AUTOMATION SYSTEM GROUP

PROJECT NAME	SMARTHORT AUTOMATION CHALLENGE
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FEASIBILITY STUDY

VERSION	0.2
DATE	03/12/2019

1. Document Control

1.1 Document Information

	Information
Document Id	ASG-AHDB-FeS01
Document Owner	Ronald Pfeng L.
Issue Date	03/12/2019
Last Saved Date	03/12/2019 15:43
File Name	WMG Feasibility STUDY SMARTHORT AUTOMATION CHALLENGE V4.docx

1.2 Document Change History

Version	Issue Date	Changes
0.1	03/12/19	Draft version
0.2	03/12/2019	Preliminar
0.3	03/12/2019	Final report

1.3 Document Approvals

Role	Name	Signature	Date
Head of ASG	Robert Harrison		
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1.4 *Glosary of terms*

Acronym	Name	Description
AHDB	**Agriculture and Horticulture Development Board**	
AGV	**Automated Guided Vehicle**	**Mobile robot that follows markers or wires in the floor, or uses vision or lasers. They are most often used in industrial applications to move materials around a manufacturing facility.**
DEFRA	**Department for Environment, Food & Rural Affairs**	**UK government department responsible for safeguarding the natural environment, supporting our world-leading food and farming industry, and sustaining a thriving rural economy.**
NPD	**New Product Development**	**Process of bringing a new product to the marketplace.**
QFD	***Quality Function Deployment***	**Structured approach to defining customer needs or requirements and translating them into specific plans to produce products to meet those needs**
VoC	**Voice of Customer's**	**Is the term to describe these stated and unstated customer needs or requirements.**
VoS	**Voice of Stakesholder's**	**Is the term to describe these stated and unstated stakeholders requirements.**

2. General information

2.1 Project name

SmartHort Automation Challenge

2.2 Background

The SmartHort Automation project includes the analysis the production process cycle to identify in which areas automation should be necessary to design and implement, in order to optimise the production processes in horticulture companies. Also, project implementation considered to implement and setup AGVs to help to transport, stack and laying out the products trays within the green house lines, according to AGVs capabilities required to develop specific tasks.

On the other hand, the boundaries are defined by technical specifications regarding the production cycle process in term the logistic analysis, infrastructure such as the conditions of the roads and routes through which the AGVs must travel, power supply, environmental conditions and technical specification about the automation systems deploys to develop all tasks predefined.

In addition, these limits must be analyzed in detail to be able to establish viable solution alternating according to the scope of the project and its financing. Thus, deliver the best product in terms of design, capabilities and performance to meet the production cycle of each company.

2.1 Essential scope.

The essential scope of the project is to identify, design, develop and integrate specialized technical means in the area of automation to support the production cycles of three horticultural companies.

Therefore, this initiative includes the financial support from the Agricultural and Horticultural Development Board and the High Value Manufacturing Catapult, with an in-kind collaboration with WMG-Automation System Group.

2.2 Typology of the project

The typology of this project is to complement and integrate the automation know-how and capabilities of the Automation System Group from WMG within the horticulture scenario according to the employment of automation systems with the main benefit to improve the production cycle of three horticulture companies.

2.3 Organizations involved

- Agriculture and Horticulture Development Board.
- Warwick University – WMG – Automation system Group.
- High Value Manufacturing Catapult.
- Crystal heart Salad Company.
- Valefresco Company.
- WD Smith & Son.

3. Methodology

This project is based on the new product development methodology,including data collection, communications, control and management. This methodology follows five stages from new product idea, design, implementation, testing & validation and final delivery detailed in Apendix 1.

The idea stage of the new product begins by obtaining the voice of the customer (VoC) obtaining the current problem to solve and their expectations in order to determine their needs and problems which may lead superior ideas (Kahn, 2013), and also require the voice of the stakeholder (VoS) where the scope, financing, and contract are defined,Fig. 1.

However, as part of this stage there are some uncertainties regarding the current status of the companies and how their production processes are executed. Therefore, a feasibility study is required that covers the following general aspects:

a) Problem definition and objectives
b) Process analysis and mapping
c) Preliminary specifications
d) Conceptual design
e) Busines case

In addition, the conceptual design represents a key part of the feasibility study by developing virtual models regarding the solution required for each company.

Thus, the virtual design model engages the customer and stakeholder and provides a preliminar overview about the solution attempted to develop.

The design stage require the AGV system requirements and specifications according to the current process analysis, also a market analysis is required as to guide to the team project to proceed to the new product design (Kahn, 2013). Also, the market analysis is an attempt to find all available solutions that meet the system specifications within the AGV market.

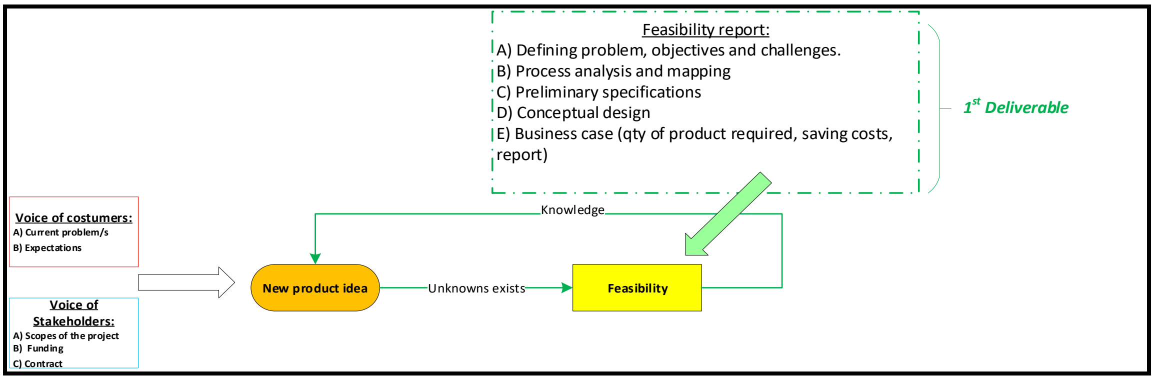


Fig. 1 Methodology stage 1

At the development stage, a quality function deployment (QFD) methodology will be adopted the analyse the requirements and transform them into specific plans to achieve the customers needs (VoC). Also, in the first level of the QFD, the performance specifications will be transformed into systems and subsystems to define acceptance criteria, and thus break up the deployment part into components and features in a second level. Thus, to be able to review the market options to determine the costs which will be presented in “NPD Phase I” with the main objective to present the second deliverable which will include the following aspects:

a) Final product design.
b) Financial report (ROI (%), payback).
c) Technical report.

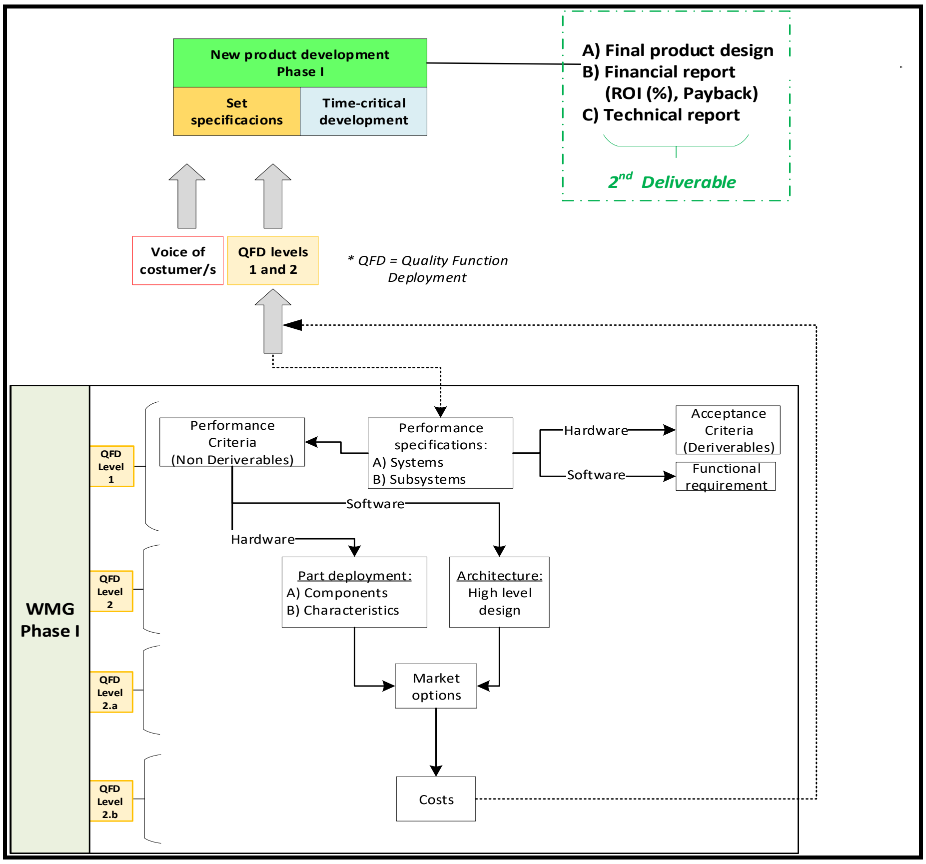


Fig. 2 New Product Development (NPD) Phase I

Furthermore, by the end of the feasibility study, the report present the main findings regarding the problem detected, objectives, current process, conceptual design and business case. This represents the first deliverable of the project, and thus determine future investments required to move to the development and implementation stage.

3.1 *Objectives*

The feasibility study objectives should form the baseline to proceed with the next project phases, in order to:

- Analyse the current production cycle from the companies, with the focus on determine the future scenario for automation systems.
- Identify commonalties and differences amongst the usage scenarios to help specify and later develop a base-level solution potentially applicable in a wide range of similar businesses.
- Create a concept design for each alternative solutions.
- Determine the most suitable AGV.
- Develop a business case for the solution selected.

4. Feasibility study work breakdown structure

The work breakdown structure is a deliverable oriented approach with an hierarchical descomposition of the work to be carried out by the project team with the aim to accomplish the feasibility study objectives and create the required deliverables.

Moreover, the work breakdown structure will follow the main task and deliverable that started with the Automation challenge in March 2019, distributing the key stages such as the kick-off meeting with the companies, and to produce the productions cycle analysis of each company.

In addition, consider yhe development of the market overview to to identify any automation solutions available in the market to satisfy the company requirements in order to improve their production cycle. Also, include the concept design development according to the fuctional requirements and production process analysis.

Finally, a final report wil be developed and delivered to the AHDB in order to present the results regarding this feasibility study. Also, include a detailed description about the following project stages with the main focus on achieving the project objectives in detail and develop a first prototype.

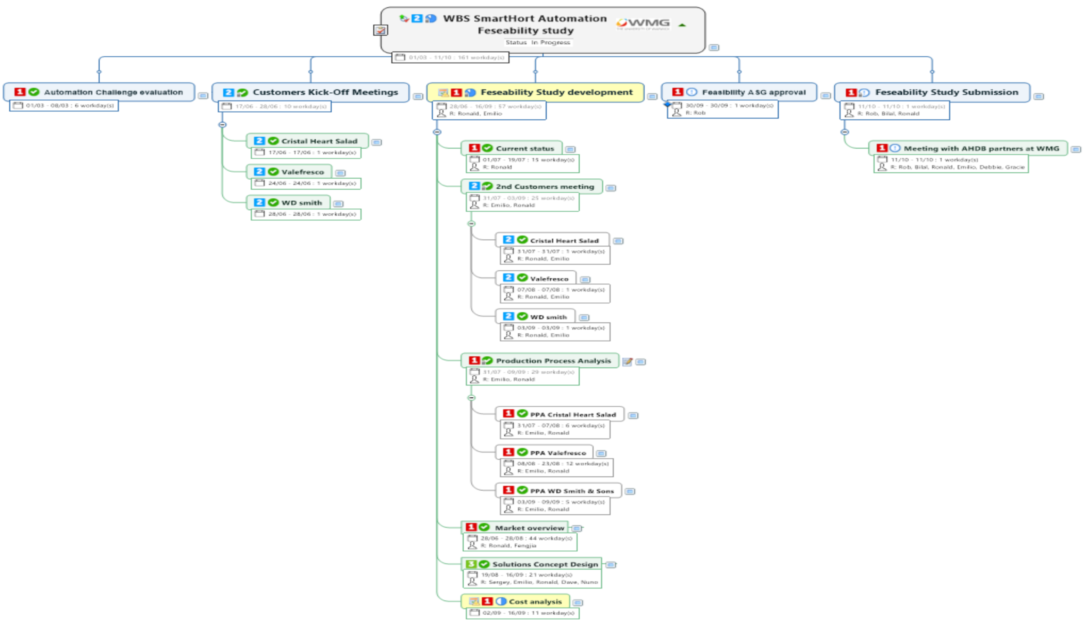


Fig. 3 Feasibility study Work Breakdown Structure"

5. Technical analysis

WMG and AHDB are working in collaboration with Crystal Heart Salad, Valfresco, and WD Smith on the Automation Challenge project to provide a form of autonomous guided vehicles (AGVs) suitable for the many fetch-and-deliver or perform tasks within a set of time frame (Llopis-Albert, Rubio and Valero, 2019), in order to achieve the logistics processes commonly required by plant-growers. The aim is to transform on-site labour-intensive manual logistics into autonomous logistics. This will enable human resources to focus on value-added aspects of the businesses rather than spending time on non-value-added tasks.

In the first phase of the project, WMG and AHDB visited the three selected businesses to conduct an on-site technical feasibility study to deploy AGVs in greenhouses bay to transport plants between locations at various stages in their grow and dispatch.

The typical task involves collecting and delivering trays of plants to and from different areas in order to support their growth in both indoor greenhouses and outdoor areas.

However, the surfaces these robots should travel over are not perfectly flat, they are generally either rough concrete or compacted earth with a plastic covering. Also, the automated systems require an investment effort from the companies to improve the traveling roads for the AGVs, in order to achieve this requirement we need to conduct an intensive analisys in the next project stages.

This project aims to define the configuration of an applicable AGV in terms of the basic robotic platform and suitable attachments to enable it to be used generally in this application domain. Thirteen off-the-shelf solutions that are currently used in manufacturing and agriculture sector, including MiR, Adept, Low Pad, HV 100, RB-Sherpa, Warthog and Thorvald, have been reviewed to assess their suitability for carrying out the logistics operation for the usage scenarios at the three project partner sites.

Aditionally, in term of costs the project is aiming at a baseline price of £80-110K per AGV. This cost line is based on commercial AGVs used in industrial environment with minimum necessary functions that are simple to deploy and produce in volume.

Our preliminary results show that the existing solutions available in the market will need to be significantly modified to adapt to the use-case scenarios. In parallel to the technical feasibility study, WMG is also conducting an economic feasibility study aimed at understanding the business case of the three use-cases in order to assess the potential impact on productivity, expected deployment cost, and the likely return on investment. Therefore, this initial cost analysis will be stated within this document in the financial analysis chapter.

Due to the significant customisation required for each use case, we envisage looking at one application in terms of AGV in physical form but will trial application scenario at more than one grower. The next phases of the project will involve understanding the functional requirements for each scenario, critical technical review the state of the art, and looking at commercially available robots and subassemblies to allow considerations of whether to buy or build the system and its subassemblies.

Subsequent work is likely to include optimising the design of the system, involving suitable partner technology companies, consideration of the business case, health and safety considerations, and implementation and testing against a suitable use-case with the selected growers.

5.1 Problem detected

According to the analysis of the current situation of each company and how its production processes are executed and how a solution should be incorporated in terms of automation. Thus, some limitations can be identified in advance that should be analyzed during the present feasibility study. in this way, although they are companies within the horticultural sector, they present different production processes which imply different requirements bases that allow the identification of the following problems which will be analyzed later.

In the case of Crystal Heart Salad, the problem detected is derived in two main components. First, there is the need for ***"Improving the tray's transport cycle reliability at layflat room, greenhouses and / or hardening off area"***, and second, the need for ***"Increasing flexibility and versatility of the operator's utilization in order to allocate them in other productive activities"***.

In this context, it can be established as a goal to be achieved for this company, the moving batch of trays from to hardening off to despatch area. This can be done under the following considerations:

- **Automation + Manual = AGV + Forklift drivers**

  AGV moves batches (pull) from lay flat room to greenhouses and drivers help to organize trays on the ground.

- **Automation + Automation = AGV only**

  AGV moves and unload batches of trays on the ground. AGV will do the same of what forklifts do currently.

In the case of Valefresco, the problem detected is mainly derived from the need to ***"Use people only to sow and harvest in order to avoid wasting time of unnecessary movements to obtain empty boxes and deliver full boxes to the freezer"***. In addition, it can be established as an objective to be achieved for this company as:

- **To transport the full trolleys to refrigeration room.**
- **To bring empty boxes to the production line.**

Finally, for WD Smth & Sons the problem detected is based mainly on the need for ***"Reducing the queue at the production line area as trolleys are waiting long time to be loaded and dispatched to greenhouses, and delivery empty trolleys to production area avoiding bottlenecks"***.

In addition, it can be established as an objective to be achieved for this company as:

- **To get products from the glasshouse door to be manually taken in and laid out while the vehicle returned empty trolleys to the production area to be used again.**

5.2 Production process mapping and analysis

The production process analysis aims is to identify the key stages within the production cycle of each companies to introduce automation and to determine the commonalities and diferences between each production processe. Also, this analysis should help to determine the production capacity between high and mid-season from each company, including the transport time and their optimal routes.

However, all of this data collected in the 2nd round of meetings had the purpose of doing the following:

- To carry out an exhaustive analysis of the productive processes in relation to the transfer times, man-hours involved, travel distance.
- To simulate and obtain quantitative data in relation to the specific amount of AGVs required in order to achieve the production volumes for each company.

5.2.1 Crystal Heart salad production cycle analysis

Crystal Heart is located in Brough - East Yorkshire. They produces trays with lettuce's seed that are sent through lorries to costumers. The following figure shows the company's production processes:

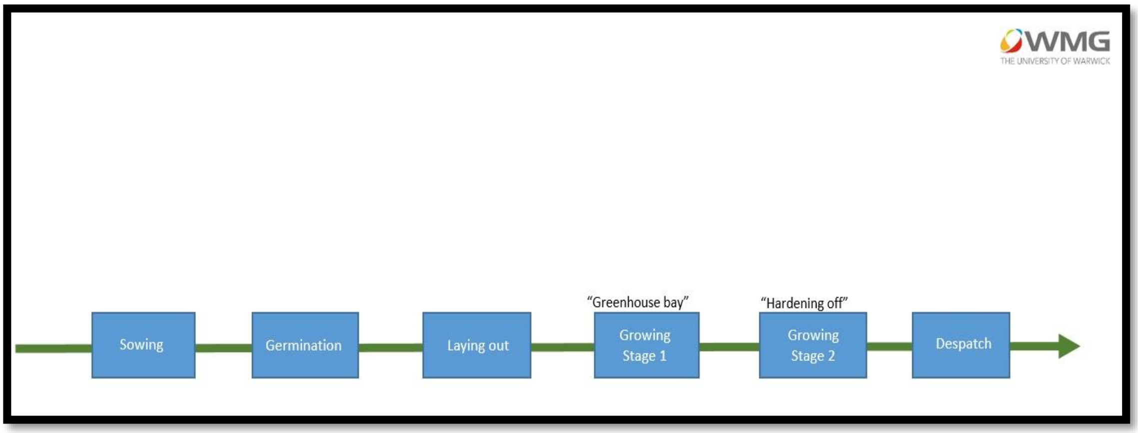


Fig. 4 *Crystal Heart Salad processes*
(Own elaboration)

(Please see appendix III the detailed activities of the processes indicated in figure above).

The objective of the "Sowing" process is to fill trays with both compost and seeds. Then, trays can be stacked and delivery to next process. "Germination" process is oriented to make seeds stronger by germinating seeds during three days. Afterward, trays are moved to "Laying out" process in order to unstack and laying them in a layout of 6 x 5 trays (01 batch of trays). Once a batch is ready, a forklift driver takes a batch with a special structure and places it on greenhouses. Trays are layed out and growing for 10 days on greenhouses before being moved outside by forklift (Hardening off process). Also outside trays spent 10 days before be moved to "Despatch" area. Finally, a forklift moves trays (batch) from hardening off to the delivery area where operators stack trays on pallets manually (85 trays per pallet).

