in the tools aim, use, and result, the evaluation questions varied in the formulation, but the content remained the same; to evaluate the tools ease of use, usefulness and possible improvement. This section contains the key takeaways of the evaluation and then an analysis of the overall performance of the support. The analysis aims to see if outstanding issues need to be fixed through a second PS iteration or if the support is ready for a comprehensive DS-II.

Usability

First off, the usability of the support tools is evaluated. The aim is to sort out what parts of the tools were easy to use and how the descriptions assisted the application. This factor measures how easy it was to grasp how the tools were supposed to be used and understand how the results were supposed to assist in the project at large.

The background study's information was overall easy to understand for the participants. As all participants had prior experience with the subject of PHS, the comprehensibility for a layman could not be evaluated. The format was logically presented and detailed enough to get a good overview.

The pre-study was also generally viewed as easy to use. The main point facilitating understanding of the interview questions was breaking down the questions into sub-questions while maintaining a certain ambiguity to elicit free discussion. However, some questions were difficult to answer and would have required additional studies or expertise in the workgroup. The gathering and understanding of rules and regulations set by government authorities or industry organisations are ongoing and was not completed during the project. The capacity calculator tool was said to be simple to apply to the planned crops and PHS concept. However, it was complicated to adapt the tool for new products or operations. Moreover, adapting the tool is particularly complex when production lines running in parallel for different crops during parts of the PHS are merging.

The material needed to create the requirement specification are the background studies material, the results from the pre-study, and the capacity calculator. These combined smoothly into the foundation of knowledge out of which the requirements specification was formed. However, complementary information was required for increased detail in the conceptual solutions. A certain amount of experience in production system development was also needed to create a detailed solution.

The instructions for the layout planning tools were helpful, and the tools proved easy to use. The visual aid assisted in making complicated relations easy to see, even without prior knowledge. However, since no existing system could be explored, the possession of prior knowledge did assist in deducing the relations of the PHS.

Relevance

Relevance was the second evaluation point for the support tools. This factor measures how well the support results could be applied to the case to achieve desirable results. The relevance of the results and how easy they were to use for the project at large were measured.

The background study had excellent overarching information but only scratches the surface of each individual process, and no benchmarking of either traditional or PF:s PHS is included as part of the support. The background study provided a momentary picture of the fast-changing technology market. Thus, the tool needs to be continually maintained to keep up with the everchanging technical solutions, which would require some academic experience or outside help.

The pre-study proved helpful as a communicative tool and a checklist over what knowledge is expected to be acquired. Competence is still required to collect valuable information, but the tool can assist in the realisation of when experience had to be acquired from external sources. Another assistance provided by the pre-study is the capturing of knowledge for future projects.

The capacity calculator tool proved extremely useful for dimensioning the workstations. Additionally, potential bottlenecks and areas where buffers would have been needed were also quick and easy to discover using the tool. The ability to modify the tool for future crops or new PHS concepts was considered very useful, but the process needs to be easier.

A complete conceptual system could be developed with a general level of detail using the results from the previous tools. Collaboration with equipment manufacturers or practical production development experience in the company would have assisted in collecting more detailed information. The increased detail level would have been especially useful for auxiliary systems such as pneumatics and foundation requirements.

There was little flexibility in placing the workstations because of the oblong and narrow facility and the mostly linear production flow sharing a single production line. However, the storage space and some support systems could be moved around and considerably affected transport efficiency. Seeing the effect on traffic along the forklift lane and conveyor belt possibilities between workstations proved helpful. This insight would not have been apparent without the layout tool. For a more complex system or facility, the visual aid was expected to have been even more helpful.

Improvements

The third point of the evaluation was potential improvements to the tools. This factor investigated possible improvements in both usabilities, such as better instructions or other mediums of providing support, and relevance, where the support could be made to provide better and more applicable support.

The background study would benefit from benchmarking. A guide for performing a simple process flow analysis or value flow analysis would be very valuable if other PHS were available for benchmarking, especially for future facilities when a first one is constructed and available for analysis. These are essential first steps when developing new production facilities to capture knowledge from existing systems to find improvement potential.

The question about stakeholders in the pre-study guide was complicated and challenging to answer without previous practical experience dealing with stakeholders as the lists can be extensive. Some additional guidance on what to consider when answering this question can assist in gaining a more helpful answer. Specifically, some categorisation of the possible stakeholders that could affect the company would potentially be helpful. Examples of guiding questions could be: "Stakeholders who can affect the company through grants or investments" "Stakeholders who can affect the business by enforcing laws or regulations?" "Stakeholders whose daily lives are affected by the company's business" or "Stakeholders who could affect the public opinion of the company".

The capacity calculator tool worked well; however, it is an Excel workbook that compromises its user-friendliness and stability. If the person using the tool does not understand the underlying links and functions, it is easy to break them mistakenly. For the calculator to achieve its full potential, it has to be coded into an application with a user-friendly interface while maintaining its versatility to be easily modified to adapt to changing conditions of the PHS. Someone without specific skills in capacity calculations or programming should be able to add new crops or create new production layouts with shared or parallel lines.

The layout tools original description come from 1977, and the implementations are done on pen and paper. While using pen and paper has its advantages, especially in its flexibility and enabling creativity, the support could benefit from a facelift into the 21st century. The tools were applied in Excel for tables and charts and PowerPoint for drawing layouts as substitute pen and paper in this study. These programs have their limitations, however, and working with them can be cumbersome. The drawing portions could especially benefit from a better method. A mind-mapping application with functionalities to create nodes and different kinds of links between them would be appropriate. It also needs the ability to reorganise nodes, modify link lines for clarity, and have filter functionalities. These functionalities could help in both creating the connection diagrams and analysing alternatives.

4.3.5. *Analysis*

The overall performance of the support was satisfactory. The project group could easily apply the guides and methods for collecting and synthesizing relevant information that was used to good effect. Many valuable insights were gathered that would likely have been missed without the guidance the supports provided. The ease of use was very satisfactory, and the supports were judged to be approachable without previous experience with production development and with only a limited knowledge of agriculture and post-harvest technology. The detailed instructions and explanations provided with each support component were handy for usability and potential for continuous improvement and development.

The relevance of the results was also very satisfactory. Just as with ease of use, the way the supports were designed to have some room for interpretation and descriptions of the thoughts behind them helped improve relevance. The slight ambiguity allowed the users to adapt the tools successfully even when circumstances not foreseen in their conceptualization occurred. Having background information included was very appreciated by the case company as the users themselves will be able to modify the tools to maintain their relevance when circumstances change.

The component designed to help to capture marketing insight through the pre-study seemed to provide relevant results. However, some minor additions could help the user understand what information needs to be gathered. Specifically, the questions regarding stakeholders were hard to work with during the case and should be clarified. Using this guide for a broader range of projects could provide further insight into providing support. As the guide was developed by researchers already introduced to the situation of the case company, there is a possibility this experience might have narrowed the guide to the specific case.

One addition that would significantly improve the support's relevance for a broader application is if the support component made for improving crop insight during the background study could be designed to help the user collect information rather than supply it. As the type of information supplied is as perishable as the crops themselves, the relevance of this component will decrease quickly. This component should also be complemented with instructions on performing process flow and value stream analysis. These tools can significantly improve the development process, and with a project team lacking in process development experience, this guidance would be of great help.

The gap between the preparatory design, where information and strategic values were gathered, and specifying design, where the layout is developed, was a challenge during the studied case. The support proved very effective at introducing the researchers to the company's plans, values, and strategies and made the process of coming up with concepts and material that could be used to make decisions together with the case company easy. However, this process was very reliant on the production development experience of the researchers and further support components to assist in filling this gap could be introduced to increase the accessibility of the support as a whole. This gap between the two *insight* and the *layout* component suggests an oversight in the reference model where the project group's development experience is not considered a factor. The capacity calculation component provided a good start at tying together and filling the gap between the two parts and was considered a very useful component for future use by the case company. The actual support provided by this tool was adjusted to fit with the case company, and adjusting it for general use is cumbersome. The intended support requires a better user interface that enables the user to easily modify the included crops and processing steps without insight into the underlying functions of the workbook. However, the actual support still passes the application evaluation for the specific case it was developed for and could be used for an extensive DS-II to perform a success evaluation.

The components aiding the specifying design successfully provided an accessible method for creating an efficient layout. The only issues found with this component were the cumbersome working methods. These could be improved significantly by including digital tools to make tables and diagrams easier to use and the graphical portions more flexible. These digital tools would make the support easier to use and allow better analysis of the relationship diagram and drawings.

The support tools combine into one conclusive method to improve the profitability of a production system. Some of the individual support components worked better than others. The component aiding the pre-study to improve a company's marketing insight worked well, and the guide was general enough to be used to its fullest and specific enough to assist in the case company. The actual support was close to original intentions, and its application to target marketing insight works well. Because of this success, the component was considered ready for a comprehensive DS-II with success evaluation.

For the support component aiding the background study to improve crop insight, there were issues regarding the actual support not living up to the expectations of the intended support. While the component was easy to apply to improve the key factor *crop insight* for this specific case, it only constitutes a snapshot of the current state of technology development which is problematic. No instructions to keep the support component up to date means it will soon become obsolete. The lack of guides to analysing existing production systems is another problem for the background study that have been an oversight for the support that became apparent when the preparatory design was to be summarised in the specification. The actual support was still applicable to this particular case when production development experience was available, and it would still be possible to do a complete success evaluation if conditions were similar. However, a second PS iteration is recommended to improve the intended support. The capacity calculation support component worked well. While the actual support is more narrow than the intended, it is still applicable for similar cases and can be adjusted for other cases with a little effort and is therefore considered ready for a complete success evaluation and a comprehensive evaluation DS-II. Overall, a comprehensive DS-II would be possible if, as previously stated, the conditions were very similar to the studied case, but as the value of such a study would be diminished by the limitations of this support component, a second iteration of PS is recommended.

While the actual support of the component for the specifying design targeting *efficient layout* lacks some of the desired user-friendliness of the intended support, it is applicable to improving the efficiency of the PHS layout. It was therefore considered ready for a comprehensive DS-II where a full success evaluation could be performed. The results of the application evaluation are visualised in Figure 25 below.

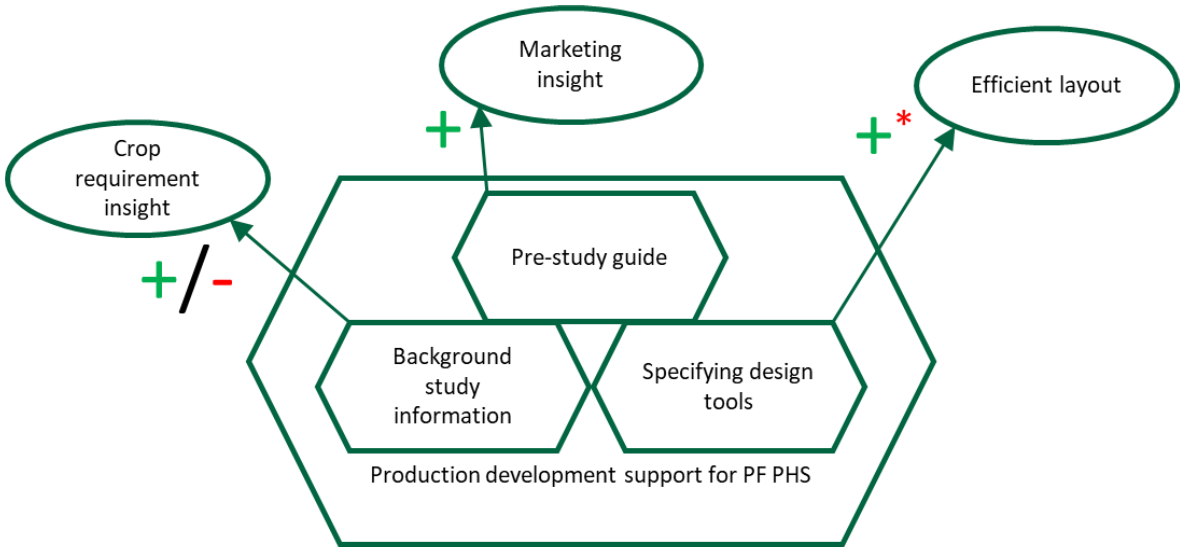

Figure 25 The results of the supports application evaluation. The components targeting market insight and efficient layout successfully improved their key factors, while the components targeting crop requirement insight only partially succeeded and should undergo a second PS iteration.