Across the processes is possible to identify different opportunities of automation. The following figure shows the potential areas to improve:

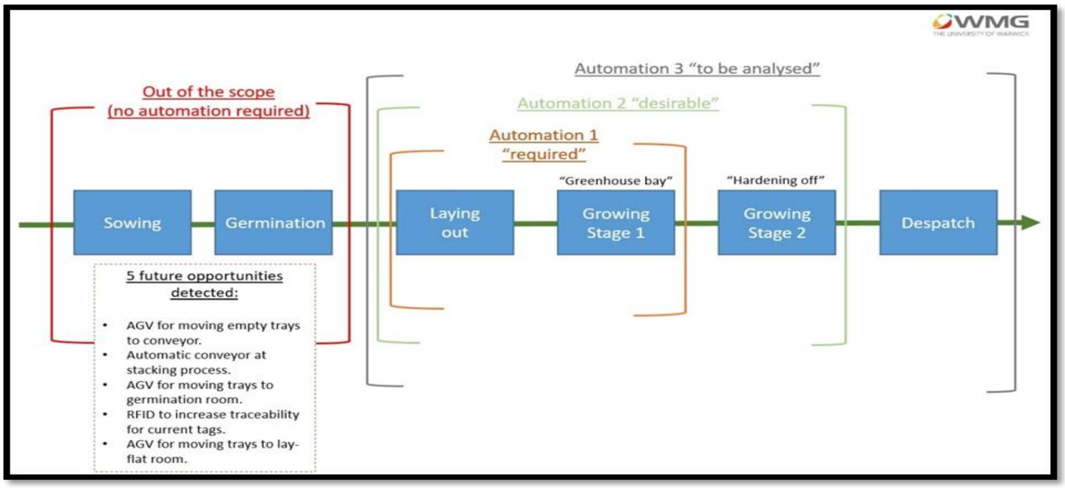


Fig. 5 Automation detected in Crystal Heart Salad's processes (Own elaboration)

The processes where divided in 4 groups: **"Out of scope", "Required", "Desirable" and "To be analysed"**.

The **"out of scope"** automations are not part of the current study. Nevertheless, **"Recommendation"** heading mention the future opportunities detected at the end of this document.

"Required" it refers to the main requirement under the company's perspective. This automation includes the process of *"Laying out"* and *"Growing stage 1 (greenhouse)"*.

Automation 2 is "desirable" as the process of "Hardening off" uses the same resources and procedures as . The option to include it was decided after analysing the preliminary results.

Automation 3 "To be analysed" was discarded to be included as part of the final solution, because this process execute different procedures to achieve its tasks.

As an example, an operator in the **"Despatch"** process need stack trays 2 meters high. This task does not happen on **"Greenhouse"** and **"Hardening off"** processes.

Therefore, the automation to be analysed will be applied directly to **"Laying out"**, **"Greenhouse"** and potentially to **"Hardening off"** processes. The integration of "Hardening off" process will depend on the critical increment of the quantity of AGVs, based on the total utilisation of the AGV and the final process's throughput expected.

5.2.2 Valefresco production cycle analysis

Valefresco is located in Hampton Lucy – Warwickshire. They produce hydroponic lettuces that are sent through lorries to costumers. As part of their business strategy, Valefresco will built a new facility during the following months. It implies that no real data available for processes where AGV will potentially operate. Therefore, to analyse this company it is necessary to use data from the current processes, as the current operator's procedures will not change regarding the current one vs the new facility. However, performance will change, as the new facility will have different distances and capacities.

The following figure shown the complete production processes and the automation required:

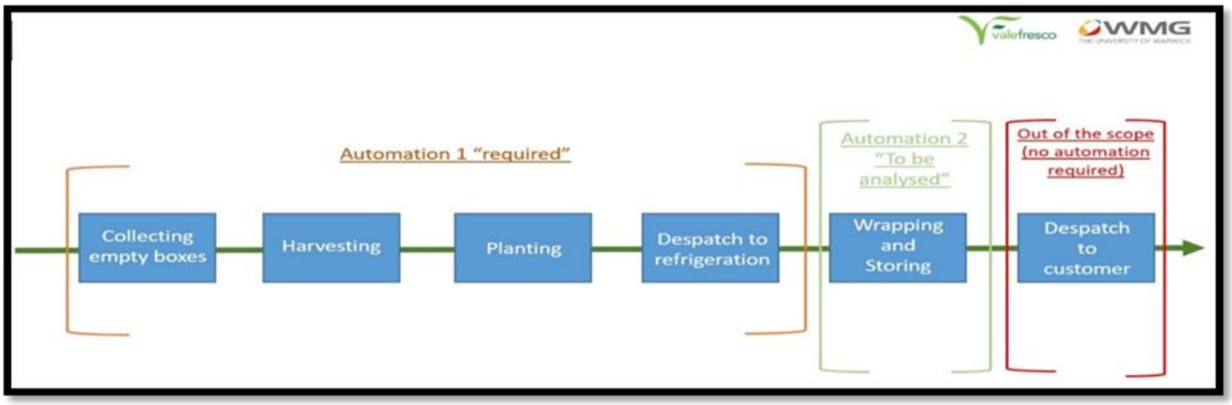


Fig. 6 ***Valefresco's processes and automation required***

(Own elaboration)

(Please see appendix IV the detailed activities of the processes indicated in figure above).

The complete process starts when operators needs to collect empty boxes to harvest lettuces. Then, operators harvesting lettuces directly from lettuce's column lines and put them on boxes. The “Planting” process happens by introducing seeds in every hole of the columns. Normally, one operator is harvesting in the morning and planting in the afternoon.

To this study, harvesting and planting use the same resources and have same performance. Once both boxes are full of lettuces and a trolley is full of boxes, then it is required to “Despatch trolley to refrigeration room”. Thus, operators will do three main tasks, take boxes out of the trolley, “Wrapping”, and “Storing” them on a pallet at refrigeration room. Finally, company sends the wrapped pallets with boxes to costumers by lorries. Therefore, the automation will affect to the first four processes of Valefresco’s production (see figure 15).

The “Automation 2 and 3” are not considered on this study for two main reasons. First, these automations will require an additional analysis where the final solution will probably require an integration of other technologies to stack and wrap boxes. Second, this kind of automations are not part of the direct company’s problem indicated in heading 5.1.

5.2.3 **WD Smith & Sons production cycle analysis**

WD Smith company is located in Battlesbridge – Essex. The Company mainly produce boxes with plants that are sent through lorries to costumers. The analysis is based on the current processes and facilities. The following figure shown the complete production processes:

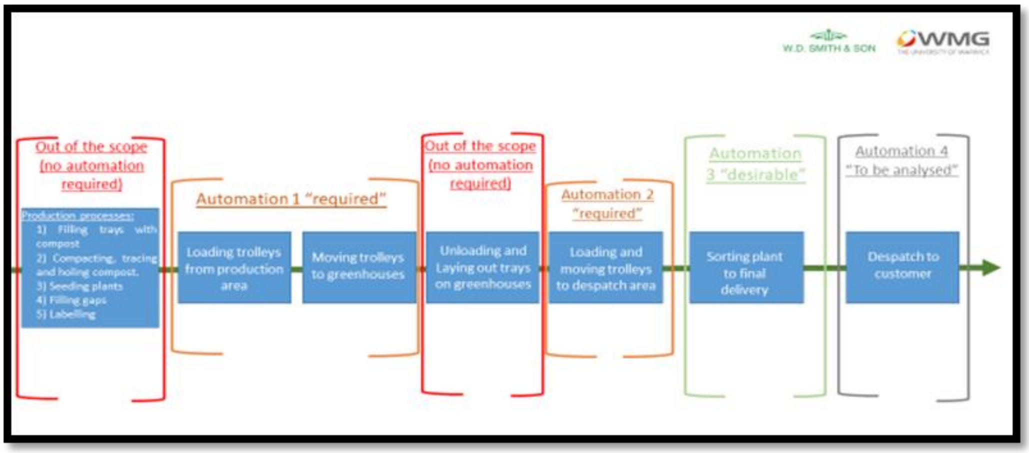


Fig. 7 ***WD Smith’s processes and automation required***

(Own elaboration)

(Please see appendix V the detailed activities of the processes indicated in figure above).

The processes start with the production line’s activities. Currently, there are two operating production lines, the main and small one (both are located in different zones of the company). At the end of this year, the company will put on service a new line, thus, the level production will increase.

The activities of the production process are “out of scope” due to two reasons. First, they are not part of the current company’s problem. Second, the final solution to propose will not impact in the final efficiency, as the production line process does not influence on the physical material movement around the company.

The automation 1 “Required” should cover two processes “Loading trolleys from production area”, “Moving trolleys to greenhouses” and automation 2 “required” covers “Loading and moving trolleys to despatch area”.

“Loading trolleys from production area” is a manual process where operators needs to fill boxes with plants from the lines to danish trolleys. There are different size of boxes depending of the plants to deliver. Thus, trolleys are filled with different quantities as it depends of the size of boxes. The details of sizes and quantities can be check in the table 10 and 13 of this heading.

According to the company, “Moving trolleys to greenhouses” and “Loading and moving trolleys to despatch area” are the most important activities to automate, as circulation of trolleys around the facilities needs to be efficient. This means, to do not only deliver full trolley to greenhouses and despatch areas but to bring empty trolleys to production areas when needed and in the right quantity required. This way, improving the current material flow could help to reduce bottlenecks in both production line and greenhouses.

“Unloading and laying trays on greenhouses” process is “out of scope”, as glasshouse’s lanes are not wide enough to allow the proper transit of AGVs.

On the automation 3 “Desirable” the process “Sorting plant to final delivery”, operators need to group right plant on trolleys according to customer’s orders. In this process, there is a good opportunity to improve efficiency of this process as it has high quantity of operators (manual tasks) who need to sort plants, labelling and pricing the products. However, it is required to integrate another type of technology different that an AGV that need to be able to sorting plants to the right costumer. Thus, this is a desirable solution but will not be part of the final proposal. In the “Recommendation” heading is possible to find more details about this opportunity.

The automation 4 “To be analysed”, the “Despatch to customer” process send trolleys from packing area (after pricing) to the lorries. This automation is classified as “To be analysed” due to three main reasons.

First, the internal facility do not allow to get a high AGV’s manoeuvrability. Second, the distances to deliver to lorries are short; it implies that the AGV probably could not be more efficient that an operator.

Third, the first priority of the company is to improve the flow of material (trolley’s transport) from and to the greenhouses. However, it is feasible in future to evaluate a possible integration of AGVs.

Finally, the automation required for WD Smith is focused on trolley’s movement from production to greenhouses and to dispatch area. This will not consider the capacity of the AGV to load and unload boxes to/from the ground. Thus, operators will continue laying boxes on the greenhouses manually.

The next two headings analyse the performance and flow of material perspective in order to get both a better understanding of the processes (from data perspective) and to estimate the quantity of AGVs required and its preliminary technical specification.

5.3 Production performance data analysis.

This analysis of performance contributes to obtaining the production’s ratios, timing, quantities of trays, etc. This data is important to calculate and understand the throughputs required by the company. From a quantitative point of view, the throughputs are the base for future improvements.

5.3.1 Crystal Heart

The production can be categorised on three main seasons middle, peak and average (please note that the average season is not the average between middle and peak seasons). In term of production’s days, James Bean (company director) indicates that the production is spanned 328 days of a normal year.

Additionally, he indicates that production's timing is not a critical issue as the company can use +/-2 days in order to get peaks on demand during the week.

The table 1 shows different production ratios of the current company's performance. The production level is increased or decreased according to the total hours of daily production. Thus, although the production ratio will not change, the total trays per week to produce will change, as it depends on the total laboured hours per day (It assumes that processes use same resources).

Intensity of production	Processes	TRAYS / WEEK (7 DAYS)	TRAYS / DAY	RATIO (TRAYS / HOUR)	HOURS / WEEK	RATIO (TRAYS / MIN)	Total time per week	QTY of people per day	Hour per people per week	Hour per people per day
MIDDLE SEASON	Laying out	28252	4036	345	81.9	5.75	387.5	6	64.58	9.23
	Hardening	28252	4036	320	88.3	5.33				
	Despatch	28252	4036	130	217.3	2.17				
PEAK SEASON	Laying out	39375	5625	345	114.1	5.75	540.1	6	90.01	12.86
	Hardening	39375	5625	320	123.0	5.33				
	Despatch	39375	5625	130	302.9	2.17				
AVERAGE	Laying out	15568	2224	345	45.1	5.75	213.5	6	35.59	5.08
	Hardening	15568	2224	320	48.7	5.33				
	Despatch	15568	2224	130	119.8	2.17				

Table 1 Crystal Heart's production performance by season

(Own elaboration based on company's data)

The current study aims to achieve the current ratios to "laying out" and "hardening off" processes. In these cases, the performance to deliver trays cannot be lower than 5.75 and 5.33 trays per minute respectively. The following two tables show the time required different quantity of batches (30, 20 and 10 trays). The company currently move batches of 30 trays from laying out room to greenhouses and to hardening off processes. The ratio of 20 trays can be used in the next heading as a possible option to the current state.

OUTPUT FROM LAYFLAT ROOM (TRAYS/TIME UNIT)

BATCH OF "X"	RATIO (TRAYS / HOUR)	RATIO (TRAYS / MIN)	"X" TRAYS ARE READY IN:
30	345	5.75	5.22
20	208.70	3.48	5.75
10	172.50	2.88	3.48

OUTPUT FROM GREENHOUSE TO HARDENING OFF (TRAYS/TIME UNIT)

BATCH OF "X"	RATIO (TRAYS / HOUR)	RATIO (TRAYS / MIN)	"X" TRAYS ARE READY IN:
30	320	5.33	5.63
20	225.00	3.75	5.33
10	160.00	2.67	3.75

Table 2 Potential batches comparison at Lay flat room and greenhouse process

(Own elaboration)

The two tables show the outputs required to the two main processes to automate. By doing so, every batch (30 trays) needs to be moved from lay flat room to greenhouse every 5.22 minutes. In the case of greenhouses to hardening off, batches needs to be despatched every 5.63 minutes. This simple analysis has a big impact on the AGV solution, as these vehicles will need to be able to move around the facility and return before next batch is ready. Otherwise, there are a potential event of bottlenecks.

Regarding to the material handling, every tray measure 665 mm x 445 mm x 120 mm high (110 mm when stacked) and weight 10 Kg. When trays leave the germination room, these are stacked in a column of 15 trays (1.65 mt high). Then, columns are unstacked in a batch of 30 trays (300 Kg approximately) which has a size of 3.99 mt x 2.2 mt.

There are 03 important production's resources to consider for automation "1" and "2", operators, forklift and Lay flat machine. Operators are drivers and maintenance support. There forklift participate directly in the process of moving columns of trays to lay flat room and for moving trays to greenhouse and outside. The lay flat machine is located in the lay flat room. This machine unstack trays from column (15 high) and create a batch of 30 trays. The following table shows the resources name and its quantity for the processes within automation 1 and 2:

Resource name	Quantity
Operators	04
Forklift	03
Lay flat Machine	01

Table 2 Resources used at Crystal Heart Company on the processes to automate (Own elaboration)

5.3.2 Valefresco

The company will build a new facility in the following months. The performance's data need to be a combination between the future capacity of the new building and the current performance of other Valefresco's facility.

According with the company, the capacity of the future new facility of the company are the following:

	Qty of column	*Qty of lettuces per system (24 lettuce per tube)*
SYSTEM 1	2500	60000
SYSTEM 2	3100	74400
SYSTEM 3	2300	55200
SYSTEM 4	2700	64800
TOTAL	**10600**	**254400**

Table 3 Future capacity of the new Valefresco's facility (Own elaboration)

Understanding this new capacity of the company allows to plan the future production performance, as it gives the scope of the total production and the harvesting advance per day. From the table above, every system is an area within the facility. This does not imply special processes as every system will harvest and sow at the same way and ratio. However, there is an impact on distances and, therefore, in the time for moving boxes from the different system to empty room and to refrigeration room.

Current performance:

Currently, Valefresco harvest 17 lettuces per box. Approximately 153 lettuces are produced (harvested) every 30 minutes, as every trolley is able to move 09 boxes at the same range of time.

The company works with a year demand. The production level to the next facility should be around the following numbers:

Type of Prod	KG / DAY	QTY Lettuces (Unit)
Low production	2000	5000
High production	10000	25000
Average	6000	15000

Table 4 Future capacity of Valefresco's new facility (Company's data)

Thus, these quantities to produce (harvest) are within the scope for the present study. The process analysis will be planned according to the high production, as it represent the worst case scenario in term of quantity of movement and material handling. The performance planed is indicated in the next table.

PRODUCTION	18	Boxes/ hour
	306	Lettuces / hour
	12.75	Tubes / hour
	2	Trolleys / hour
	162	Boxes / day per operator

Table 5 Future capacity of Valefresco's new facility

(Own elaboration based on company's data)

The company plan to have 07 operators working at the same system and time on the new building. They will work approximately 09 hours per day. In this way, the total quantities expected to collect per day are the following:

Lettuces per day (per operator)	Boxes per day (per operator)
2754	162
Total lettuces per day	**Total boxes per day**
19278	1134

Table 6 Future capacity of Valefresco's new facility

(Own elaboration based on company's data)

Using the data indicated on tables before, it is possible to obtain the quantity of tubes or columns to harvest, boxes to move, and the total operators required per level of production. Thus, it seems that the high production level will require 9.1 operators per day instead of 07; So, it will imply both, the 09 hours of daily job will need to be increased to 11.6 hours on peak seasons and/or increased the quantity of operators. However, both option could increment the cost of production. The following table shows the quantity of operators required per type of production.

Type of Prod	KG / DAY	QTY Lettuces	Qty of tubes	Qty of boxes	Boxes per hour	Qty of operators
LOW PROD	2000	5000	208.3	294.1	32.7	1.8
HIGH PROD	10000	25000	1041.7	1470.6	163.4	9.1
AVG	6000	15000	625.00	882.35	98.04	5.45

Table 7 Quantity of boxes and operators required to the new facility

5.3.3 WD Smith

The company produce plants in 07 different type of boxes. All of them have different sizes that impact on the quantity of boxes to use on Danish trolleys and six shelf barrows. These boxes are produced on three production lines main, small and manual lines (new line). Two of them are currently in use; the new production line will be online at the end of this year. However, the production forecast for the new line is highly known by the company. This study contemplates the forecast of the new line. Although there are three lines, trolleys are delivered from only two locations as small line and manual line are located at the same building. Therefore, the production's ratio from that location is considers as one.

The production rate per type of production line and boxes are the following:

TYPE OF PROD LINE	*TYPE*	RATIO PER HOUR (boxes per hour)	RATIO PER MIN (boxes per minute)
MAIN LINE	DOUBLE 6 DOUBLE 10	450	7.5
MANUAL	JUMBO 6	120	2
SMALL + MANUAL	9 CM POT	100	1.7
MANUAL	10.5 CM POT	100	1.7
MANUAL	13 CM POT	50	0.8
MANUAL	17 CM POT	50	0.8

Table 8 Production rate per type of product

(Own elaboration based on company's data)

There is a combination between the production lines to produce certain type of boxes and in different ratios. The main line has the higher ratio with 450 boxes per hour and represents the 53% of the total production. The 75% of the annual production occurs in peak season. This season covers from March to May (03 months). The normal season represent only the 25% of annual production. However, the main line represents the 62% of total production. Thus, the most important product to analyse are double 6 and double 10. The following two tables show the production rate at peak and normal season.