5. CONCLUSION AND RECOMMENDATIONS

This thesis developed, applied, and evaluated a set of support components to assist smaller companies in developing and designing PHS:s for PF:s. In this chapter, the research questions will be answered, and recommendations for future research are presented.

5.1. Conclusion

The project's overall aim was to use DRM to develop support for the design of PHS:s for PF:s and, in doing so, also present a method for developing similar supports for other applications and industries. By adapting a generic production development framework to a specific application, this thesis also demonstrates how other businesses could do the same to adapt the concepts of a background study, pre-study, and systematic layout planning to their unique conditions. This transferability is due to the universal importance of marketing and product insight and efficient layout planning for most producing companies.

Research question 1: *How does the farming techniques of a PF affect the requirements on its PHS as compared to traditional farming?*

The requirements on the PHS are, for the most part, similar for a PF and traditional farming, but there are some key differences. A complete comparison is provided in section 4.2.1, but the main takeaways are as follows. The year-round production enabled by CEA, the protection against contamination provided by the combination of HF and CEA and the positive effects on logistics enabled by UF reduced the requirements on the PHS. Used together correctly, they remove the need for decontamination of crops altogether, reduce the need for cooling and increases the potential for automation. A PF also put some specific demands on the PHS. The first is the increased cost of real estate that comes with UF, which increases the need for flexible and space-efficient processes. The second is the care that must be taken to ensure extra high sanitational standards throughout the PHS. This second demand naturally only applies if decontamination is omitted to capitalise on CEA and HF's advantage.

Research question 2: *How can production development methodology be applied to design PHS for a PF?*

Through the execution of this study, the use of DRM to adapt a general production development framework for the conditions of a PHS for a PF has been demonstrated. Using the principles of a PS, a set of support components were devised to assist the designer through the preparatory and specifying design stages of production development. They were then demonstrated through a case study following the principles of an initial DS-II. The use of the developed support is presented in full in section *4.3.3 Implementation,* and the process of their conception is demonstrated in section *4.2 PS*.

Research question 3: *How suitable is the application of the developed support for designing a PHS for a PF?*

The suitability of the developed support was tested using the principles of an initial DS-II, and the complete evaluation is demonstrated in section *4.3.4 Support evaluation*. Based on this evaluation, the developed support shows prospects for improving the efficiency of a PHS. The developed support proved very useful for the investigated case, and with its conditions, the application evaluation was considered a partial success. Marketing insight and efficient layout were successfully improved and indicated that the intended support is ready for a comprehensive DS-II. The support components targeting crop requirement insight needs more work to provide the intended support for other cases. Performing a success evaluation at the same case company or for a similar case could still be possible to test how well the impact model simulates the desired effects of the support on the measurable success factors. However, the value of the DS-II would increase if a second PS iteration was performed.

5.2. Future research

During this thesis, several new threads of research were discovered. Three of these are here presented as recommendations for future research.

5.2.1. *A second PS iteration*

As demonstrated during the evaluation, the support components targeting crop requirement insight failed to realise the intended support. A second PS iteration is therefore recommended. A second DS-I iteration where production development experience is considered as a factor could also be beneficial.

5.2.2. *Comprehensive DS-II*

A comprehensive DS-II includes a success evaluation is the natural next step for the developed support. However, because of the partial success of the application evaluation, a second PS iteration is recommended to be performed before the comprehensive DS-II.

During the DS I, the measurable success factors *production capacity per* m^2, *Unnecessary or over-engineered processes*, and *losses* were selected. The comprehensive DS-II has to be performed during the design and construction of an operational PHS and needs two design teams with similar qualifications where only one team uses the developed support. The first two success factors are recommended to be measured by comparing the completed plans of the two development teams, possibly using simulations to test production capacity, to measure the effects of the support. The last success factor can only be tested while the facility is in operation, and the recommended method is to construct the facility designed using the support, but then running it under conditions as close to those of the design by the other development team. This way, simulation of the conditions of the alternative facility could be measured without the need for a second control facility.

5.2.3. *More cases*

The researchers were well aware of the conditions of the case while developing the support. This bias could have affected how well the support handles other circumstances, and further case studies are therefore recommended to ensure broader applicability. Further, to promote profitable PF:s, more cases investigating ways of improving their design are recommended.

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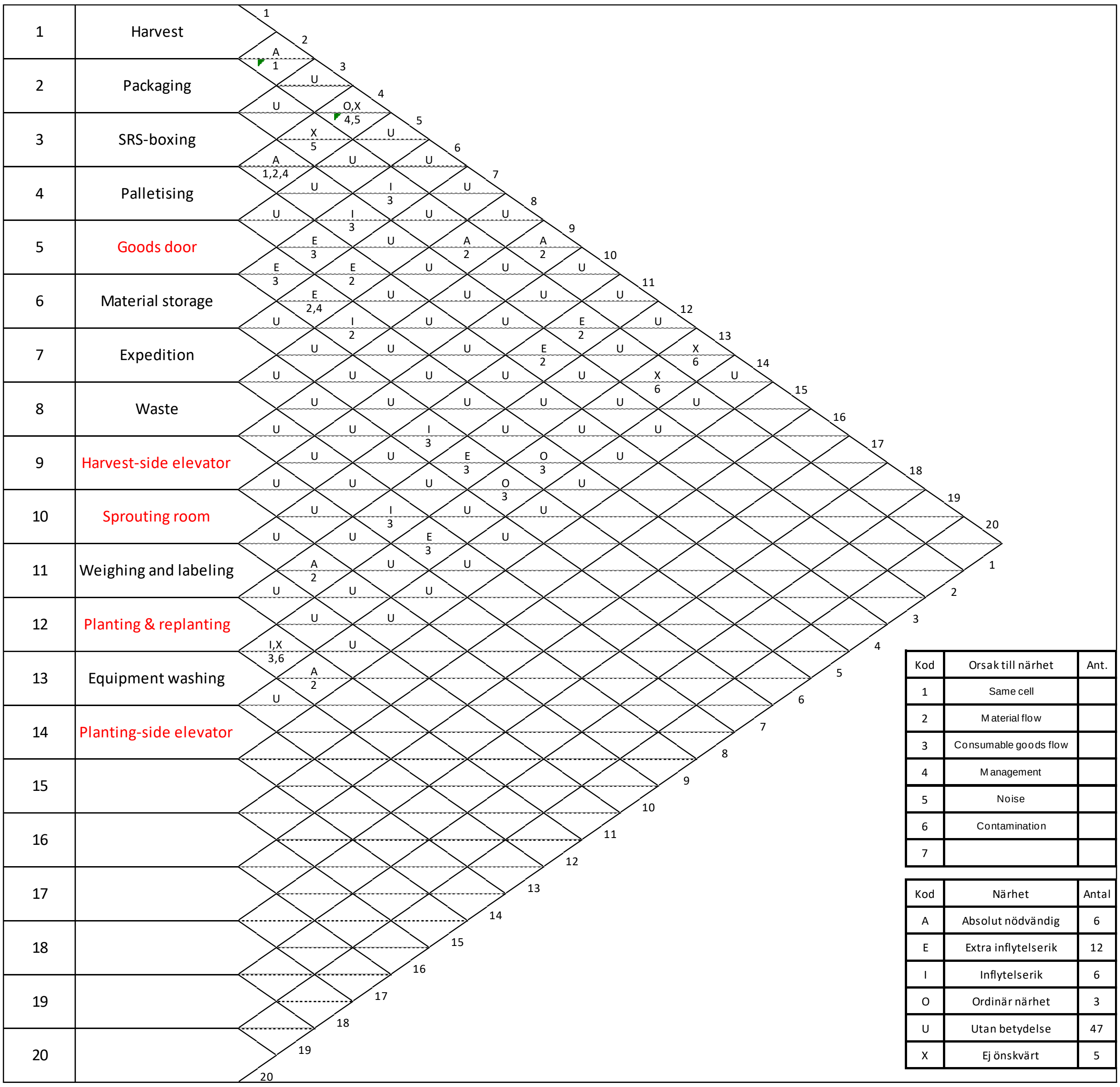
APPENDICES

Appendix 1 Connection diagram



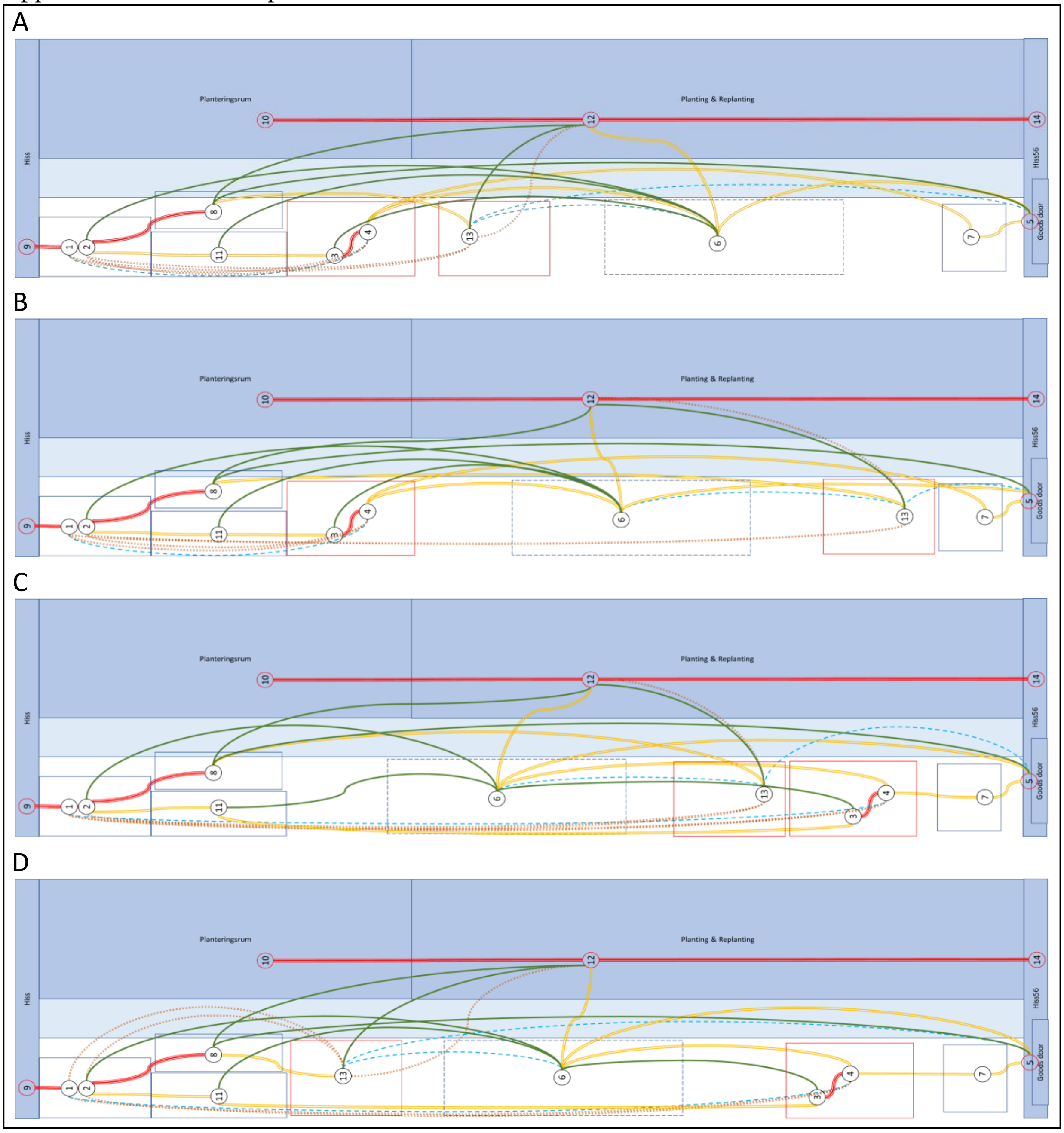
Kod	Orsak till närhet	Ant.
1	Same cell	
2	Material flow	
3	Consumable goods flow	
4	Management	
5	Noise	
6	Contamination	
7		