Peak season:

TYPE OF PROD LINE	*TYPE*	% OF TOTAL PRODUCTION	DAY OF OPERATIONS	BOX OR TRAY / WEEK	RATIO PER HOUR	HOURS PER DAY
MAIN LINE	DOUBLE 6 DOUBLE 10	53%	4	18000	450	10
MANUAL	JUMBO 6	18%	5	6000	120	10
SMALL + MANUAL	9 CM POT	15%	5	5000	100	10
MANUAL	10.5 CM POT	3%	1	1000	100	10
MANUAL	13 CM POT	6%	5	2000	50	8
MANUAL	17 CM POT	6%	5	2000	50	8

Table 9 Production at peak season

(Own elaboration based on company's data)

Normal season:

TYPE OF PROD LINE	TYPE	% OF TOTAL PRODUCTION	DAY OF OPERATIONS	BOX OR TRAY / WEEK	RATIO PER HOUR	HOURS PER DAY
MAIN LINE	DOUBLE 6 DOUBLE 10	62%	2	7000	450	7.8
MANUAL	JUMBO 6	4%	1.5	1500	120	8.3
SMALL + MANUAL	9 CM POT	4%	1.5	1200	100	8.0
MANUAL	10.5 CM POT	1%	0.5	500	100	10.0
MANUAL	13 CM POT	1%	1.5	500	50	6.7
MANUAL	17 CM POT	2%	2	600	50	6.0

Table 10 Production at normal season

(Own elaboration based on company's data)

Due to the variability on the production, this study considers the 85% of the total production at peak season (highlighted in light blue colour on the table 11). Taking a higher level of production (instead of the 53% and 62% the main line) allows to get a better understanding of the current tasks and material handling. This has a big impact, as the main line and the other two lines are located in different sectors of the company. Thus, the distance of the material flow will change accordantly. Peak season data was selected, as is it the worst-case scenario in term of movement performance and require a high level of coordination between production process and the internal logistics.

The quantity of trolleys required depend on the production rate and the capacity available to load boxes on trolleys. Currently the company use two type of trolleys Danish Trolleys and Six Shelf Barrows. The next table shows the loading capacity in term of boxes per type of trolley.

	DANISH TROLLEYS	SIX SHELF BARROWS
TYPE	***TOTAL***	***QTY***
DOUBLE 6	80	126
DOUBLE 10	80	126
JUMBO 6	120	180
9 CM POT	48	54
10.5 CM POT	48	54
13 CM POT	60	60
17 CM POT	16	0 (not used)

Table 11 Total capacity per trolley and per type of boxes

(Own elaboration based on company's data)

Although danish trolley has less capacity than six shelf barrow. This study will used Danish trolley as a base of analysis for different reasons. First, this trolley is more versatile and is highly used by farms. Second, the company validated to researchers that is better to use Danish trolley as a standard solution for their processes. Third, it is the worst-case scenario because less capacity imply a faster trolley turnover on the different processes. The time required to deliver a trolley from production lines to greenhouses will depend on the batch time.

Delivery rate from production lines:

The delivery rate is the result between the total of a specific type of box and its production ratio. For instance, 01 trolley is able to carry 80 units of "Double 6" boxes. Therefore, if the main line produce 7.5 boxes per minute, 01 trolley of "Double 6" is ready every 10.7 minutes.

The following two tables shows the delivery rate according to the type of boxes and production line:

Main line	
DANISH TROLLEY	MIN
DOUBLE 6	10.7
DOUBLE 10	
JUMBO 6	
9 CM POT	
10.5 CM POT	
13 CM POT	
17 CM POT	

Small and manual lines	
DANISH TROLLEY	MIN
DOUBLE 6	
DOUBLE 10	
JUMBO 6	60.0
9 CM POT	28.8
10.5 CM POT	28.8
13 CM POT	72.0
17 CM POT	19.2

Table 12 Delivery rate per production line

(Own elaboration)

Finally, each trolley from the main line is ready every 10.7 min. To the small and manual lines, a second validation was required. According to the data analysed, a Danish trolley is full loaded with "Jumbo 6" boxes every 60 minutes and 72 minutes to 13 cm POT. So, the data needs to be re-evaluated as the loading time does not represents the current performance. After consulting to the company, the researchers concluded that the ratio depends on the total use of both machines and do not on independent ratios per machine. Therefore, the total ratio for these production line sum 420 boxes per hour or 07 boxes per minute (see table below).

TYPE OF PROD LINE	*TYPE*	RATIO PER HOUR (boxes per hour)	RATIO PER MIN (boxes per minute)
MANUAL	JUMBO 6	120	2
SMALL + MANUAL	9 CM POT	100	1.7
MANUAL	10.5 CM POT	100	1.7
MANUAL	13 CM POT	50	0.8
MANUAL	17 CM POT	50	0.8
		420 boxes / hour	***07 boxes / minutes***

Table 13 Delivery rate small and manual line

(Own elaboration)

Therefore, the delivery rate for the small plus manual production line is a trolley every 12 minutes.

<u>Delivery rate from greenhouses:</u>

This delivery time allows to calculate the AGV's movement cycle. This means how many different points (different greenhouses) can the AGV cover before a new trolley or batch is ready.

In order to analyse the worst case scenario, the time to be use is the shortest time between the Danish Trolley and Six Shelf Barrow capacity. Please check the section "A" in appendix XIII ("Batch times") for more information.

TYPE		**DANISH TROLLEYS**	MINUTES	**SIX SHELF BARROWS**	MINUTES
		TOTAL OF BOXES	TIME FOR LOADING	TOTAL OF BOXES	TIME FOR LOADING
DOUBLE 6	BOX	80	7	126	11
DOUBLE 10	TRAY	80	7	126	11
JUMBO 6	TRAY	120	10	180	15
9 CM POT	TRAY	48	4	54	5
10.5 CM POT	TRAY	48	4	54	5
13 CM POT	TRAY	60	5	60	5
17 CM POT	TRAY	16	1	0	0

85 % of total production (DOUBLE 10, JUMBO 6, 9 CM POT)

Table 14 Delivery rate from greenhouses

(Own elaboration)

The time indicated above, is the time that operators take for loading boxes to a trolley. Every box takes 5 seconds as an average to be loaded. Therefore, 7.78 minutes per trolley is the total time expected for loading tasks. This calculations are based on the average time to the 85% of production.

The time for a batch of two and four trolleys is 15.56 and 31.11 minutes respectively.

5.4 Process analysis and flow of material.

The process analysis and flow of material give an understanding regarding resources, routes, operational logic, and procedures on site. This heading aim to analyse the logic used to measure operators and machine movement and performance on the different processes per company. This evaluation allows the analysis of potential material movement combination with AGVs.

5.4.1 Crystal Heart

The appendix VI shows a figure that contain a star, different letters and numbers allocated on the company's layout. The star icon indicates the position of the lay flat machine. The current analysis start at the lay-flat room, as batches with trays are produced, the numbers indicate two different concepts: on one hand, the orange's numbers are key point's areas that indicate movements of trays from "Start" to greenhouses; on the other hand, the number on the different lines indicate the distance from one point to another. It is important to notice that the colour of lines clarify the direction and destiny of the movement. Finally, the letters represent the key point's areas from greenhouses to hardening off process.

The key point's areas were selected in order to have different possible combination within the layout. These points have the largest distance that operators, machine and potentially AGVs need to move trays, therefore, these represents the worst-case scenario to analyse. In this way, it is assumed that there is no other worst point on the layout that imply longer time of movement. As an example, one batch is ready to be delivered from "star" (lay flat room) to point "2" (greenhouse). Thus, the point "2" represents the longest distance (140

MTS) of the left and central sectors on the greenhouse process. Therefore, it is possible to calculate the time of moving material across the layout, by calculating distances and evaluating different possible speed to the AGV.

Battery performance, payload, speed, and loading/unloading trays are basic variables that can limit the task of moving batches. Battery performance is one of the most important variable on electric vehicles as it gives the energy for operating. Thus, the battery duration, life cycle, speed of charge, etc. are factors at the moment of deciding which battery is suitable for the future AGV's design. Payload limitation impact on both, speed and battery duration. According to the literature review and the current AGV market options, a safety speed for outdoor could fluctuate between 0.8 and 1.1 m/s. The following table sum up the preliminary specification for these variables:

Critical factor found	Acceptance criteria
Daily Operation (this is an average between the seasons indicated in table 01)	09 hours
Payload	10 KG per tray (approx. 300 KG)
Speed	0.8 – 1.1 meters/seconds
Loading batch from lay flat room and ground	10 – 12 SEC
Unloading batch to ground	18 – 20 SEC

Table 15 Acceptance criteria for the basic variables to analyse

(Own elaboration)

Currently, batches are loaded and unloaded with forklift that use a special metal framework. This framework is able to move 30 trays (see appendix III, laying out process - laying flat trays activity). However, the AGV to implement needs to face the production batch time from the lay flat machine and from greenhouse to hardening off. Therefore, the focus for the conceptual design is to match the current batches time (throughput) instead of carrying the same quantity of trays per travel. However, there is always a cost factor involve, thus, this study is aim to arrive to the less possible quantity of AGV to get the current throughputs.

<u>Analysis of the current processes – Calculating the quantity of AGVs required.</u>

Two type of AGV capacity will be analysed in order to arrive to the quantity of AGV that are able to face the current production performance. First, is evaluate an AGV able to carry 30 trays (the same that forklift) and under the same current condition. Second, is analyse an AGV able to move 20 trays, but directly from stacked columns. This means that lay flat machine (and process) will be no longer required.

<u>30 Trays AGV:</u>

The analyses has two different possibilities. On one hand, it is tested separately lay flat to greenhouses and greenhouse to hardening off movements. On the other hand, both processes are mixed, thus, AGV can go to different processes (key points). For instance, AGV can go from hardening off to lay flat room or to greenhouse.
The table A6.1 (see appendix VII) considers the common variables to be used on all companies (loading time, distances, throughputs, etc.) and the different combination of "key points" that allow the evaluation of the AGV's movements. The following table shows an example of combinations.

	INITIAL POINT	FINAL POINT
LAY FLAT ROOM TO GREEN HOUSES	STAR	1
	1	STAR
	STAR	2
	2	STAR
	STAR	3
	3	STAR
FROM GREEN HOUSES TO HARDENING OFF (OUTSIDE)	A	B
	B	C
	C	D
	D	E
	E	B
	B	C
	B	STAR

Different Combinations

Table 16 Example of movement combinations

(Own elaboration)

The column "Difference with Throughput" (see table A6.1) indicates the difference between the current batch time and the time when only 01 AGV is evaluated. Additionally, it is added a "safety time" of 01 minute and 30 seconds in the case that the time's performance is less than expected or if the AGV to propose is not able to achieve the speed assumed. Therefore, the results indicate (with the exception of the key points “1” and “2”) that it is not possible to use only 01 AGV to go from lay flat room to all key points and return within both the batch time and safety time. The following table shows the results:

	INITIAL POINT	FINAL POINT	DIFFERENCE WITH THROUGHPUT
LAY FLAT ROOM TO GREEN HOUSES	STAR	1	3.02
	1	STAR	
	STAR	2	1.77
	2	STAR	
	STAR	3	0.94
	3	STAR	
FROM GREEN HOUSES TO HARDENING OFF (OUTSIDE)	A	B	0.93
	B	C	
	C	D	-1.99
	D	E	
	E	B	1.35
	B	C	
MIX BOTH PROCESSES	STAR	3 OR C	-4.09
	3 OR C	D	
	D	STAR	
	STAR	3 OR C	
	3 OR C	B	-3.68
	B	STAR	-1.68

Table 17 Difference with the lay flat batch throughput (30 trays)

(Own elaboration)

As a result, it is necessary to increase the number of AGV in order to achieve the batch throughput and the safety time. The column “AGV required” of the following table, shows the increment on AGVs to get the safety time constraint required.

	INITIAL POINT	FINAL POINT	AGV REQUIRED	FINAL OUTPUT WITH AGV APPLIED
LAY FLAT ROOM TO GREEN HOUSES	STAR	1	1.15	3.31
	1	STAR		
	STAR	2		2.22
	2	STAR		
	STAR	3		1.50
	3	STAR		
FROM GREEN HOUSES TO HARDENING OFF (OUTSIDE)	A	B	1.85	3.09
	B	C		
	C	D		1.51
	D	E		
	E	B		3.31
	B	C		
MIX BOTH PROCESSES	STAR	3 OR C	2.5	1.50
	3 OR C	D		
	D	STAR		
	STAR	3 OR C		
	3 OR C	B	2.26	1.51
	B	STAR	1.86	1.51

Table 18 Final output and quantity of AGV required

(Own elaboration)

Finally, with this option of AGV ("30 trays AGV") it is necessary 1.15 AGV for moving 30 trays from lay flat room to green houses and 1.85 AGVs from greenhouses to hardening off. Thus, the all process will required 3 AGVs for completing the total operations.

In the case of the "mixing both processes" row, 03 different possible mixing combination. As a result, it is required 2.5, 2.26 and 1.86 AGVs depending on the combination are evaluated in order to get an average time. The total AGVs required in "mixing processes" will be obtained calculating the average among the options. The total quantity required is 2.21 AGVs.

Finally, mixing processes is the suggested option to select, as it is 26% more efficient that the "not mixing processes" alternative regarding the AGV's use. Additionally, the final average time available from the final outputs are the following:

- Lay flat room to greenhouses = 2.34 minutes
- Greenhouses to hardening off = 2.64 minutes
- Mixing processes = 1.51 minutes

<u>20 tray AGV</u>

The analysis contemplated the same alternatives lay flat room to greenhouses, greenhouses to hardening off, and mixing processes. In this case, the difference with the last scenario (30 trays) is that AGV will move 20 trays in column of 10 instead a batch of trays from the lay flat machine. James Bean suggest that a current forklift can moved out the columns of trays from germination to lay flat room. By doing so, an AGV can take 2 columns of 10 trays and unstacking trays on the ground at greenhouses. As a consequence, the unstacking and batch creation process at the lay-flat machine (30 trays) is eliminated. This action can benefit by eliminating an extra process of the company and transfer this tasks to a robot (AGV). As a result, it is no longer required an operator at the machine with the potential benefits of reduce cost in maintenance, electricity, supervisor, etc.

A new throughput needs to be calculated as a result of the trays reduction. The following tables show the throughput required to move 20 trays.

OUTPUT FROM LAYFLAT ROOM (TRAYS/TIME UNIT)

BATCH OF "X"	RATIO (TRAYS / HOUR)	RATIO (TRAYS / MIN)	"X" TRAYS ARE READY IN:
30	345	5.75	5.22
20	208.70	3.48	5.75
10	172.50	2.88	3.48

OUTPUT FROM GREEMNHOUSE TO HARDENING OFF (TRAYS/TIME UNIT)

BATCH OF "X"	RATIO (TRAYS / HOUR)	RATIO (TRAYS / MIN)	"X" TRAYS ARE READY IN:
30	320	5.33	5.63
20	225.00	3.75	5.33
10	160.00	2.67	3.75

Table 19 Throughput required to move 20 trays

(Own elaboration)

As a new constraint, the output for germination room to greenhouses cannot increase in comparison with the current state by changing the configuration and eliminating the lay flat process. This constraint helps to compare performances with the same initial variables. Therefore, the maximum time to move 20 trays should be 3.48 minutes from germination room to greenhouses, and 3.75 minutes from greenhouse to hardening off.

The appendix VIII shows the result of the analysis. The speed increase to 1.1 m/s and the loading and unloading time changed as well. In the case of the speed, the change is argued basically as the AGV will move 100 KG less than the current state. This was checked with the current commercial AGVs. However, this assumption needs to be evaluated at the design stage of the project. The loading and unloading time changed to 7 seconds and 120 seconds respectively. The loading time is reduced as the AGV needs to take and lift the columns as a normal forklift. The unloading time increase substantially as a robotic arm needs to be able to unload to the ground two trays at the time (it will be explained in the Heading 5). Loading and unloading time were checked from available commercial AGV's solutions. The following table shows the preliminary results (the same logic explained in the last subheading is used to this scenario):

Different Combinations

	INITIAL POINT	FINAL POINT	DIFFERENCE WITH THROUGHPUT
LAY FLAT ROOM (Area but not machine) TO GREEN HOUSES	STAR	1	
	1	STAR	2.42
	STAR	2	
	2	STAR	1.51
	STAR	3	
	3	STAR	0.91
FROM GREEN HOUSES TO HARDENING OFF (OUTSIDE)	A	B	
	B	C	0.19
	C	D	
	D	E	-1.93
	E	B	
	B	C	0.49
MIX BOTH PROCESSES	STAR	3 OR C	
	3 OR C	D	-4.48
	D	STAR	
	STAR	3 OR C	
	3 OR C	B	-4.89
	B	STAR	-2.73

Table 20 Difference with the lay flat batch throughput (20 trays)

(Own elaboration)

From the table above is possible to see that the differences with the throughput when 01 AGV is used. The result indicates that only the key points from "star" to "2" (2 ways) is able to be achieved within the safety time of 1.5 minute. It suggests to increment the quantity of AGV to fit the constraint required in term of output and safety time. Therefore, the following table shows the final AGV required.

	INITIAL POINT	FINAL POINT	AGV REQUIRED	FINAL OUTPUT WITH AGV APPLIED
LAY FLAT ROOM (Area but not machine) TO GREEN HOUSES	STAR	1	1.14	
	1	STAR		2.83
	STAR	2		
	2	STAR		2.03
	STAR	3		
	3	STAR		1.50
FROM GREEN HOUSES TO HARDENING OFF (OUTSIDE)	A	B	1.898	
	B	C		2.62
	C	D		
	D	E		1.50
	E	B		
	B	C		2.78
MIX BOTH PROCESSES	STAR	3 OR C	2.40	
	3 OR C	D		1.49
	D	STAR		
	STAR	3 OR C		
	3 OR C	B	2.67	1.50
	B	STAR	2.60	2.49

Table 21 Difference with the lay flat batch throughput (20 trays)

(Own elaboration)

The results suggests that the total AGV required to move trays from lay flat room area (from germination room) to greenhouses and from greenhouses to hardening off are 3.038 units. In the case of mixing processes the total average to the 3 options of combinations is 2.56 units. Additionally, the final average time available from the final outputs are the following:

- Lay flat room to greenhouses = 2.12 minutes
- Greenhouses to hardening off = 2.30 minutes
- Mixing processes = 1.83 minutes

As a sum up, the following table compares the different performance on carrying 30, 20 or 10 trays. 10 trays option is included as a way to compare how efficient could be this alternative (see appendix IX).

Variable	30 trays	20 trays	10 trays (appendix "IX")
Qty of AGVs from Layflat room to greenhouse	1.15	1.14	1.94
Qty of AGVs from greenhouses to hardening off	1.85	1.898	2.79
Total AGV required in NOT Mixing processes option	3.0	3.03	4.73
Total AGVs required in mixing both processes option	2.21	2.56	3.69

Table 22 AGV required by quantity of trays to carry

(Own elaboration)

It is possible to verify that the option "10 Trays" uses the largest quantity of AGVs and it is the less efficient solution. From mixing processes alternative, 30 trays is 15.8% more efficient in the quantity of AGV to use than 20 trays and 67% regarding "10 trays" option. On the other hand, 20 trays is 44% more efficient in the same alternative than "10 trays" option. From not mixing processes alternative, 30 trays is 1% more efficient than 20 trays and 57.6% than 10 trays. Conversly, 20 trays is 57.5% more efficient in the same alternative than "10 trays" option. Therefore, the best option for this scenario is use the AGV with the mixing process alternative.

Finally, the comparison of the two scenarios suggest to choose the "30 trays AGV as this option suggests to use less quantity of AGVs and it has more available time at the "final output". However, there are other variables and critical factors that need to be reviewed before decided the best approach to the AGV for this company. In term of cost saving, it is expected to reduce the quantity of forklift driver as a main direct cost. Secondly energy, maintenance and support staff can be reduced.

5.4.2 **Valefresco**

The appendix X shows the new facility that will be allocated on the company. The material flow is mainly through the different aisles between the columns or tubes with lettuces across the 4 system. The processes start when operators receive empty boxes from the "empty room". Then, they start to load lettuces into empty boxes and to move trolleys with full boxes until the end of every aisle (09 – 10 boxes approximately). Then, trolleys need to be unloaded on a pallet and boxes moved to the "refrigeration room".