Kod	Närhet	Antal
A	Absolut nödvändig	6
E	Extra inflytelserik	12
I	Inflytelserik	6
O	Ordinär närhet	3
U	Utan betydelse	47
X	Ej önskvärt	5

Appendix 2 Functional requirements

Funktion		Yta totalt: 1040(65*16 m) m2	Fri takhöjd	Max takbelasning	Max golvbelastning	Minsta pelardening		Vatten och avlopp	Ånga	Tryckluft	Fundament och gropar	Brand- och explosionsrisk	Speciell ventilation		Relativa vikten av behoven: A = absolut nödvändig E = Extra inflyteserik I = Inflytelserik O = Ordinrt behov - = Ej erfoderlig
Nr	Benämning	m2	m	ton	ton/m2	m		A, E, I, O eller -							Krav på ytans form
1	Skörd	28 eller 32						A	-	-	?	-	-		
2	Packetering					3		I	-	-	?	-	-		7x4 eller 4x8
3	SRS-lådepack	40						I	-	A	A	-	-		
4	Palletering					6			-			-	-		8X5
5	Godsdörr	3													
6	Materialförråd	30		Ej relevant				-	-	-	-	-	-		Requires room for X pallets and Y shelves
7	Expedition	12						-	-	-	-	-	I		3 x 6,5 = 5x3 pallar
8	Avfall	20						I	-	-	?	-	O		4x5 eller 2,5x8
9	Hiss, skördesida	4													
10	Grodd-rum	170													8 x 25 m
11	Vägning och märkning	25				5		-	-	?	-	-	-		8,5 x 3 m eller 5 x 5 m
12	Plantering och transpla	350													8 x 40 m
13	Tvättstation	35				5		A	-	?	?	-	O		5 x 7 m
14	Hiss, Planteringssida														
15															
16															
17															
18															
19															
20															

Appendix 3 Alternative plans



Förstudie

Förstudien tydliggör vilka konkurrensfördelar som ska eftersträvas samt hur dessa ska realiseras genom att agera riktmärke inom aktuella beslutskategorier.

Genom att blicka utåt på marknaden, bedöma variationer i efterfrågan och undersöka externa intressenter identifierar och förstår vi vår ideella marknad. Genom att blicka inåt kan vi identifiera hur produkten utformas samt vilken tekniknivå och kompetens som kommer krävas inom företaget för att vi ska positionera oss på den ideella marknaden.

Det här dokumentet ska vara en guide under utförandet av förstudien och en plats att sammanfatta diskussionerna, uppfattningarna och slutsatserna från individuella delstudier. Beroende på hur omfattande delarna bedöms behöva vara kan det vara lämpligt med studiegrupper inom företaget eller med externa intressenter, marknadsundersökningar, genomgångar av styrdokument eller liknande för att samla in material. Detta dokument bör hållas levande och uppdateras när förutsättningar förändras.

I. Marknad

Att förstå marknadslandskapet är en av de viktigaste aspekterna för att kunna ta informerade strategiska och taktiska beslut. Att ständigt fokus på kundvärde är en hörnsten för lyckad marknadsföring och för det krävs att man identifierar dessa kunder och förstår hur de tänker. Det är också viktigt att känna till de andra aktörerna på marknaden och hur de differentierar sig.

a. Kunder:

Det är viktigt att kunna identifiera sina nyckelkunder och vad som särskiljer dem. Både de direkta kunderna och slutkunderna bör identifieras då deras önskemål kan variera men båda är av vikt för marknadsföringen.

i. <u>Vilka är dagens direkta kunder?</u>

I första hand lokala butiker, restauranger och kommunala verksamheter.

ii. <u>Vilka är de direkta kunderna i framtiden?</u>

Butikers centrallager.

iii. <u>Vem är slutkunden?</u>

Gemene man är målet. Det ska inte vara något pris-premium.

iv. <u>Vad för krav sätter kunderna på produktionen?</u>

Kundens krav i avtagande rangordning.

Direkta: Priset, miljöfrågor (inkl. märkning), leverans-säkerhet, -hastighet och -flexibilitet, livslängd, kvalitet.

Slut: Priset, visuellt intryck, miljömärkning, varumärke:(livslängd, miljö, smak)

b. Konkurrenter:

För att kunna placera sig på marknaden är det kritiskt att ha kännedom om sina konkurrenter och deras styrkor och svagheter.

i. Vilka är konkurrenterna?

Allt jordbruk som producerar samma grödor till ”gemene man” konkurrerar.

ii. Vilka styrkor och svagheter har konkurrenterna?

Traditionellt jordbruk: + Volym, pris. – Kvalité, miljö, låg flexibilitet.

Ekologiskt jordbruk: + Miljö, hälsa. – Pris, låg flexibilitet.

Närodlat: + Miljö, kvalité, Varumärke. – Väldigt låg flexibilitet, pris, volym.

c. Marknadsbeskrivning:

i. Vad är den beräknade efterfrågan på produkterna?

Efterfrågan förväntas vara över kapacitet.

ii. Hur förväntas efterfrågan förändras i framtiden

Efterfrågan förväntas öka stadigt.

iii. Kommer efterfrågan variera med tid, till exempel över säsonger?

Inga säsongsvariationer förväntas.

iv. Finns det möjliga framtida marknader?

Urbana center globalt, framför allt i torra och varma klimat.