With automation solutions, trolleys will be moved by an AGV and boxes will be unloaded on "refrigerator room" instead of aisles. This automation helps to centralize the palletisation process on one place and to improve use of the resources. The process to evaluate is the following:

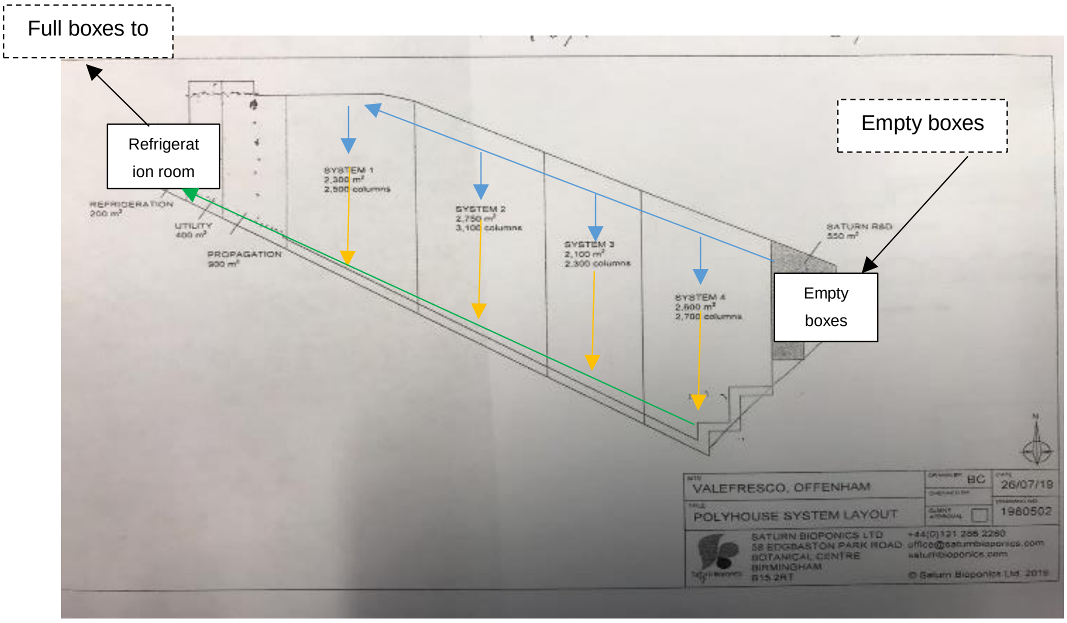


Fig. 8 AGV movements at the new building

(Own elaboration)

From the figure above, it is possible to identify different colour of arrows. The blue arrows show the direction where AGVs need to move empty boxes. The orange arrows show the harvesting direction. The green arrow shows the full boxes transit from aisles (per system) to "refrigeration room".

The automation required will impact directly the internal transportation activities, this helps to improve the efficiency of harvesting as the operators will not need to walk for moving empty and full boxes. In this way, the main task is to find the right quantity of AGVs that is able to match the current throughput. The quantity of AGVs depend basically of the distance of transit and the available time without queues or idle time.

Distance implies how long the AGV need transit in order to achieve the normal operations tasks. Queues and idle time are produced if AGVs take more time than the established throughput. The two main outputs are "full box ready" and "empty box required time". Both times are slightly different because the distances to/from empty/refrigeration rooms respectively. However, the target time needs to be the same for both processes, as when a trolley is ready to be deliver with full boxes, another trolley with empty boxes is required at the same time and place (aisle).

The target to evaluate is based on the current data performance of operators from other company's facilities. The average production rate (harvesting performance) is 18 boxes per hour or 02 trolleys per hour (01 trolley every 30 minutes). The distance's relations are the following:

DISTANCE (MT)	SYSTEM 1	SYSTEM 2	SYSTEM 3	SYSTEM 4	REFRIGERATOR	EMPTY BOXES (COMPLETE CIRCLE)
SYSTEM 1	X	46.9	86	125	70	382.8
SYSTEM 2	46.9	X	39	78	117	340.6
SYSTEM 3	86	39	X	36	156	304.7
SYSTEM 4	123.5	78	36	X	187.5	265.6
EMPTY BOXES	172	125	92	55	234.3	X

Table 23 Relation of distances between systems, refrigeration and empty room (Own elaboration).

By using a speed of 1.1 m/s, the expected time the final result is the following:

TIME FROM SYSTEM X TO REFRIGERATOR (WITH RETURN IN MIN)		QTY OF OPERATORS AND 02 AGV PER SIDE (EMPTY AND FULL)				
		5	**6**	**7**	**8**	**9**
SYSTEM 1	4.24	10.61	12.73	14.85	16.97	19.09
SYSTEM 2	6.01	15.02	18.02	21.03	24.03	27.03
SYSTEM 3	7.24	18.09	21.71	25.33	28.95	32.56
SYSTEM 4	8.05	20.12	24.15	28.17	32.20	36.22
TIME FROM SYSTEM X TO EMPTY BOXES AND RETURN (MIN)		**5**	**6**	**7**	**8**	**9**
SYSTEM 1	7.33	18.33	22.00	25.67	29.33	33.00
SYSTEM 2	6.25	15.63	18.75	21.88	25.00	28.13
SYSTEM 3	5.30	13.24	15.89	18.54	21.19	23.84
SYSTEM 4	4.03	10.08	12.10	14.12	16.14	18.15

Table 24 Final result – Quantity of AGVs current target time

(Own elaboration)

The table above indicates the relationship between distances, time and operators. This shows the time expected when AGV travels from system “x” (1,2,3 or 4) to refrigeration or empty room. The time required is the result of the distances of table 25 and the speed target. The column “Qty of Operators and 02 AGV per side” indicates the total time expected when 02 AGVs are been used to bring empty boxes and to move full boxes to refrigerator room (04 AGVs in total). The numbers 5 to 9 on the same column indicate the quantity of operators that are working at the same time. it means that the AGV will go to the “refrigeration room” and it will return within the time indicated on the table above (according to the “quantity of operator” selected). For instance, if there are 7 operators working the system 1, the AGV will move 01 trolley to refrigerator and it will return to pick the trolley for the next operator. This movement is repeated until reach the 7 operators. Afterwards, the AGV will return to the first operator in approximately 14.85 minutes.

From the same table the colours green, orange and red show how much available time is between the AGV transportation time and the target time. More than 5 minutes are available (green), less than 5 minutes and 0 minute (yellow), more than target time (red). It is possible to identify that the target time (30 minute) is achieved with 5, 6 and 7 operators and using 4 AGVs (2 per sides). However, system 4 cannot be achieved with 8 operators and systems 1, 3, and 4 when 9 operators are in place. This situation impacts the process, where it is necessary to hire more people in the case of potential peak seasons (The Company planned to operate with 7 workers).

If the target time is reduced, thus, more AGVs movement, this scenario is possible if the boxes turnover is increased. This can be understood as an increment on the productivity as the output is higher when the same resources have been used. As it was indicated, nowadays operators move trolleys, however, in the future, the time spent in moving trolleys will be transfer to AGVs. Therefore, the moving waste can be eliminated and it is expected that operators work in harvesting / sowing activities only.

According to Nick Mauro (company's director), the potential time saved if AGV is introduced can reach the 40%. The productivity will increase to 30 boxes per hour and the target time to AGVs for arriving with empty boxes and pick full trolleys is reduced to 18 minutes. As a consequence, the quantity of AGVs is increased to 03 per side (06 in total) according to the following details:

TIME FROM SYSTEM X TO REFRIGERATOR (WITH RETURN IN MIN)	QTY OF OPERATORES AND 03 AGV PER SIDE (EMPTY AND FULL)				
		6	7	8	9
System 1	7.07	8.48	9.90	11.31	12.73
System 2	10.01	12.02	14.02	16.02	18.02
System 3	12.06	14.47	16.88	19.30	21.71
System 4	13.42	16.10	18.78	21.46	24.15
TIME FROM SYSTEM X TO EMPTY BOXES AND RETURN (MIN)	5	6	7	8	9
System 1	12.22	14.67	17.11	19.56	22.00
System 2	10.42	12.50	14.58	16.67	18.75
System 3	8.83	10.59	12.36	14.13	15.89
System 4	6.72	8.07	9.41	10.76	12.10

Possible inconvenient

Table 25 Final result – Quantity of AGVs (new target)

(Own elaboration)

There is a potential inconvenient on the system 4 when is required to deliver full boxes to refrigerator room and return before 18 minutes. The AGV will probably takes 0.78 minutes (47 seconds) more than the target time. However, the quantity of AGVs to be used is accepted with this limitation as it is possible to use one of these options, save time in other task (01 minute), accept this delay, or reduce the new increment of productivity from 40% to 36%. These options are suggested in order to avoid to introduce more AGVs and, therefore, increment the level of investment.

For further details, the appendices 10 and 11 show the result of the evaluation of using 02, 04 and 06 AGVs with current and new target times respectively.

Finally, 06 AGVs are needed in order to increment the productivity from 38 to 40%. However, the capacity of harvesting lettuces on the new building is limited. According with the current process and data understood, it is not possible to harvest/sowing with 07 people during 9 hours every day as the lettuce's capacity is limited. Therefore, either the quantity of operators or the harvesting/sowing time (per day) needs to be reduced, if the company wants reduce cost with the new potential productivity. The next table shows the current production performance in term of total capacity to be installed:

	Qty of column	*Qty of lettuces per system*	*Qty of boxes*	*QTY of operators (ASSUMPTION)*	*Working hour per day (AVG)*	*Boxes per hour (per operator)*	*Boxes per system per day*	*% of advance of the system*	*Qty of trolleys per hour*	*Qty of trolleys per (total per day)*
SYSTEM 1	2,500	60,000	3,529	7	9	18	1134	32%	2	18
SYSTEM 2	3,100	74,400	4,376	7	9	18	1134	26%	2	18
SYSTEM 3	2,300	55,200	3,247	7	9	18	1134	35%	2	18
SYSTEM 4	2,700	64,800	3,812	7	9	18	1134	30%	2	18
TOTAL	**10,600**	**254,400**	**14,965**			**72**	**4536**	**31% (AVG)**	**8**	**72**

Table 26 Facility capacity – current state performance

(Own elaboration)

Currently the total harvesting/sowing advance (average) per system is 31% per day, thus, 3.22 days takes for harvesting 01 system. The company harvest and sows the same day, so, the total days for harvesting is 6.44 days. The total system's turnover or production cycle is 25.76 days or 5.15 weeks. Notice that the total AGV movements per day are 126. The new performance expected needs to be close to these results (the full performance is indicate as a reference only). Thus, the options available to achieve the same production cycle are the following:

Options	Total trolley to be moved to refrig. Room (Units)	% of production of total systems (AVG)
Current performance with 07 operators and 9 hours per day	126	31
New performance with automation, 07 operators and 09 hours per day	210	51
New performance with automation, 4.5 operator and 9 hours per day	135	33
New performance with automation and 5.5 hours per day and 7 operators.	128	31

Table 27 Final performance comparison

(Own elaboration)

Finally, the introduction of AGVs can bring either future savings by reducing operation hours or quantity of operator, or the opportunity to increment the capacity to get the 51% of diary production advance (with the same resource). The second option will increase on the gross margin as it is possible to sell more lettuces. The option to evaluate is reducing cost.

5.4.3 WD Smith

The main objective on the material flow of the company is to deliver trolleys with plants from two main areas to the different greenhouses (glasshouses) and to the delivery area or packing area at the right time, quantity and opportunity. Additionally, it is necessary to guarantee a continuous flow (cycle) of trolleys to the production lines. The figure 18 shows the different Key points on the company. These points show the areas where the AGV will transit.

Fig. 9 Key points on WD

(Own elaboration)

The layout is divided in three main areas zone 1, zone 2 and zone 3. The zone 1 indicates the main line (blue star) area and the biggest glasshouses. The zone 2 shows the middle zone of the company. In this zone is located the small + manual line (blue star). The zone 3 is the top side of the layout. The blue star indicates the delivery zone. Therefore, the layout is divided in 09 glasshouses, 02 production lines and 01 packing area. It is important to mention that the zone 1 is separated by a lane from zone 2 and 3. This is a public road where car can transit without any special permission. It is necessary to take in consideration this hazard on the preliminary specifications.

The logic of analysis is the same that was used with Crystal Heart Co. The same variables are used to calculate the quantity of AGVs required. The throughput to compare was indicated in the previous heading. The analysis is applied to two types of AGV "Lifter" and "Towing". The Lifter AGV has the capacity to lift two Danish trolleys at the same time. It is expected a high level of manoeuvrability and speed. The towing AGV has the capacity to pull a trailer with 4 trolleys. The conditions to be proved are the following:

I. No mixing key points:

- Lifter AGV:
  - From main line to different key points and zones.
  - From small + manual lines to different key points and zones.
  - From greenhouses key points to delivery area.
- Towing AGV:
  - From main line to different key points and zones.
  - From small + manual lines to different key points and zones.
  - From greenhouses key points to delivery area.

II. Mixing all key points:

- Lifter AGV.
- Towing AGV.

Proving two types of AGVs allows for the understanding of the implications on the material flow performance as AGV can carry 2 or 4 trolleys respectively. Moving a trailer with trolleys is replicate the current company's processes. On the other hand, changing to use two trolleys, allow to the company to increase agility on processes as the trolleys turnover will be increased. The following table shows the sum up of the variables to be used on the process and material flow analysis.

Variable	AGV lifter	AGV towing
Loading	10 Seconds	40 Seconds
Speed	1.1 MTS / SEC	0.8 MTS / SEC
Unloading	10 Seconds	40 Seconds
Batch time (Main line)	21.33 minutes	42.67 minutes
Batch time (small and manual line)	24.00 minutes	48.00 minutes
Batch time (greenhouse)	15.56 minutes	31.11 minutes

Table 28 Sum up of variables used on the process analysis

(Own elaboration)

The following sub-headings show the main results of the process's analysis of the lifter AGV and towing AGV (see appendix XIII for the complete analysis):

I. No mixing key points (see section "B" in appendix XIII):

I.A. Lifter AGV:

- From main line to different key points and zones.

	INITIAL POINT	FINAL POINT	DIFFERENCE WITH THROUGHPUT	AGV REQUIRED	FINAL OUTPUT WITH AGV	TOTAL AGV
ZONE 1	STAR	A		0.28	2.50	1
	A	STAR	16.00			
	STAR	B		0.13	2.50	1
	B	STAR	18.88			
	STAR	C		0.23	2.50	1
	C	STAR	16.91			
	STAR	D		0.32	2.50	1
	D	STAR	15.24			
ZONE 2	STAR	E		0.36	2.50	1
	E	STAR	14.64			
	STAR	F		0.45	2.50	1
	F	STAR	12.91			
	STAR	G		0.53	2.50	1
	G	STAR	11.39			
ZONA 3	STAR	H		0.57	2.50	1
	H	STAR	10.61			
	STAR	I		0.63	2.50	1
	I	STAR	9.55			
	STAR	DISPATCH		0.44	2.50	1
	DISPTACH	STAR	13.12			

Table 29 Main line to different key point option – Lifter AGV (Own elaboration)

Results:

This option shows the possibility to send 01 AGV with two trolleys from main line to different key points only. Thus, the AGV will not be allowed to include other possible tasks.

The maximum quantity required is **0.63 AGV**.

- From small + manual lines to different key points and zones.

	INITIAL POINT	FINAL POINT	DIFFERENCE WITH THROUGHPUT	AGV REQUIRED	FINAL OUTPUT WITH AGV APPLIED	TOTAL AGV
ZONE 1	STAR	A		0.42	2.50	1
	A	STAR	14.88			
	STAR	B		0.29	2.50	1
	B	STAR	17.73			
	STAR	C		0.38	2.50	1
	C	STAR	15.91			
	STAR	D		0.47	2.50	1
	D	STAR	14.00			
ZONE 2	STAR	E		0.09	2.50	1
	E	STAR	22.15			
	STAR	F		0.16	2.50	1
	F	STAR	20.55			
	STAR	G		0.23	2.50	1
	G	STAR	19.06			
ZONA 3	STAR	H		0.27	2.50	1
	H	STAR	18.21			
	STAR	I		0.31	2.50	1
	I	STAR	17.27			
	STAR	DISPATCH		0.16	2.50	1
	DISPTACH	STAR	20.64			

Table 30 Small and manual lines to different key point option – Lifter AGV

(Own elaboration)

Results:

This option shows the possibility to send 01 AGV with two trolleys from secondary lines to different Key points only. Thus, the AGV will not be allowed to include other possible tasks.

The maximum quantity required is **0.47 AGV**.

- From greenhouses key points to delivery area.

	INITIAL POINT	FINAL POINT	DIFFERENCE WITH THROUGHPUT	AGV REQUIRED	FINAL OUTPUT WITH AGV APPLIED	TOTAL AGV
ZONE 1	A	DELIVERY		0.91	2.50	1
	DELIVERY	D	3.71			
	D	DELIVERY		0.90	2.50	1
	DELIVERY	C	3.86			
	C	DELIVERY		1.10	2.50	2
	DELIVERY	B	1.25			
	B	DELIVERY				
ZONE 2	DELIVERY	E	0.22	1.17	2.50	1
	E	DELIVERY				
	DELIVERY	F				
	F	DELIVERY				
	DELIVERY	G				
	G	DELIVERY				
ZONA 3	DELIVERY	H				
	H	DELIVERY				
	DELIVERY	I				
	I	DELIVERY				

Table 31 Greenhouse to different delivery area option – Lifter AGV

Results:

This option shows the possibility to send 01 AGV with two trolleys from greenhouses to delivery area. Thus, the AGV will not be allowed to include other possible tasks. As the difference of the last two analysis, this activity require more AGVs. The AGV will not be able to go from a key point at a greenhouse to delivery area and return to other key point within the batch time and using 01 AGV only. Therefore, the Zone 1 requires 2.91 AGVs and the total quantity required in this process are **4.07 AGVs**.

Finally, the total AGVs required to achieve the current performance (throughputs) are:

NO MIXING PROCESSES	
Main line to all zones	0.63
Small + manual prod line to all zones	0.47
Delivery area from zones	4.07
Total AGVs required	5.16
Total AGV	**6**

Table 32 Total AGV required for option "Not mixing process"

(Own elaboration)

I.B.Towing AGV:

- From main line to different key points and zones.

	INITIAL POINT	FINAL POINT	DIFFERENCE WITH THROUGHPUT	AGV REQUIRED	FINAL OUTPUT WITH AGV APPLIED	TOTAL AGV
ZONE 1	STAR	A		0.20		1
	A	STAR	34.46		2.50	
	STAR	B		0.11		1
	B	STAR	38.42		2.50	
	STAR	C		0.17		1
	C	STAR	35.71		2.50	
	STAR	D		0.23		1
	D	STAR	33.42		2.50	
ZONE 2	STAR	E		0.25		1
	E	STAR	32.58		2.50	
	STAR	F		0.31		1
	F	STAR	30.21		2.50	
	STAR	G		0.36		1
	G	STAR	28.13		2.50	
ZONA 3	STAR	H		0.39		1
	H	STAR	27.04		2.50	
	STAR	I		0.43		1
	I	STAR	25.58		2.50	
	STAR	DISPATCH		0.30		1
	DISPTACH	STAR	30.50		2.50	

Table 33 Main line to different key point option – towing AGV

(Own elaboration)

Results:

This option shows the possibility to send 01 AGV with 04 trolleys from main line to different Key points only. Thus, the AGV will not be allowed to include other possible tasks.

The maximum quantity required is **0.43 AGV**.

- From small + manual lines to different key points and zones.