II. Produkt

Frågorna kring produkter handlar om att definiera de bästa möjliga produkterna vi vill leverera. Dessa beskrivningar ska vägleda beslut i produktionen som kan komma att ha en effekt på produkterna. Det är viktigt att återkoppla till svaren på marknadsfrågorna för att säkerställa konkurrenskraft mot andra aktörer och fokus på kundvärde.

a. Produkter, produktflora och produktmix:

Vilka är de tänkta produkterna (produktfloran) och hur kan den ändras över tid? Hur stor andel av produktionen förväntas varje produkt ta upp (produktmix)?

i. Hur kan produkterna beskrivas i en mening?

”Ny generation av vardagsgrönt”.

ii. Vilka grödor ska säljas och hur ska förpackningen se ut?

Körsbärstomater, (mini-?)paprikor och minigurkor.

Förpackningarna så universella som möjligt.

iii. Vilka grödor och förpackningar kan bli aktuella i framtiden?

Bladsallat, kryddor och mer ”värdefull” frukt och grönt.

Förpackningsformer ska inte ändras regelbundet.

iv. Hur är prognosen för produktmixen och produktfloran?

Produktmixen förväntas vara stabil över en månad men kan ändras något över flera månader. Över lag förväntas produktmixen hålla sig i närheten av värdena i tabellen nedan.

Gröda	Fas 1 (kg/dag)	Fas 2 (kg/dag)
Tomat	1 500	4 500

Gurka	1 000	2 500
Paprika	500	1 000

Produktfloran förväntas inte ändras regelbundet och i första hand endast förändringar som inte påverkar produktionsanläggningen.

b. Ledtider

Detta är den tid det får det ta för en produkt att nå kunden från skörd eller order. Dessa tider är viktiga att ta i beaktning vid valet av produktionsutrustning, logistiksystem och utformning av produktionsanläggningen.

i. Hur lång tid önskas mellan order och leverans?

Små ordrar eller förändringar (kanske +-5% av kapacitet) ska gå på inom en vecka eller två.

Större ordrar eller förändringar beror på odlingstiden (en till några få månader).

Stora upphandlingar på årsbasis eller mer.

ii. Hur lång tid mellan skörd och leverans?

2-2.5h till bil, 4-5 till kund.

Max 24h till bord är ledord.

c. Konkurrensfördelar

Dessa är anledningarna till att en kund väljer våra produkter framföra konkurrenternas. Dessa ska tas fram med marknaden i åtanke, samt de kompetenser som finns inom företaget.

i. Hur differentierar vi oss från konkurrenterna?

Ett helt nytt koncept för att producera frukt och grönt miljövänligt nära konsumenterna ned miljömässig och social hållbarhet i fokus.

ii. Vilka konkurrensfördelar har våra produkter?

Finare och godare grödor, lägre miljöpåverkan och inga kemikalier. Billigt i jämförelse med ekologiskt och premiumprodukter.

iii. Vilka konkurrensfördelar har vår service?

leveransflexibilitet och förmåga att året runt kunna producera närodlat.

III. Riskanalys

Här ska de prognoser som gjorts gällande marknad och produkter granskas och osäkerheter presenteras. Det är viktigt att anpassa produktionen för att kunna hantera rimliga osäkerheter och svaren på dessa frågor ska leda valet av produktionstyp och teknikivå.

a. Produktflora:

i. Vilken osäkerhet finns i prognosen för ändringar av produktfloran?

Prognosen för produktfloran anses säker. Nya produkter kan komma att införas om möjligheter dyker upp men förändringarna förväntas inte vara nödvändiga.

ii. Hur ska osäkerheten hanteras?

Processerna ska med fördel vara någorlunda flexibla så liknande produkter kan införas om möjligheter dyker upp.

b. Volym och produktmix:

i. Vilken osäkerhet finns i volymprognosen

Volymprognosen anses säker. Stor del av produktionen sker mot långvariga upphandlingar.

ii. Vilken volymflexibilitet behövs för att hantera osäkerheter?

Dimensionera för temporär ökning med 50% men daglig variation +-15%.

iii. Kan produktmixen snabbt behöva ändras och hur ska det hanteras?

Inget yttre tryck på kort sikt då produktionen huvudsakligen sker mot längre upphandlingar men över tid ska produktmixen kunna ändras.

iv. Hur ska dessa variationer hanteras?

Produktionen ska vara så flexibel som mjöligt så att produktmixen kan ändras utan inverkan på produktionsanläggningen. Modulära lösningar som går att ställa om mellan grödor är att föredra.

IV. Teknik

Här ska den önskade teknikivån på produktionen definieras. Värderingar rörande automation, manuellt arbete, modularitet etcetera ska granskas. Svaren på dessa frågor ska göras med svaren på tidigare frågor i beaktning för att säkerställa fokus på kundvärde, konkurrensfördelar, riskhantering etcetera.

a. Teknikivå:

i. Vad är den nuvarande teknikivån?

En stor del manuellt arbete är acceptabelt men anpassat för framtida uppgradering till automation.

Ask till låda bör ske automatiskt. Undersök möjlighet för pack i ask att ske automatiskt för gurka och paprika i samma maskin. Undersök möjlighet för pack i ask av tomat att ske automatiskt. Skörd och sortering sker manuellt.

ii. Vad är framtida målet för teknikivån?

Möjlighet till full automation på lång sikt. I första hand flexibel automation som kan hantera en bred produktflora i samma produktionslina med minimala omställ. Arbetsstationerna ska i den mån det är möjligt vara anpassade för att kunna konstrueras för automation eller manuellt arbete med minimala förändringar.

Endast stödfunktioner ska behöva ske manuellt.

iii. Vilken uppgradering av nuvarande teknikivå krävs för att nå detta mål?

Avancerad vision och gripdon med känsel som kan hantera universella uppgifter krävs för skörd och för universella lösningar för sortering och pack.

iv. Finns denna teknik redan?