	INITIAL POINT	FINAL POINT	DIFFERENCE WITH THROUGHPUT	AGV REQUIRED	FINAL OUTPUT WITH AGV APPLIED	TOTAL AGV
ZONE 1	STAR	A				
	A	STAR	35.58	0.27	2.50	1
	STAR	B				
	B	STAR	39.50	0.19	2.50	1
	STAR	C				
	C	STAR	37.00	0.24	2.50	1
	STAR	D				
	D	STAR	34.38	0.30	2.50	1
ZONE 2	STAR	E				
	E	STAR	45.58	0.05	2.50	1
	STAR	F				
	F	STAR	43.38	0.10	2.50	1
	STAR	G				
	G	STAR	41.33	0.15	2.50	1
ZONA 3	STAR	H				
	H	STAR	40.17	0.17	2.50	1
	STAR	I				
	I	STAR	38.88	0.20	2.50	1
	STAR	DISPATCH				
	DISPTACH	STAR	43.50	0.10	2.50	1

Table 34 Small and manual lines to different key point option – towing AGV (Own elaboration)

<u>Results:</u>

This option shows the possibility to send 01 AGV with 04 trolleys from secondary lines to different Key points only. Thus, the AGV will not be allowed to include other possible tasks.

The maximum quantity required is **0.30 AGV**.

- From greenhouses key points to delivery area.

	INITIAL POINT	FINAL POINT	DIFFERENCE WITH THROUGHPUT	AGV REQUIRED	FINAL OUTPUT WITH AGV APPLIED	TOTAL AGV
ZONE 1	A	DELIVERY	12.61	0.65	2.50	1.00
	DELIVERY	D				
	D	DELIVERY	12.82	0.64	2.50	1.00
	DELIVERY	C				
	C	DELIVERY	15.53	0.54	2.50	1.00
	DELIVERY	B				
	B	DELIVERY	21.34	0.34	2.50	1.00
ZONE 2	DELIVERY	E				
	E	DELIVERY	25.94	0.18	2.50	1.00
	DELIVERY	F				
	F	DELIVERY	24.84	0.22	2.50	1.00
	DELIVERY	G				
	G	DELIVERY	24.22	0.24	2.50	1.00
ZONA 3	DELIVERY	H				
	H	DELIVERY	23.92	0.25	2.50	1.00
	DELIVERY	I				
	I	DELIVERY	17.24	0.48	2.50	1.00
	DELIVERY	D				

Table 35 Greenhouse to different delivery area option – towing AGV (Own elaboration)

Results:

This option shows the possibility to send 01 AGV with 04 trolleys from greenhouses to delivery area. Thus, the AGV will not be allowed to include other possible tasks. As a difference of the last two analysis, this activity require more AGVs. The AGV will not be able to go from a key point at a greenhouse to delivery area and return to other key point within the batch time and using 01 AGV only. Therefore, the Zone 1 requires 2.17 AGVs and the total quantity required in this process are **3.55 AGVs**.

Finally, the total AGVs required to achieve the current performance (throughputs) are:

NO MIXING PROCESSES	
Main line to all zones	0.43
Small + manual prod line to all zones	0.30
Delivery area from zones	3.55
Total AGVs required	4.27
Total AGV	**5**

Table 36 Total AGV required for option "Not mixing processes" (Own elaboration)

II. Mixing key points:

Mixing process analysis combine tasks from the different key points, delivery area, and production lines. The throughput to be used are the batch time from production lines only, as it could avoid bottlenecks on production area. It is recommended to check the section "C" in appendix XIII before analyse the following results.

It is necessary to establish a common variable to compare performance of towing and lifter option when process performance are mixed. Therefore, the analysis uses 6, 8 and 16 "travel points" to evaluate the changing on the quantity of AGVs. The maximum quantity of AGV to evaluate are 04, as it was the best option of the "not mixing processes".

Please read the appendix XIII carefully before the following results:

Qty of Travel points	Qty of AGV required – "Lifter"	Qty of AGV required – "Towing"
6	1.36	0.81
8	2.16	1.30
16	3.95	2.38

Table 37 Total AGV required for option "Mixing processes"

(Own elaboration)

Finally, the next table shows the comparison among the 4 different options on 3 common variables.

Variable to compare	AGV lifter – not mixing processes	AGV towing – not mixing processes	Qty of AGV required – "Lifter"	Qty of AGV required – "Towing"
Total Key points to cover per cycle	11	11	16	16
Total AGV required	5.16	4.27	3.95	2.38
Total trolley to handling per cycle	22	44	32	64

Table 38 Final comparison of AGV's options

(Own elaboration)

Finally, it is possible to verify that the towing option and mixing processes is the most efficient alternative. The AGV is able to carry more trolleys (total of trolleys) and move them through 16 different key points on the company's layout. Therefore, all option to be selected will replace the forklift machine and its drivers.

6. Market overview

The market overview reflects a summary of the agriculture industry by providing an up to date analysis of its sectors, specifically the horticultural, the drivers and the external balance of forces regulating it. These summary reports profile the key activities within the market, outlining its current state, as well as the short-term future following the introduction of automation technologies. Fundamentally determining the viability of the industry as an avenue for technological investment.

6.1 Agriculture Industry

The industry is subdivided into two categories: livestock (activates relating to the raising and use of animals in the farm) and crops (activities relating to the cultivation and harvesting of field and cereals, potatoes, protected fruits, vegetables and plants) (Harris and Fuller, 2014). These activities are a cornerstone of society as they provide the resources to the essential human right to food. In the United Kingdom, 69% of the land area is utilized by the industry, employing upwards of 477.000 workers (National Statistics, 2019).

However, the industry is facing a downfall. In 2018 the total income from agriculture dropped 17% from the year prior, to £4,697 million which was reflected in its contribution to the GDP £9,586 million, a 6% decrease. There being two main reasons for this, a drop in production, the increases in costs (National Statistics, 2019).

6.2 Agriculture production

Agriculture's gross output increased 2% to £26,651 million, this was driven by the livestock sector, which account for slightly more than half of the output value. Contrastingly, the crops suffered a 2% decrease falling to £9,388 million of which about 37% came from horticulture. This is of especial importance as the companies in question operate in this market (National Statistics, 2019).

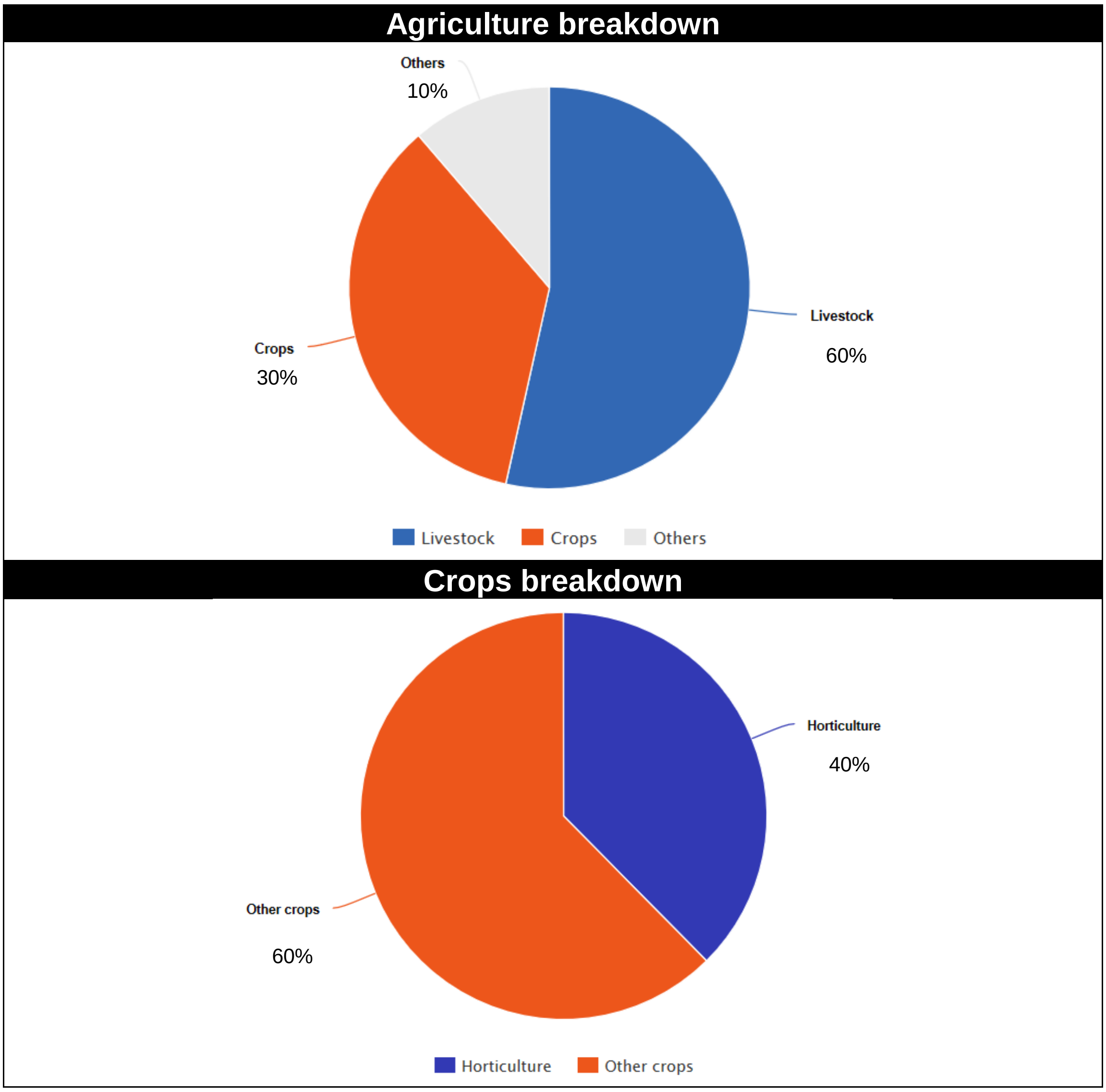


Fig. 10 Agriculture & crops market breakdown

(Own elaboration)

Further analysing horticulture, it is characterised by three aggregates of crop types: vegetables, fruits and ornamentals. All three experienced a decrease in volume of production, having vegetables suffered the largest decrease in production, especially field vegetables (National Statistics, 2019).

The reason for the steep downfall in volume output is attributed to the harsh weather conditions experienced all throughout 2018, having an extremely dry summer and an abnormally cold winter resulted in the volume shrinking by ~4% when compared to 2017.

Although the production dropped, the gross output of horticulture only suffered a minor change, dropping 2%. This was due to the increase in product price, as each commodity continued to experience the growth trend, thus rising 6.9% from last year.

Finally, the final value of the output volume produced by the agriculture industry still rose, as the offset served to compensate the aforementioned factors, which had a minor effect on the livestock half (National Statistics, 2019).

6.3 *Costs*

Costs as a whole experienced an increase as nearly all cost of production increased. This was driven two factors: compensation of employees and intermediate consumption cost.

Compensation of employee's accounts for the payment wages to employees, this continues to rise as both the minimum salary in the UK increased to £7.70, alongside the small increase (0.6%) in the number of fulltime farmers and regular employers created this situation.

Lastly, the total intermediate consumption cost was a major culprit of the decrease in market income, as it affected every activity in agriculture. While it accounts for a large agglomerate of expenses, the largest contributors are: animal feed, energy and fertilisers.

Animal feed increased by 10% when compared to the prior year, standing close to £5.6 billion in costs, it being the largest item of expenditure. Driving up the value of animal meal is the constant increase in demand and exchange rates/world prices.

Energy cost rose to £1,346 million as the price of oil and gas has increased globally, yet the growing concern to reduce consumptions helped mitigate a large impact. However, energy prices have a substantial influence on the cost of fertilisers.

Fertilisers require an energy intensive manufacturing process therefore, both through the increased demand energy price increases, so has the fertilizer costs reaching £1,345 million, £116 million more than 2017 (National Statistics, 2019).

Therefore, this unsustainable balance has to be addressed as increasing the price is only a short-term solution for the ever-increasing climate changes and employer wage. Technology aims to abet these factors.

6.4 *Macro-analysis*

As observed the factors affecting the market are external, thus a complete macro analysis aids to define the likely path of the current state of the industry and its future through the introduction of automation and technological solutions (Agri-tech). This is accomplished through a PESTEL analysis for both the horticulture market and the Agri-tech market detailed in Table 41.

From both analysis, it is possible to extrapolate the opportunities and threats of the market, as well as how agri-tech serves to improve present shortcoming of the industry. Below is a list of the biggest factors and their relationships (Satellite Applications Catapult, 2019)(AHDB, 2019).

Furthermore, the macro analysis is complemented with the understanding of the industry competitor forces. These can be summarised with the undifferentiability of both buyers and suppliers, which birth a competitive market mainly composed of small to medium farms, where the threat of substitution is low and so are new entrants unless championing a niche product.

Therefore, the market demonstrates an opportunity for a technological solution with the following characteristics:

1. Bespoke;
2. Data driven;
3. Autonomous;
4. UK developed;
5. Low to medium cost;
6. Compatible with other technologies.

<u>Why AGV is the Agri-tech solution?</u>

The technological solution that would address all the aforementioned characteristics is ambitious a compromise has to be done in order to satisfy the areas deemed most important. Therefore, there are three type of solutions, just as observed in the market: a fixed robot, an appendix robot or an autonomous robot. While a fixed robot or an appendix robot can be optimized do a specific task, one’s activity is restricted to a small area surrounding the fixed robot, while the other is dependent on an external mechanism to provide movement, like a tractor towing it.

Horticulture	Agri-tech
Political • Growing non-UK ownership of parts of UK supply chains. • Climate change and diet & nutrition are key issues for the government and drive policies. • Brexit uncertainty affects available workforce.	*Political* • Brexit uncertainty can readjust government priorities to champion technology. • International partnerships may be compromise due to Brexit.
Economical • UK economical regression. • Domestic production vulnerable to fluctuations. • Cost of production constant increase. • UK agriculture mainly small to medium farms.	*Economical* • Agri-tech opportunity to develop low cost solution. • Technology in agriculture influences production and profit.
Social • Increased consumer awareness of ethics and sustainability. • Consumer lack of trust in GMO and pesticides (science). • Decline in workforce. • Health and safety concerns. • Farmer isolation.	*Social* • Agri-tech helps connect communities. • Automation reduces health and safety concerns. • Technology reduces workforce. • Data driven technology helps reduce scepticism. • Training is required.
Technological • Poor IT understanding and adoption. • Coping reduced number of agrochemicals. • Lack of R&D for industry.	*Technological* • Technology often not compatible. • Technologies mainly adopted form other industries. • Poor internet connectivity in rural areas • Technology helps with the reduction of pesticides.
Environmental • Inability to match demand sustainably. • Water usage and disposal. • Introduction of alien species. • Climate change.	*Environmental* • Agri-tech helps manage and optimise resources. • Autonomous solutions must be robust
Legal • Challenges complying with regulations. • Brexit impact on legislation and enforcement of such. • Tax avoidance.	*Legal* • Post Brexit legislation must account for new technologies. • Technology helps better monitor production and sales. • Data privacy issues.

Table 39 PESTLE analysis

From the table we can decompose the following relationships:

Threat	Opportunity
Initial negative affects impacting the product chain and workforce;	The restructuring of the government priorities;
The observable trend of increase costs and market volatility;	Low cost automation solutions;
Ethics, sustainability and scepticism are end user growing concern.	Data driven technologies provides evidence.
Decline in workforce followed by health & safety concerns of increasingly old workforce;	Automation helps reduce labour intensive activities and reduces the overall number of workers required;
Low focus of R&D and bespoke technology. Tech not cross compatible;	Gap in the market for modular multipurpose specific solution;
Growing demand and use of finite resources (water, etc…);	Optimization of management of resources;
Ever-changing regulations and data privacy issues.	

Table 40 Threats and opportunities

Conversely, an autonomous robot can operate in a specific activity of a much wider range as it has freedom of movement, yet the opportunity to develop a modular platform capable of operating in different activities is appealing. This solution could be an AGV as a base platform, with the modularity coming from attachments, where the value would come from the versatility of the robot.

6.5 Market Analysis

The automation market is in full expansion and highly demanded since it allows to save in terms of labor costs, also improving the development of productive work in terms of production and efficiency (Lu, et al., 2017). Thus, in terms of economic projection, the size of the AGV's market is valued at around $2.49 billions with an expansion horizon of 15.8% during the 2019-2025 period (Grand View Research, 2019). Which implies that the sustained growth of the automation market will allow the solutions offered to first have support in logistic and after-sales terms, as well as research, develop and implement new technologies more adaptable to the increasingly demanding requirements and needs by customers. The solution would be applied to specific activities within not only the horticulture sector, but also the whole industry as these are closely paralleled across all sectors. There are 11 different activities identified, however the analysis will mainly focus on field crops shown in the Figure 11.

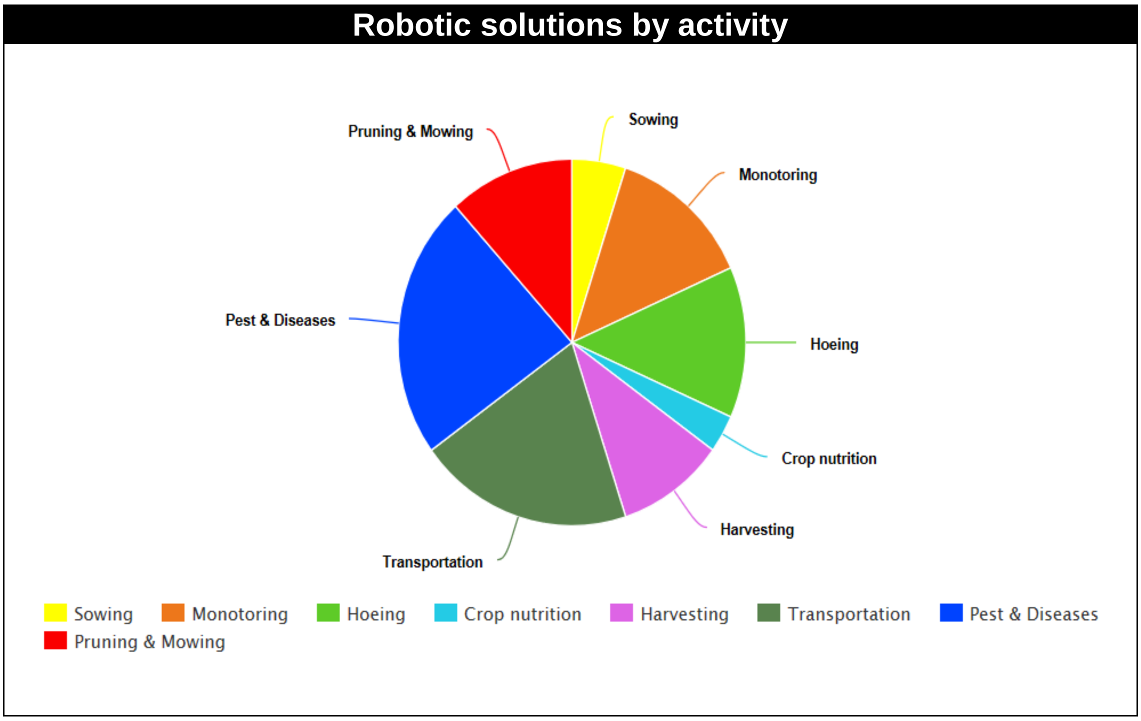


Fig. 11 Robotic solutions by activities

From the Figure 11, it can be observed that transportation and pest & diseases account for nearly half of the whole automation solutions, this is due to the simplicity and repeatability of the actions required (see the Appendix II). Contrastingly, sowing and crop nutrition represent the activities with the fewest number of automation solutions, this can be attributed to the necessity to carry the goods and distribute them accordingly, which adds a layer of complexity not experienced in the others.

The market in terms of geography is vastly diverse, with the companies that provide automation solutions ranging to 5 out of the 6 continents, however Europe and North America have most of the market, with ~30% and ~53% respectively. While the United Kingdom accounts for ~6.5% of the market evaluated.

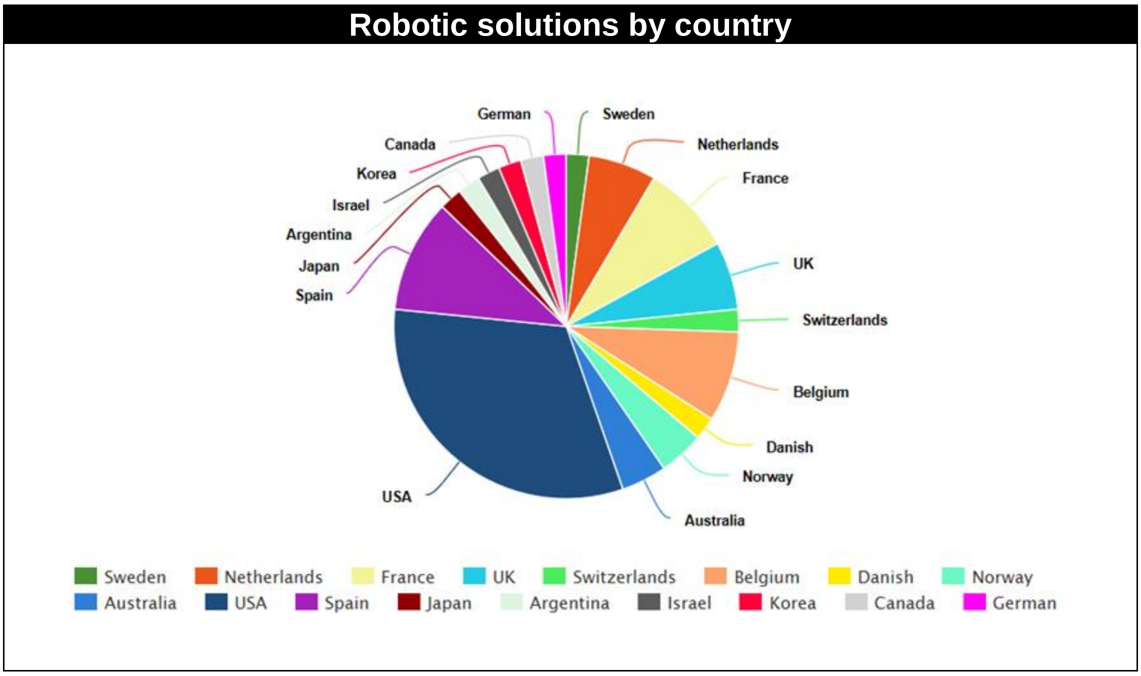
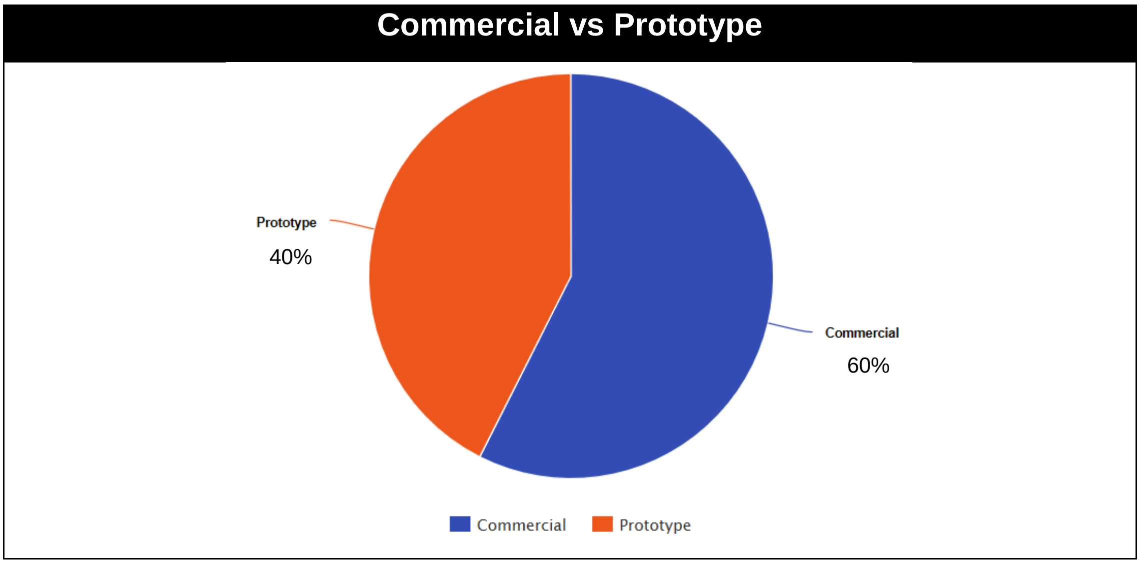


Fig. 12 Robotic solutions by country

Further analysing the sets of data collected, three noteworthy statistics are:

The market is somewhat at its infancy, as 43% of it is still prototypes. Also, rereinforced by the number of partnerships and joint ventures with universities, demonstrating the lack of technical expertise within the industry now.

When analysing the proposed type of solution, only 23% of the companies in the market deliver or have a prototype for a modular AGV platform (Information detailed in Appendix II).



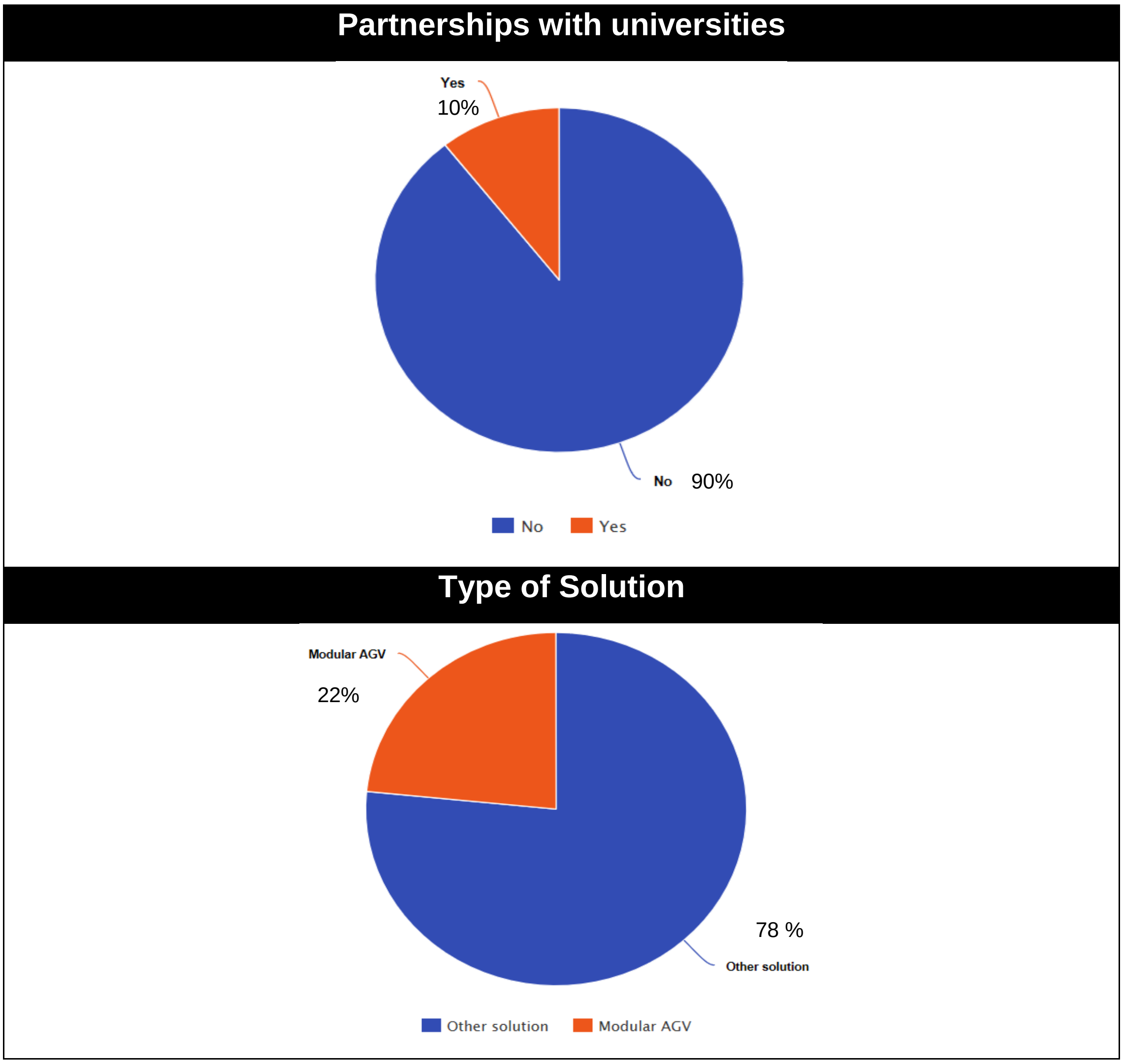


Fig. 13 Robotic solutions in-depth analysis

Finally, the feasibility according to the market analysis of delivering the ideally solution of a UK based company, capable of delivering a modular AGV platform is possible as there are companies that fit the criteria.

Consecuently, the technology selection entails the need to identify any automation solutions available in the market to satisfy the company requirements in order to improve their production cycle. Thus, the following solution details will indicate the best automation products currently available in the market.

There are different types of AGVs that allow you to perform various tasks according to the specific requirements for their use. Thus, autonomous guidance vehicles (AGVs) or driverless vehicles deliver versatility and flexibility through their programming capabilities to move to destination, route selection and positioning at predefined points.

In this way, autonomous guidance vehicles are divided into the following types:

- Towing AGVs (Designed to move trailers, pallets and cranes)
- Pallet truck AGVs (Designed to Lift, maneuver, and transport palletized load)
- Fork lift truck AGVs (Designed To pick-up and drop-off palletized load)
- Load transporter AGVs (Designed to move and distibute goods point-to-point)

However, depending on the type of AGV required, there is a large number of companies that develop autonomous guided vehicles (AGVs). Also, in relation to the search within the market there are several solutions available that are preliminary adjusted to the requirements of each company.

In addition, aspects regarding the cost of each solution, and other specifications such as load capacity, vehicle weight, average speed, dimensions, operating time, battery system and operating system will be considered.Therefore, each of them is detailed below.

6.5.1 **Thorvald**

Thorvald is a technology developer for agricultural field providing modular and versatile AIVs which are configured for diverse agricultural environments. Also, the mobile robotic platform can perform several tasks from picking fruits and vegetables to in-field transportation including data collection and crop prediction.

Modular Robotic platform (Outdoor)		
Cost	£80 K	
Payload	250 kg	
Weight	180 kg	
Speed	1.5 m/s	
Dimensions	825 x 1750 x 3000 mm	
Run times	10 h	
Batteries	48V Li-Ion batteries with 70 Ah	
Controller	Open arquitecture ROS	

6.5.2 **Clearpath Robotics**

Clearpath robotics is a technology developer of complex autonomous systems providing heavyduty AIVs for land, sea and industrial environments including learning platforms and a wide range of accesories such as sensors, manipulators and actuators, and cameras among others.

Warthog is a large all-terrain unmanned ground vehicle capable of traveling on land and in water. It can handle tough environments with its rugged build, low ground pressure, and traction tires, which allow effortless mobility through soft soils, vegetation, thick muds, and steep grades (Clearpath, 2019).

Warthog (Outdoor)		
Cost	65,000 USD	
Payload	272 kg kg	
Weight	280 kg	
Speed	18 km/h	
Dimensions	1.52 x 1.38 x 0.83 m	
Run times	3 hrs	
Batteries	110 Ah Li-Ion batteries	
Controller	ROS Indigo (includes RViz, Gazebo support). Matlab API available	

6.5.3 **Robotnik**

Robotnik is a mobile robot paltform development and manufacturing company providing Autoamtion solutions for logistics, security & defence, inspection and maintenance and agruiculture among others. Also, in the agricultural field they develop an Agrirobot project to harvesting stage or VinBot for autonomous cloud –computing vineyard to optimise yield management.

RB-SHERPA is a general purpose mobile platform designed to target logistics tasks.. In this sense, RB-SHERPA is suitable for logistics tasks in warehouses or pick & transport & place applications (Robotnik, 2019).

RB-SHERPA (Outdoor)		
Cost	>£45k	
Payload	100 kg	
Weight	123 Kg	
Speed	3 m/s	
Dimensions	1,142 x 1,413 x 626mm	
Run times	10 h	
Batteries	LiFeP04 15Ah@48V	
Controller	N/A	

6.5.4 Oceaneering

Oceaneering is a technology company with one focus on developing, implementing innovative logistic solutions based on AGVs technology. Also, their AGV systems provide an increase in productivity reducing operating costs thorugh advanced control software optimising the custoemers needs.

UniMOVER - Mini (Indoor)		
Cost	>£45k	
Payload	700 kg	
Weight	120 Kg	
Speed	1.6 m/s	
Dimensions	265 x 68 x 38.5 cm	
Run times	8 h Aprox.	
Batteries	Lead acid: 24V/100Ah	
Controller	N/A	

The UniMover Mini offer a haigh capability in a compact design with an exceptional maneuverability required to transport high to medium loads. Also, includes a superfrog supervisory software system control fleet and traffic amangement collecting performance data, battery comsupmtion and control multiple AGVs in the same layout (Oceaneering, 2019).

Compact Mover FLT AGV Oceaneering (Indoor)		
Cost	>70k USD	
Payload	800 kg	
Weight	190 Kg	
Speed	1.6 m/s	
Dimensions	230.0 x 93.5 x 160.0cm	
Run times	8 h Aprox.	
Batteries	Lead acid: 24V/420Ah	
Controller	ROS	

6.5.5 Robtonik

SUMMIT-XL STEEL is a robotic platform for application development (logistics, indoor transport, etc.). It has a robust design and can carry up to 250 kg payload.

Also, the AGV has skid-steering and omnidirectional kinematic providing an aoutonomous navigation system and can be setting up with a diferent types of sensors (Robotnik, 2019).

SUMMIT-XL STEEL (Indoor)		
Cost	>£25k	
Payload	105 kg	
Weight	250 Kg	
Speed	3 m/s	
Dimensions	847 x 663 x 509 mm	
Run times	10 h	
Batteries	LiFePO4 15Ah 48V	
Controller	Open arquitecture ROS / Integrated PC with Linux (Intel BayTrail J1900 or similar)	

6.5.6 Mobile Industrial Robots

Mobile industrial robots is a leading AIVs manufacturer company based in Denmark, with focus on to provide a quality solutions and developing user-friendly robots to help companies increase product operations to reach a fast return of investment.

With extraordinary flexibility and smart technology, the MiR200 can be used in nearly any situation where employees are spending time pushing carts or making deliveries. Also, it can be mounted with customized top modules such as bins, racks, lifts, conveyors or even a collaborative robot arm, including safe an efficient maneuvering to avoid people around and obstacles (MIR, 2019).

MiR 200 (Indoor)		
Cost	25k Aprox.	
Payload	63 kg	
Weight	200 Kg	
Speed	1.1 m/s	
Dimensions	890 x 580 x 352 mm	
Run times	10 h	
Batteries	Li-NMC, 24 V, 40 Ah	
Controller	Open arquitecture ROS	

6.5.7 Savant Automation

Savant Automation's company design and develop in-house solutions using inertial guidance, and DC-10S Automatic Guided Vehicle is a compact load transporter.

The new generation design incorporates the latest technologies and features that customers have stressed are important for automated material handling systems. The AGV can be provided with various configurations to adapt to most any application (AGVSYSTEMS, 2019).

DC-10S (Indoor)	
Cost	50k Aprox.
Payload	900 kg
Weight	180 Kg
Speed	1.03 m/s
Dimensions	1560 x 510 x 330 mm
Run times	8 h
Batteries	Two (2) 12V, 89 amp-hour sealed
Controller	Can BUS

6.5.8 Kuka

The KUKA is company who offer a brad range of automation solutions, and their KMP 1500 represents a solution to the emerging demand in relation to shorter production times. Also, is an autonomously controlled platform that integrates seamlessly into any production process to optimizing the logistics management and provides cost-effective support for your warehouse organization.

KMP 1500 (Indoor)	
Cost	£67K
Payload	1500 kg
Weight	180 Kg
Speed	1 m/s
Dimensions	2000 x 800 x 470 mm
Run times	4 h
Batteries	52 Ah / 96 V (Minimum 4 hours)
Controller	ROS

6.5.9 Gebhardt

Gebhardt is an innovative company providing automated guided vehicles according to the high demand in logistic and complex scenarios changing production conditions and permitting short throughput time optimising while also optimizing utilization of individual stations for high overall availability.

In addition, Depending on AGV type, goods of different weights can be autonomously moved through the warehouse appliying dinamic route planning including RFID sensors to position the AGV in the requested area.

However, A characteristic feature of all GEBHARDT products is combining the most simple design with high effectiveness and long-lasting operational safety (Gebhardt, 2019).

KMP 1500 (Indoor)		
Cost	£35K aprox	
Payload	80 kg	
Weight	150 Kg aprox	
Speed	1.8 m/s	
Dimensions	990 x 680 x 1,240 mm	
Run times	10 h	
Batteries	Li-NMC battery	
Controller	ROS	

6.5.10 Innok Robotics

Innok Robotics is a developer and manufacturing company in the field of autonomous mobile robots - including mechanical, electrical and computer engineering with base in Germany. Also, they provide robot solutions that can be used efficiently and flexibly by companies of all sizes, in partucular in outdoor environments (Innok-Robotics, 2019).

In addition, they develop a modular software Innok Cockpit to cover all common navigation tasks, including remote control, following persons or following paths autonomously – Innok Cockpit handles all navigation tasks of a mobile robot (Innok-Robotics, 2019).

Induros –Towing AGV (Indoor / Outdoor)		
Cost	£ 40k aprox	
Payload	400 kg	
Weight	Kg aprox	
Speed	m/s	
Dimensions	920 x 720 x 1440 mm	
Run times	10 h	
Batteries	battery	
Controller		

With the use of AVG’s in the horticulture sector, it will allow the moving products within their respective production lines in a flexible manner and will minimize human intervention, retricting it to only for specific tasks such as loading or unloading, as necessary. However, it requires a synchronization of the AGVs within the production line that allows the optimization of the workload to obtaining the required performance.

Having analyzed the market in general terms, we can state that the available solutions represent fixed alternatives that do not tend to solve the functional requirements derived from the analyzes performed at each company. that is to say, to achieve a solution that meets these requirements, an analysis must be carried out to identify a concept design prototype for each company oriented in the modularity and adaptability that also allows other sectors of agriculture to be approached.

7. Conceptual design idea and criteria

The conceptual design is based on the functional requirements of the processes analysed on the last headings. The conceptual design shows visually what could be the "state of art" and researchers' future vision of what AGV could be the most appropriate according to the current project's requirement. Therefore, the different technologies from the conceptual design would need, potentially, to be redesigned and reanalysed during the next stage, in order to obtain the final AGV design to prototype.

7.1 General idea of the AGV's conceptual design.

7.1.1 Crystal Heart

- AGV functional requirements:

➢ The AGV needs to place and lift trays to/from the ground and then return to the batch area before the takt time (batch time).
➢ The space between trays placed on the greenhouses and outside should be less than 1 cm.

- Description of the conceptual ideas:

Two conceptual ideas are selected from the results of the previous headings. First, there is a possibility to move 30 trays and second, move only 20. On one hand, 30 trays were decided has the AGV will tried to maintain the same procedures of the company. On the other hand, 20 trays were selected has it represents a better alternative in terms of use of resources (AGV quantity) regarding 10 trays (see table 24). The two alternatives are described as following:

➢ **"30 Trays" AGV.**

The conceptual idea of "30 trays" AGV is to use this vehicle link with the current lay-flat machine. This vehicle can move 27 to 36 trays, but it was fixed on 30 for this study. As it was mention before, the AGV will replicate the same tasks that forklift drivers do with the machine and the current tray's platform. However, it is difficult to design and AGV able to move a flat batch of 30 trays. The main inconvenient are the size of the platform (4.65 m x 2.22 m), manoeuvrability and the potential health risks to operators.