Flera lösningar finns på experimentell nivå men ej ekonomiskt försvarbara i dagsläget. De är ofta för långsamma och dyra för att vara applicerbara i dagsläget. Lösningar för hård (icke-flexibel) automation existerar och flera leverantörer erbjuder lösningar för produktionsvolymer i nivå med fas 2. Dessa lösningar hanterar oftast bara en enda gröda.

b. Specialisering eller generalisering:

i. Under vilka förutsättningar är det värt att ha en stor anläggning i stället för flera små?

Mål: Så låg volym som fortfarande är ekonomiskt försvarbart. Flexibla små lokala fabriker men som fortfarande har kapaciteten att producera varierade produkter.

ii. Under vilka förutsättningar är det värt att ha modulära processer?

Mål: Så modulära processer som möjligt. Skalbarhet, uppgraderbarhet och flexibilitet är målsättningar.

iii. Under vilka förutsättningar är det värt att ha universella processerna som klarar flera grödor?

Mål: Viktigt för mikrofabriker. Kan en, eller ett fåtal arbetsstationer hantera hela närområdets önskade produktflora kan man skala ner post-harvest rejält.

V. Personal

Personalen och den kompetens och kunskapsnivå de tillsammans besitter är en viktig resurs för företaget. Det är viktigt att veta vilka kompetenser som kommer behövas inom företaget för att man ska kunna producera enligt de målsättningar man angett ovan.

a. Roller:

i. Vilka roller förväntas behövas?

Operatörer som sköter skörd, kontroll och assisterar eller utför pack.

Övriga roller: Underhåll, underhållsplanering, produktionsplanering, utveckling, kvalité.

ii. Vilka kompetenser kommer rollerna behöva?

Operatörer: Inga specifika kompetenser. Grundskolebehörighet.

iii. Vilka utbildningsbehov finns?

Operatörer: Max 1v upplärning

iv. Vilka kompetenser kommer behövas tas in utifrån genom konsulter och entreprenörer?

VI. Övriga intressenter

Kunder och konkurrenter är inte de enda intressenter som kan påverka produktionen. Här nedan ska vilka intressenter som behöver tas i beaktning undersökas. Dessa är alla som av någon anledning har ett intresse för vad som försiggår på företaget, som anställda, ägare, fackföreningar, myndigheter etcetera.

a. Interna intressenter:

i. Vilka är de övriga interna intressenterna för produktionssystemet?

Anställda, ledning, ägare. Möjligen ”hållbarhetsinvesterare” men inga riskkapitalister eller vinstkrävande investerare.

ii. Hur påverkar de oss?

Anställda: Arbetsförhållanden.

Ledning/ägare/investerare: Krav på miljö och hållbarhet. Ansvar.

b. Externa intressenter:

i. Finns det övriga externa intressenter för produktionssystemet?

Myndigheter (livsmedelsverket, Jordbruksverket)

Fack och leverantörer

ii. Hur påverkar de oss?

Myndigheter: Lagar och regler för säkerhet, hälsa och miljö.

Fack: Arbetsförhållanden.

Leverantörer: Frön, förbrukningsvaror och förpackningar. Kan ha krav på upphandlingar för framtiden med säkra prognoser. Våra krav på dem: Hållbarhet och spårbarhet.

Appendix 5 Capacity calculator

Fyll i målvärdet för önskat antal kg per dag och askstorlek.
Antal grödor per ask kan fyllas i för att få antal enskilda plock per dag.
- Grå rutor räknas ut automatiskt och ska inte röras.
- Flera av uträkningarna är beroende av namnet på grödan och stavningen är viktig för att kopplingen ska fungera.

Gröda	Fas 1 (kg/dag)	Fas 2 (kg/dag)
Tomat	1500	4500
Gurka	1000	2500
Paprika	500	1000

Önskad produktion:

Gröda	kg/dag	askstorlek (kg)	Antal grödor per ask	ask/dag	Grödor per dag
Tomat	1500	0,25	20	6000	120000
Gurka	1000	0,5	11	2000	22000
Paprika	500	0,5	3	1000	3000
Total	**3000**			**9000**	**145000**

Fyll i de antal askar som ryms i lådor, och lådor som ryms på pallar.

Packstorlekar:

Gröda	ask/srs-låda	srs-låda/pall
Tomat	24	28
Gurka	18	28
Paprika	6	28

Uträkning av de dagliga behoven av de olika enheterna.

Dagligt behov:

Gröda	Grödor/dag	kg/dag	Ask/dag	SRS-låda/dag	pall/dag
Tomat	120000	1500	6000	250,0	8,9
Gurka	22000	1000	2000	111,1	4,0
Paprika	3000	500	1000	166,7	6,0
Total	**145000**	**3000**	**9000**	**527,8**	**18,8**

Efter utförd eller uppskattad tidsstudie, mata in stycktiden (bearbetningstiden per enhet) för en operatör eller maskin för vardera station.
Markera uppskattade tider med röd text.

Tidsstudie:

					Total bearbetningstid		
Gröda	Skörd i ask (s/kg)	Skörd i ask (s/ask)	pack i låda (s/srs-låda)	pack på pall (s/pall)	Skörd i ask (s)	Pack i låda (s)	Pack på pall (s)
Tomat	112	28	48	280	168000	12000	2500
Gurka	40	20	36	280	40000	4000	1111
Paprika	30	15	12	280	15000	2000	1667

Ange timmar av produktion per dag.
Under ges den högsta (genomsnittliga) cykeltiden för de olika stationerna för att nå dagliga behovet. Dessa kan användas som riktmärke men individuella cykeltider för varje gröda ges längre ner

Medelcykeltid:

Produktionstimmar/dag:	8
Enhet	**s/enhet**
kg	9,6
Ask	3,2
SRS-låda	54,56842105
Pall	1527,915789

Totala bearbetningstid som krävs för att nå målvärdena för varje station samt minsta antal operatörer/maskiner som krävs för att komma upp i den bearbetningstiden på det angivna antalet produktionstimmar per dag.