Additionally, the idea of towing the platform was discarded, as the high time of movement, low manoeuvrability and the difficulty to integrate a robotic mechanism to unload trays from the platform. Therefore, the AGV's design integrates 3 layer platform linked by a chain of hooks. The idea is shown in the following figure:

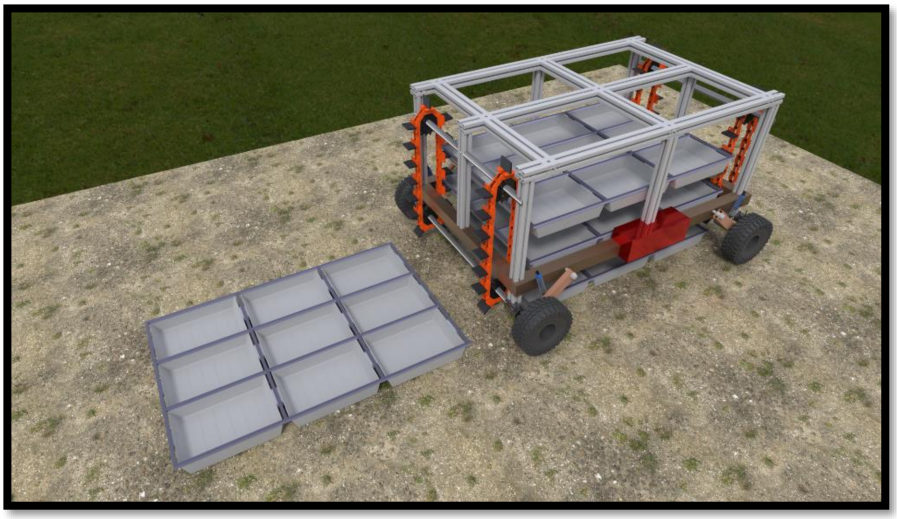


Fig. 14 "30 trays" AGV conceptual Idea

(Own elaboration)

The trays can be lifted by layer through the special hooks indicated on the figure (black colour on the orange chain) from the lay-flat machine. According to James Bean, this machine can be adapted to unstack different quantity of trays. Then, the AGV will go to greenhouses and will execute the inverse process. It will need to approach the last batch of trays (already on the ground) and place the new batch close to each other. Then, the AGV moves back and will place the second and third layer of trays respectively. In the case of the process from greenhouse to outside, the AGV will needs to approach to the right line of trays and lift in batch of 9. Then the processes to take trays down is the inverse process.

- **"20 Trays" AGV.**

This AGV is an alternative solution to the current processes. This option will eliminate the lay-flat process from the lay-flat machine. However, the unstack task will need to be done by the AGV itself. A forklift will bring the columns outside the germination room, then, AGVs will need to approach to columns and pick 2 columns of 10 trays. A basic design of the lifter mechanism is shown on the following Figure:

Fig. 15 Basic idea of the Lifter mechanism

(Own elaboration)

As a difference with the “30 trays” AGV, the “20 trays” AGV needs to be open at front in order to take the 02 columns required. Once the columns are loaded, the AGV will drive to greenhouses and it needs to be able to unstack trays to the ground. The process is inverted when the process takes part from greenhouses to outside. The AGV will need to stack trays from the ground and unstack again outside. Then it will need to approach to the trays that are already on the ground and place 2 trays at the time. These trays need to be close to each other (the limit is 01 cm of space between trays). Then, the AGV will rotate the wheels in 90 degrees and it will start to take down trays from one side to the other on the same line.

Therefore, this AGV needs to include a special mechanism to execute the stack and unstacking tasks. The following figures show the conceptual idea of a robotic arm required.

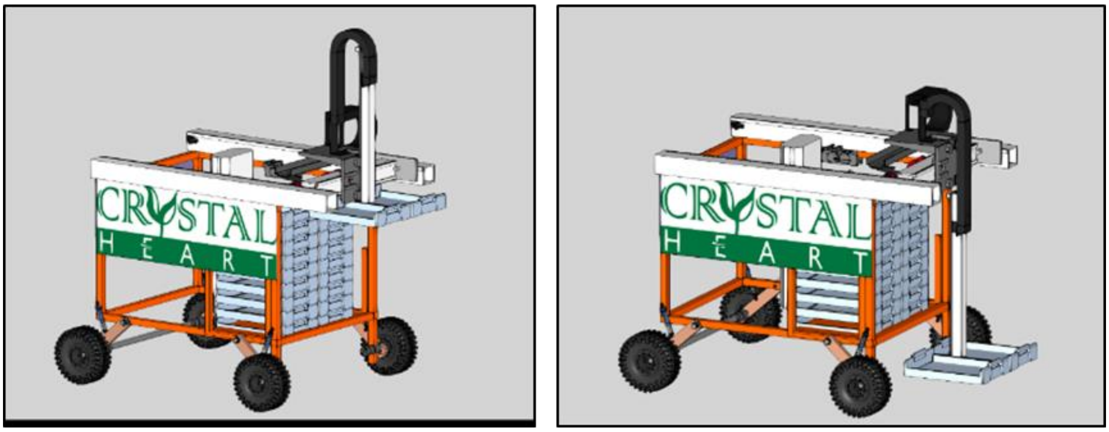


Fig. 16 Basic idea of the robotic mechanism

(Own elaboration)

7.1.2 Valefresco

➢ AGV functional requirements:

- The company require an AGV able to transit through in narrow aisles.
- AGV needs to turn in a short radio.
- 01 trolley needs to be transported all time (empty or full)

➢ Description of the conceptual idea:

The width and height of every aisle is 1.1 m and 2 m respectively. This restriction does not allow to introduce a towing AGV as a conceptual solution.
The Valefresco's AGV is a narrow AGV able to transport 01 trolley at the time. This trolley has the capacity to carry 09-10 boxes in order to match with the company requirements explains the material flow and movement).The conceptual idea start on the "empty room". The AGV needs to pick a trolley with empty boxes (09 boxes according to company data) and moving it to the harvesting area. Then, the trolley is took down close to the operator at one side of the aisle (top). On the other side of the aisle (bottom), the full trolley is picked by another AGV and it is transported to the "refrigeration room".
Therefore, it was mention 03 important variables to consider on the AGV's design. First, the AGV cannot be wider than 1 m. Second, the AGV needs to integrate a lifter mechanism in order to elevate trolleys. Third, the AGV require a clamping mechanism in order to affix trolley and avoid any undesirable movement when it is being lifted and/or transported.

The next figure shows the conceptual idea of the Valefresco's AGV.

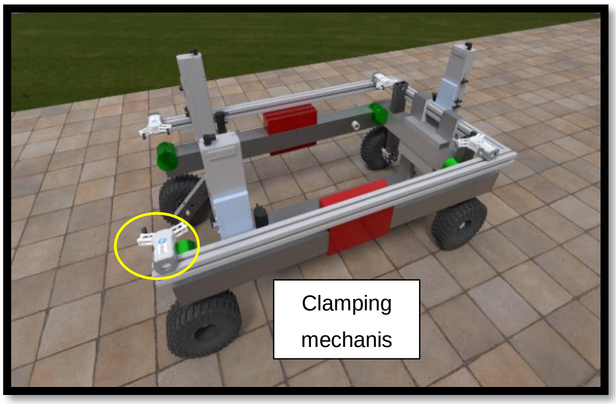


Fig. 17 Conceptual idea of Valefresco's AGV

(Own elaboration)

7.1.3 **WD Smith**

- AGV functional requirements:
  - AGV needs to transit longer distances than in Crystal Heart and Valefresco.
  - 02 trolley are required to be carried at the same time.
  - Towing task needs to be included as an extra function of the AGV.

- Description of the conceptual idea:

WD Smith needs to transport trolleys from production lines areas to the different key points. Two types of AGV were evaluated in previous headings, "towing" and "lifter" AGV. The towing AGV should have a capacity to pull a trailer with 04 trolleys. The lifter AGV needs to transport two AGVs at the same time.

"Lifter" AGV has the same features required to Valefresco's AGV, but in WD Smith the AGV needs to carry two trolleys. This impacts on the payload as the weight is incremented to the double. As a consequence, the battery system could change regarding the Valefresco's AGV as it needs more capacity to get the same operation hours. Therefore, this AGV will require:

- Clamping mechanism to affix load.
- Lifter system.
- Open at the front. The size would be approximately the double that Valefresco's AGV.

A pulling capacity is required in order to design a “towing AGV”. In this way, it is necessary to calculate other factors such as traction, torque, force, etc. that allow to define if the same lifter AGV (simple or double) could be able to tow a trailer with 04 trolleys or if it is necessary to improve other capacities of the vehicle. However, the commercial research shows that the towing capacity can be easily integrated to AGV. Therefore, the towing capacity needs to be evaluated as an additional capability to the AGV that will not limit other modular solutions.
The following figure 18 shows the conceptual idea of the WD smith “Lifter” AGV.

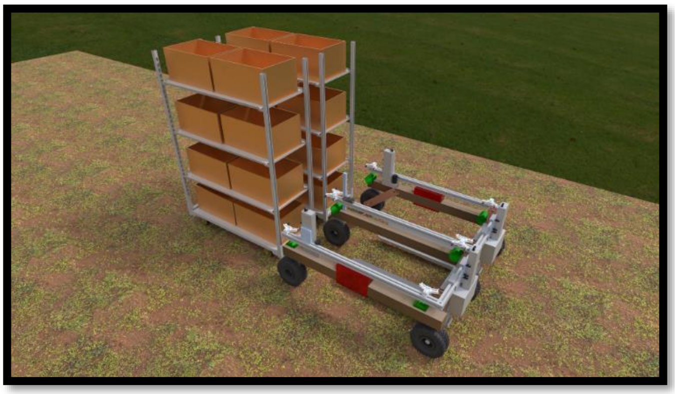


Fig. 18 Conceptual idea of the WD Smith’s AGV
(Own elaboration)

It is possible to identify on the figure above, that the AGV require to be very accurate in order to pick trolleys to transport. This is an example of different difficulties or problems that the development of this technology needs to consider, understand and face on the next stage.

7.1.4 **Main problems and challenges to face.**

The results of the analysis from the previous headings help to design the conceptual ideas of AGV per company. However, there are different design problems and challenges that need to be identified to obtain the final AGV concept and determine the preliminary specification.
Therefore, the main problems per company are the indicated in the following table:

Crystal heart	Valefresco	WD Smith
Size of the AGV to move 30 trays *(The expected size of this AGV is 209.5 cm (length) x 143.5 cm (width) x 87 cm (height))*	Narrow driving *(Maximum allowed 90 cm)*	Trolley's proximity accuracy *(AGV needs to detect the best way to pick trolleys)*
Payload to carry *(This is a trade-off between battery duration, AGV architecture and payload to carry) Total payload for "30 trays" AGV = 300 KG + platforms weight*	Battery duration *(10 hours. This will impact on the type, weight and size of the battery)*	Trolley identification *(AGV needs to identify the right trolley among a group of trolleys at the same area)*
AGV weight without load *(AGV weight This impact on the battery performance)*	AGV weight without load *(AGV weight This impact on the battery performance)*	AGV weight without load *(AGV weight This impact on the battery performance)*
Battery duration *(10 hours. This will impact on the type, weight and size of the battery)*	Accuracy performance to going through aisles *(AGV needs to detect tubes of lettuces at the access and while it is moving throw aisles)*	Battery duration *(10 hours. This will impact on the type, weight and size of the battery)*
Accuracy to place trays within 01 centimetre of error *(Trays to be placed on the ground cannot be separated more than 01 Cm)*	Clamping mechanism and the payload of trolley *(This mechanism helps to affix the trolley to the AGV and avoid risky movements)*	Payload to carry *(This is a trade-off between battery duration, AGV architecture and payload to carry)*
Trays identification *(AGV needs to identify those trays on the ground that need to be moved to other location)*	Trolley identification *(AGV needs to identify the right trolley among a group of trolleys at the same area)*	Stabilization control *(Some ground locations on the company are not flat and load needs to be protected)*
Column identification *(AGV needs to identify those columns on the ground that need to be moved to other location)*	AGVs synchronisation *(Arrivals of AGVs to aisles needs to be synchronised according to the manual harvesting process of operator)*	Crossing and proximity sensors *(The risk of collision on the public lane needs to be avoided)*
Production Schedule synchronised with fleet manager *(Production data and fleet manager need to working synchronised and dynamically).*	Lifter system *(AGV needs to lift a trolley from the ground. A special system needs to be added to the AGV)*	Production Schedule *(Production data and fleet manager need to work synchronised and dynamically).*
Loading and unloading accuracy and time *(The time for loading and unloading can impact on the total cycle time and, so, on AGVs required)*	Trolley's proximity accuracy *(AGV needs to detect the best way to pick trolleys)*	Towing capacity *(Towing capacity needs to be measured and integrated to the AGV)*
Robotic arm design and its coupling to the "20 trays" AGV *(Currently, speed of loading/unloading trays is a big constraint to get the required performance)*	Off road Condition (Rain, cold, mud, etc.). *(AGV needs to be weatherproofs and face difficult terrains, rain and mud)*	Lifter system *(AGV needs to lift 2 trolleys from the ground. A special system needs to be added to the AGV)*
Hooks design to operate the "30 trays" AGV *(Hooks of the lift chain and of the batch platforms need to be design carefully. This development can probably take time to be achieved)*		Clamping mechanism and the payload of trolley *(This mechanism helps to affix the trolley to the AGV and avoid risky movements)*
Coupling design for batch's platform *(The layer platform will take 9 trays at the same time. The middle trays need to be link in a way that do not reduce efficiency when trays are being took down to the ground)*		Communication range *(AGV needs to travel long distances. Communication with the fleet manager system cannot be lose)*
Off road Condition (Rain, cold, mud, etc.). *(AGV needs to be weatherproofs and face difficult terrains, rain and mud)*		Off road Condition (Rain, cold, mud, etc.). *(AGV needs to be weatherproofs and face difficult terrains, rain and mud)*

Table 41 Main problem and challenge during the identification of the final AGV concept

7.2 Conceptual design idea.

The AGV to propose as a final conceptual design comes to provide a potential solution to the evaluated companies. However, there is a possibility to cover new market's options or activities indicated on the Market Research.

This report describe, define and analyse the different requirements per company in term of production performance, material flow and handling, and efficiency.

This conclusion allowed to establish the potential conceptual ideas per company. These are based on the main requirements, critical factors and problems / challenges detected. The understanding of these variables will help to arrive to the final concept of the AGV, the preliminary specification and at the beginning of the next stage.

The "30 tray" AGV option for Crystal Heart will not be consider due to three important factors the lifter system, size of AGV, and the space between trays. For WD Smith, the lifter AGV will need to include the towing capacity. Same situation will be prove on Valefresco's AGV. However, a towing AGV will not be used on Valefresco but the same trolley with towing capacity can be used on WD Smith. In this case, WD Smith AGV will use an AGV without lifter system but with a towing capacity and with the size and capabilities of Valefresco's AGV.

The final conceptual idea is to establish an "AGV base" with limited capacities but with the potentiality to be integrated with other technologies. The new capabilities will allow to the AGV to increase functionality and modularity. The functionality is improved as the companies can use the AGV to more than one specific function. The modularity is an implicit concept when different technologies can interact and work together in order to achieve the same objective. For instance, WD smith can use the towing AGV to pull a trailer or to tow a horticulture machine. The figures below show example of different functions and modularity.

Figure 19

Figure 20

Fig. 19, Source: https://www.forbes.com/sites/alanohnsman/2018/12/13/honda-cant-sell-you-a-self-driving-car-yet-but-how-about-a-robot-atv/

Fig. 20 , Source: https://pragmatic-net.eu/product-name/husky/

Therefore, although the final concept of the AGV can be used to face the current problem of the companies on study, it is possible to escalate the final concept to different activities of Agriculture and Horticulture sectors. Under this point of view, the researcher believe that the final conceptual idea will not need to be based on the current problem of the three analysed companies only, but on other activities detected on the Market Research as well. This vision allow to increase the potential functionalities and modularity of the AGV. Thus, the market analysis shown on the appendix II becomes relevant to understand where are the potential GAPs to face in term of technologies and which type of activities can be automated.

To get the final idea of the AGV, it is necessary to understand the different systems, subsystems, technical discrimination's factor, and the potential components that are part of this technology. The next figure shows the different systems defined to this project (Please note that the parts shown do not represent the final concept to propose)

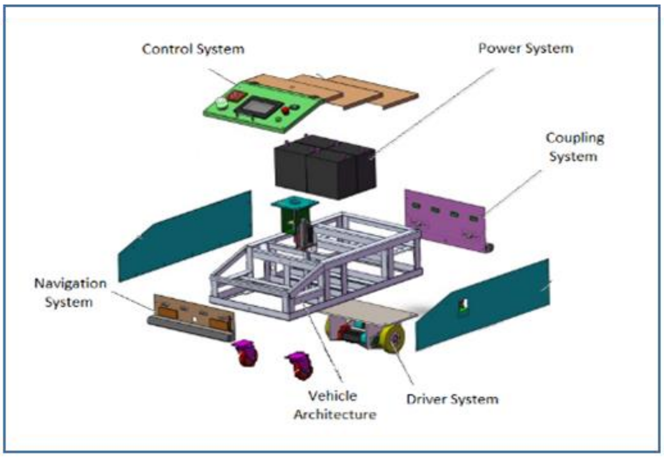


Fig. 21 AGV system breakdown

(Own elaboration)

The technical discrimination's factors allow (per subsystem) to understand which technical aspects need to be define on the AGV's specification. For instance, "Payload" is a critical factor that need to be evaluated and defined. In this way, the factor is defined as 220 kg (Crystal Heart), 120 KG (Valefresco), and 240 kg

(WD Smith). Thus, 56 different factors were detected in order to define the final AGV, its functionality and modularity.

Additionally, it is important to understand the potential option that can be included to the final AGV. Once factors are defined, it is necessary to evaluate the components that need to be potentially installed/placed on the AGV. This final evaluation will be done on the next stage of the project. However, the potential component to use are indicated in the appendix XIV.

7.2.1 Preliminary AGV's specifications

The preliminary specification are the base to define the final conceptual idea of the AGV. These are the different conditions, variables, function, etc. that the AGV require to operate. As it was indicated before, the specification were detected according to both important aspects, the results of the analyses of the current companies and the potential commercial uses detected on others Agriculture's activities.

The preliminary specifications contain 56 different technical factors. Some of them cannot be predefined at this stage, as it is require additional evaluations and/or measurement in order to get the final specifications. Thus, the next stage become relevant as it needs to obtain the final measurement and its "acceptance criteria" for every factor.

The preliminary specification are detailed on the appendix XIV. Additionally, the appendix XV shows the linkage between the critical factors and the different AGV's systems identified.

7.2.2 Final conceptual design of the AGV

Although the final conceptual design is feasible to design according to the preliminary specification results, some of the specifications needs to be calculated and obtained on the next stage of the project. However, there are not limitations to affirm that the AGV to propose is feasible to achieve from the technical point of view.

The "AGV base", will be able to incorporate devices, sensors, robots, etc. in order to increase the level of modularity and functionality. The preliminary specification is based on the results of the analysis of the "20 trays" AGV (Crystal heart), Valefresco's AGV, and from the mix of "Lifter" and "Towing" AGV (WD Smith). Additionally, the market overview and its potential opportunities was considered at the moment to obtain the AGV's specifications.

Therefore, the "AGV base" and its potential modularity consider the following aspects:

"AGV Base" package (autonomous guided vehicle capable of transporting loads)
The AGV Base is able to carry material on the internal fixed platform. It uses sensors for location, proximity and collision and a limited capability to tow. However, the total towing capacity needs to be discussed on the next stage. The general information is the following: **Robot Structure:** • 89 CM open at front • AGV size Length: 1330 mm + frame ; Width: 890 mm + frame ; height: 80 mm • Off road suspension • Ground clearance 200 mm **Robot Capabilities:** • Carry a payload 220 kg • Max Speed 1.1 m/s • Water and dust resistant • Outdoors in wet and muddy terrains **Wheels:** • 4 wheels • 4x4 traction • Wheels 100 mm radius • 90° rotation of wheels **Battery:** • Operation time up to 5 hours • 2 batteries • Durability no less than3 years • Low maintenance • Overnight charging **Hardware & software** • ROS • Sensors - proximity and positioning • Communication system

• Navigation system and weather resistant • Fleet manager system • Safety standard
Potential modularity - Optional packages to be added (autonomous guided vehicle capable of self-loading/unloading payload)
• Special coupling mechanism: - Towing hook. Towing capacity up to 500 kg. - Robotic arm to stack and unstack load. - Forklift (lifter) • Operation time up to 10 hours • Chassis maximum 1130 mm • Payload 250 Kg • Increase level of accuracy on positioning and proximity to columns and unstack trays to the ground. • Sensor - coupling sensor adaptable • Adaptable to product in the payload • Flexible fleet manager • Other sensors: Inclination/tilt warning, gravity centre accuracy, temperature, emergency system.