Värde	Skörd i ask	pack i låda	pack på pall
Total bearbetningstid:	223000	18000	5278
Min antal Op. el. mskn.	8	1	1

Tabellen nedan visar den resulterande cykeltiden för de angivna antalen operatörer/maskiner ovan. Tabellen visar även hur stor andel av produktionstimmarna som behövs för resp. produkt samt hur mycket produktionstid som blir över.
Som riktmärke bör totaltiden vara som högst för första stationen för att skapa sug genom systemet och undvika behov av buffertlager. Ökar tiden nedströms markeras cellen gul.

Cykeltider och produktionstid

Gröda	Skörd i ask Cykeltid	Skörd i ask Totaltid (s)	Skörd i ask % av dagen	Pack i låda Cykeltid	Pack i låda Totaltid	Pack i låda % av dagen	Pack på pall Cykeltid	Pack på pall Totaltid	Pack på pall % av dagen
Tomat	3,5	21000	72,9%	48	12000	41,7%	280	2500	8,7%
Gurka	2,5	5000	17,4%	36	4000	13,9%	280	1111	3,9%
Paprika	1,875	1875	6,5%	12	2000	6,9%	280	1667	5,8%
Tid över:		**0 h 15 m 25 s**	**3,2%**		**3 h 00 m 00 s**	**37,5%**		**6 h 32 m 02 s**	**81,7%**

Tabellerna nedan kan användas för att manuellt ange antalet operatörer/maskiner och procent av produktionstiden för att experimentera med egna lösningar.

Ange antalet operatörer eller maskiner för vardera station i första tabellen. Under visas de resulterande cykeltiderna med det antalet operatörer eller maskiner.

Ange andelen av produktionstiden som dedikeras åt vardera gröda i andra tabellen för att få ett målvärde på cykeltiden. Detta målvärde kan då jämföras med cykeltiden ovan för att se om antalet operatörer/maskiner räcker.
Obs: uträkningar baserade på "timmar per dag" och "dagligt behov" ovan

Total arbetstid per gröda och steg:

Antal op el. mask	8	8	1	1
Gröda	**Skörd i ask (s/kg)**	**Skörd i ask (s/ask)**	**pack i låda (s/srs-låda)**	**pack på pall (s/pall)**
Tomat	168000	168000	12000	2500
Gurka	40000	40000	4000	1111
Paprika	15000	15000	2000	1667
Total	**223000**	**223000**	**18000**	**5278**

Målvärden baserat på % av plock:

						Balanseringsförlust			
gröda	s/kg	s/Ask	s/SRS-låda	s/Pall	% av tid	Ask	SRS-låda	Pall	
Tomat	14,0	3,5	84,1	2354,7	73,0%	0,1%	31,3%	64,3%	
Gurka	5,0	2,5	45,1	1263	17,4%	0,0%	3,5%	13,5%	
Paprika	4,0	2,0	12,1	339	7,0%	0,5%	0,1%	1,2%	Medelförlust
Tid över:				**Tid över:**	**2,6%**	**0,6%**	**34,9%**	**79,1%**	41%

Utvärdering av hjälpmedel

Dessa frågor är till för att utvärdera de hjälpmedel som har tagits fram för att underlätta utformandet av efterskördssystemet för en växtfabrik. Läs igenom det material (instruktioner etc.) som finns för varje hjälpmedel, samt resultaten (ifyllda mallar, ritningar etc.) innan frågorna svaras på.

Bakgrundsstudie

- Hur relevant är informationen från bakgrundsstudien för utformningen av post-harvest systemet till exempel genom kravspecifikationen?
- Hur enkelt är det att ta till sig information från bakgrundsstudien, och hur man kan använda den för utformningen av post-harvest systemet?
- Är det någon information som saknas nu eller som dök upp senare i projektet men borde ha samlats in under bakgrundsstudien?
- Är det någon information som känns irrelevant eller svårbegriplig?
- Är det någonting annat som hade kunnat gjorts bättre? T.ex. hjälpmedel eller verktyg
- Är den här informationen något som du skulle kunna använda i framtida projekt? Varför eller varför inte?
- Övriga kommentarer

Förstudie

- Hur relevanta är frågorna för att vägleda insamlandet av rätt information?
- Hur enkelt är det utifrån frågorna att förstå vilken information som ska samlas och hur man ska gå till väga för att hitta informationen?
- Är svaren från förstudien användbara för resten av projektet, till exempel utformandet av kravspecifikation?
- Är det någon information som saknas nu eller som dök upp senare i projektet men borde ha samlats in under förstudien?
- Är det någon fråga som kändes irrelevant eller svårbegriplig?
- Är det någonting annat som hade kunnat gjorts bättre? T.ex. hjälpmedel eller verktyg
- Är den här guide något som du skulle kunna använda i framtida projekt? Varför eller varför inte?
- Övriga kommentarer?

Kapacitetsverktyget

- Hur enkelt är kapacitetsverktyget att använda?
- Hur relevant och användbart är resultatet från kapacitetsverktyget?
- Är det någon information som saknas som kapacitetsverktyget borde räkna ut?
- Är det någon information som känns irrelevant eller svårbegriplig?
- Är det någonting annat som hade kunnat gjorts bättre? T.ex hjälpmedel eller verktyg
- Är det här verktyget något som du skulle kunna använda i framtida projekt? Varför eller varför inte?
- Övriga kommentarer?

Specifikation

- Är mallen för specifikationen enkel att förstå och använda?
- Är informationen från bakgrundsstudien och förstudien tillfredställande för att formulera specifikationen.
- Är någon del av mallen otydlig med vad den ska innehålla?
- Är någon del av mallen irrelevant eller överflödig?
- Fanns det något i mallen som saknades eller kunde bli bättre?
- Är den här mallen något som du skulle kunna använda i framtida projekt? Varför eller varför inte?
- Övriga kommentarer?

Lokalplanering

- Är verktyget användbart för att ge relevant information?
- Hur lätt är verktyget att använda?
- Är resulterande layout tillfredställande?
- Är det något som saknas eller kan bli bättre?
- Är det något som känns irrelevant eller svårbegriplig?
- Är det här verktyget något som du skulle kunna använda i framtida projekt? Varför eller varför inte?
- Övriga kommentarer?