Table 42 AGV Base and its potential modularity

(Own elaboration)

The figure 22 below shows the final AGV concept propose. This is an "AGV base" that is able to transport material on an internal fixed platform. The table above indicates the general description of this AGV.

According with the results of previous analysis, it is possible to integrate different modules. The examples modules are shown on the figure 23, 24, 25 and 26. These are robotic arm, towing hook, and lifter. The total optional package are indicated on the table above. The appendix XIV "preliminary specifications" group all the critical factors required for the "AGV Base" and the potential modularity integration.

Finally, the conceptual idea of the AGV to propose is shown in the following figures:

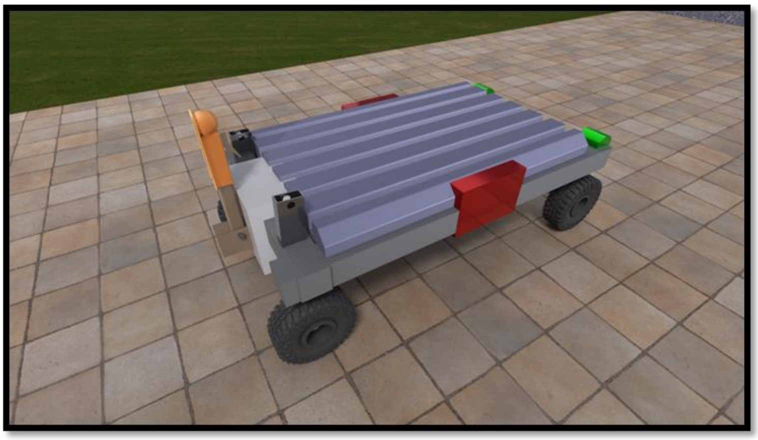


Fig. 22 AGV Base

(Own elaboration)

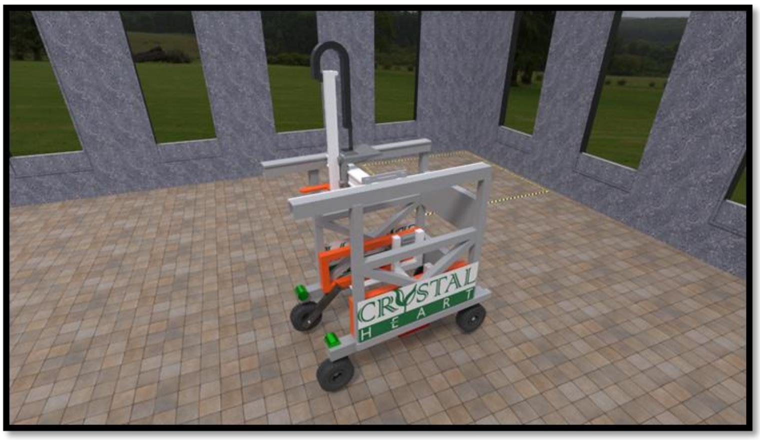


Fig. 23 AGV Base plus the "Crystal Heart" modules

(Own elaboration)

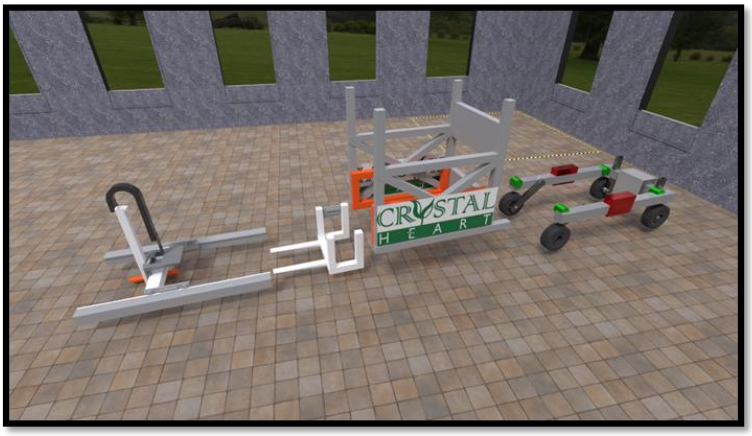


Fig. 24 Module's Breakdown of "Crystal heart's AGV"

(Own elaboration)

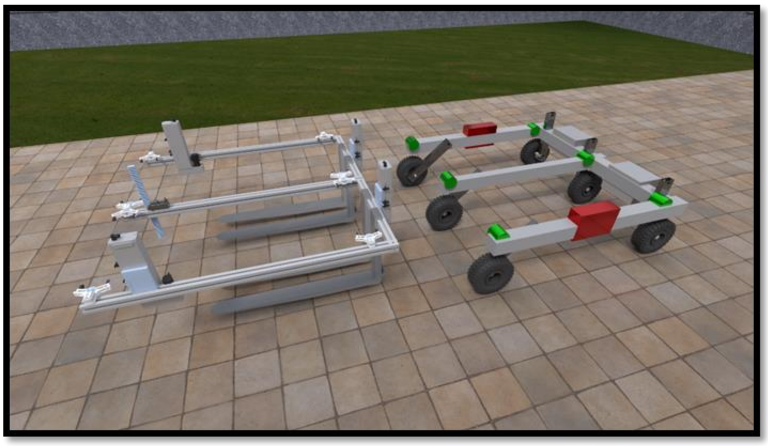


Fig. 25 Module's Breakdown of "WD Smith's AGV"

(Own elaboration)

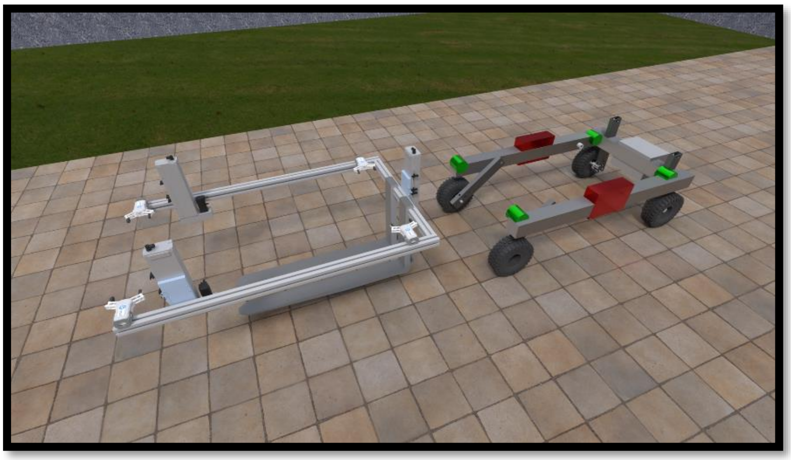


Fig. 26 Module's Breakdown of "Valefresco's AGV"

(Own elaboration)

The final part of the feasibility report integrates the financial feasibility. This heading evaluate if the investment on the AGV is feasible to achieve within an acceptable range of years.

8. Financial analysis - Business Case.

8.1 Impact of the technology to invest (benefits).

As it was stated on the market research, the AGV can improves internal logistics performance, and to help to reduce the labour cost, qualified jobs, and hiring problem. However, there are other benefits and some disadvantages to consider before introducing this type of technology.

Benefits:

- Reduce labour cost
  - Wages
  - Monetary benefits
  - Lost time
  - Recruitment time
  - Training
  - Injuries

- Increase accuracy and productivity
  - Reduce walking, motion, and transportation wastes from processes.
  - Can increase efficiency. Current analysis contemplate a safety time of 1.5 and 2.5 min. If this time is reduced the output can be increased. AGV will use a sensor for its operation in order to increase accuracy.
- Reduce manual error and product damage
  - AGV is configured to operate repeatedly and with the same standard of quality and safety.

- Increase workplace safety
  - AGV use sensor and devices for avoiding collision with people and/or infrastructure.

- Modularity and functionality
  - Different modules can be integrated in order to increase functionality.

- Operate continuously.
    - AGV can work overnight and in difficult weather conditions.

- Help to increase inventory control an accuracy.
    - Fleet manager software, production schedule and control system of the AGV needs to be synchronise to increase control over handled products and avoid inventory inefficiencies. For instance, moving a trolley that do not need to be dispatched in a short time, or use moving more trays/boxes that is required according to the production schedule.

Disadvantages:

- High initial investment
    - Although the price of AGV on the market has being decreased, it still be a high level of investment that include the quantity of AGV, charging station, software, and network (depending of the operating distances).

- Limited flexibility (Multitask activities)
    - There is difficult that an AGV can execute more than 01 or 02 objectives or tasks in the short time. Although the modularity help to face flexibility, it still be useful for a one or two particular tasks. Thus, the AGV cannot work as a human. As an example of this is explained by agvnetwork.com that indicates that forklift operator performs a defined job for 85% of its time and remaining 15% moves many other different things. Human manned vehicles can handle different sized loads and pallets, and they are flexible at handling different jobs. However, the flexibility can be increased if the companies' tasks/activities from processes are analysed, known, standardised, and evaluated in order to get the maximum performance.

It is possible to verify that there are more advantages than disadvantages. If the processes and tasks are efficiently planned, the only disadvantage can be the initial investment. However, the investment constraint can be faced by understanding both, the potential future benefits (efficiency) and cost savings that the introduction of AGVs can bring to a company. The performance of the AGV and its efficiency was previously analysed. The tangible results is the quantity of AGVs required per company. The cost saving is analysed in the next headings.

8.2 AGVs required by company.

The total AGV required by companies were justified in the technical analysis heading 5, and the following table summarise the different options suggested to be evaluated on the cost analysis:

	Crystal Heart Salad	Valefresco option 1	Valefresco option 2	WD Smith
AGV option suggested	20 tray AGV	(not apply)	(not apply)	Towing AGV
Alternative of process	Mixing processes	Get the current performance	Get more productivity	Mixing processes
Quantity of AGV required	2.56	04	06	2.38

Table 43 Final option to evaluate on the cost analysis (Own elaboration)

The table above shows the technological options suggested in term of efficiency and productivity. However, it is required to analyse what is the cost impact on the company, and how big is the potential investment required. Therefore, the final AGV option to suggest will be the combination between efficiency / productivity and cost.

Valefresco has two potential options. First, to use the current output analysed (with 04 AGVs), and second, to increase the productivity by reducing the 36% of operator waste (walking and picking). The option suggested is to get the current performance of the processes, as it the same variable considered to the other two companies (04 AGVs). The option to increase 36% of extra productivity needs to be contrasted with the cost evaluation and analyse future benefits and the return of investment. This second option uses 06 AGVs.

In the case of WD Smith, the “Lifter AGV” will not be analysed in term of cost, as it is not the most efficient solution when the cash flow that will face the investment is based on a cost cutting perspective.

8.3 Potential saving cost.

This heading is aimed to obtain the cost analyse to the AGV’s options indicated in the table 45. The companies helped to fill an Excel spreadsheet “Cost’s Form” in order to get the main costs (oriented to the current operational processes). The consolidated cost’s form is shown in appendix XVII.

The intervention of technology brings a movement of cash flow in term of saving costs and investment. The technology will impact in two main ways. First, it can reduces the current cost of sales as the direct production cost can decrease. Second, the technology helps to reduce the profit after taxes of non-direct cost (i.e. machine energy, PPE, depreciation, etc.). Therefore, it is necessary to evaluate the amount of investment and the potential saving cost to face the level of investment required. The final variable to discuss will be the payback period.

The tables at “Payback period evaluation” heading explains the final payback per company and it contains the following information on its columns:

A. Year
B. The expected saving cost
C. Cumulative cash flow
D. Options of investment

A. Year: This column indicates the year of the cash flow and investment.

B. The expected saving costs: This concept is refers to all potential cost that the company can save after introducing the proposed technology. The saving cost will vary from one company to other. Thus, the total expected saving cost indicated on the information sent by the companies are the following:

Company Name	Total potential cost savings
Crystal Heart	£ 175.740
Valefresco	£ 176.000
WD Smith	£ 73.873

Table 44 potential saving cost by company

(Own elaboration)

The difference on the saving costs between WD Smith and the other two companies is based on the annual operations. Crystal Smith and Valefresco have operation during all year, where their average production is between the 40 to 55% of its high season. However, WD smith has peak seasons in just 04 month during the year, while the other months has very low production's activity. As a consequence, the quantity of worker decrease as it is not required to move high volume of trolleys. However, the company indicates that 01 operator is kept in order to move potential requirements.

The potential costs to be saved in these 03 companies will be progressively reduced from the first to the third year. It was a conclusion obtained from meetings with the managers from companies who indicate that the technology to implement needs to get a high level of reliability and low operational risks (after the implementation on the companies) before escalate to change completely the current internal logistics procedures. In this way, the total costs to be saved per year, is a percentage of the current total cost of the company. The first and second years are expected to save less costs in comparison with the third year. From the 4th year on, it is expected that the saving cost are the same of the third. This means, that there are not more potential cost to be saved with the automation proposed. On the table below, it is possible to notice that the proposed automation technology will not save the 100% of costs, as the companies prefer to maintain a certain level of manual processes. Therefore, and according to the results obtained on the technical analysis, the progressive cost cutting process is the following:

- Crystal Heart will reduce operators until maintain only 02 workers at the beginning of the 4th year.

Year	Quantity of operator reduced per year	% of current total operators	Total cost cutting expected from current operations
Year 1	01 operator	20 %	£ 35.148
Year 2	01 operator	40 %	£ 70.296
Year 3	01 operator	60 %	£ 105.444
Year 4	0 operator	0%	£ 105.444

Table 45 Potential reduction of operators (Crystal Heart)

(Own elaboration)

- Valefresco option 1 will reduce operators until maintain only 4 workers at the beginning of the 3th year.

Year	Quantity of operator reduced per year	% of current total operators	Total cost cutting expected from current operations
Year 1	01 operator	14.3 %	£ 25.168
Year 2	01 operator	35.7 %	£ 50.160
Year 3	01 operator	42.9%	£ 75.504
Year 4	0 operator	0%	£ 75.504

Table 46 Potential reduction of operators (Valefresco)

(Own elaboration)

- Valefresco option 2 will not reduce operators but it will increase the production in 36%.

Year	Quantity of operator reduced per year	% of current total operators	Total cost cutting expected from current operations
Year 1	0 operator	0 %	£ 57.056
Year 2	0 operator	0 %	£ 76.074
Year 3	0 operator	0%	£ 90.338
Year 4	0 operator	0%	£ 90.338

Table 47 Potential reduction of operators (Valefresco)

(Own elaboration)

- WD Smith will reduce operators until maintain only 01 worker at the beginning of the 4th year.

Year	Quantity of operator reduced per year	% of current total operators	Total cost cutting expected from current operations
Year 1	01 operator	25 %	£ 18.468
Year 2	01 operator	50 %	£ 36.937
Year 3	01 operator	75 %	£ 55.405
Year 4	0 operator	0%	£ 55.405

Table 48 Potential reduction of operators (WD Smith)

(Own elaboration)

C. Cumulative Cash flow: This is refers to the cumulative saving cost per year. From table above, it is possible to verify that the 4th year is the maximum cost expected to be saved. This amount of cost will be used for the following years of company's operation.

D. Options of Investment: This indicates the range of values of investment. The total cost of investment is partially unknown at the moment and it needs to be evaluated, determined and evaluated on the next stage. However, there are different options on the market (see appendix II as an example) that gives a sort of range about the potential price of the AGV. The AGV "Thorvald II" developed by SAGA Robotic is selected has it has high level of similarities in term of structure and modularity of the proposed final conceptual design to develop.

This AGV has a price (standard platform) of £66.000 exc. VAT, final price £79.200 (this price was obtained from a Saga Robotics' quote). Thus, this price plus the monetary correction for 2020 can be the starter price. However, the conceptual AGV proposed could integrated other modules (robotic arm, towing, lifter, sensors, etc.) that will increment the starter priced of the "AGV base". Therefore, a range of values need to be evaluated in order to get a clear figure regarding the potential investment.

The following table shows the combination between range of investment (start price is 80.000 to 110.000) and the quantity of AGV (2 to 7). The start price is the "sell price" as the AGV needs to be a commercial option. The result is the total amount of money to invest.

	AGV'S INVESTMENT OPTIONS			
Quantity of AGV	**£80,000**	**£90,000**	**£100,000**	**£110,000**
2	£160,000	£180,000	£200,000	£220,000
3	£240,000	£270,000	£300,000	£330,000
4	£320,000	£360,000	£400,000	£440,000
5	£400,000	£450,000	£500,000	£550,000
6	£480,000	£540,000	£600,000	£660,000
7	£560,000	£630,000	£700,000	£770,000

Table 49 AGV's investment options

(Own elaboration)

- ***Please notice that the values are the sell price and do not the cost of sales or production costs.***

Therefore, the next heading shows the evaluation of the investment, cost saving and the calculation of the payback period per company.

8.4 Payback period evaluation

8.4.1 Crystal Heart

The investment is based on 03 AGVs. The cash flow per year is indicated in the following table:

03 AGV REQUIRED				FINAL CUMULATIVE CASH FLOW PER INVESTMENT OPTIONS (PER YEAR)			
YEAR	% SAVING FROM TOTAL	ANNUAL CASH FLOW (SAVING COSTS)	CUMULATIVE CASH FLOW (CUM SAVINGS)	£80,000	£90,000	£100,000	£110,000
0	AGV INVESTMENT (03)			-£240,000	-£270,000	-£300,000	-£330,000
1	20%	£35,148	£35,148	-£204,852	-£234,852	-£264,852	-£294,852
2	40%	£70,296	£105,444	-£134,556	-£164,556	-£194,556	-£224,556
3	60%	£105,444	£210,888	-£29,112	-£59,112	-£89,112	-£119,112
4	60%	£105,444	£316,332	£76,332	£46,332	£16,332	-£13,668
5	60%	£105,444	£421,776	£181,776	£151,776	£121,776	£91,776

Table 50 AGV's investment options to Crystal Heart

(Own elaboration)

The final payback period is indicated in the following table:

Payback period	£240,000	£270,000	£300,000	£330,000
YEARS	3	3	3	4
MONTHS	3.3	6.7	10.1	1.6

Table 51 Payback period of Crystal Heart

(Own elaboration)

Therefore, the money to investment on Crystal Heart can be recovered between the 3rd and 4th year.

8.4.2 Valefresco

Two option will be evaluated. The first investment is based on 04 AGVs. The cash flow per year is indicated in the following table:

04 AGVS ARE REQUIRED				DIFFERENCE WITH INVESTMENT REQUIRED			
YEAR	% SAVING FROM TOTAL	SAVING COSTS	CASH FLOW Cum SAVINGS	£80,000	£90,000	£100,000	£110,000
0	AGV REQUIRED (04)			**-£320,000**	**-£360,000**	**-£400,000**	**-£440,000**
1	14.3%	£25,168	£25,168	-£294,832	-£334,832	-£374,832	-£414,832
2	28.5%	£50,160	£75,328	-£244,672	-£284,672	-£324,672	-£364,672
3	42.9%	£75,504	£150,832	-£169,168	-£209,168	-£249,168	-£289,168
4	42.9%	£75,504	£226,336	-£93,664	-£133,664	-£173,664	-£213,664
5	42.9%	£75,504	£301,840	-£18,160	-£58,160	-£98,160	-£138,160
6	42.9%	£75,504	£377,344	£57,344	£17,344	-£22,656	-£62,656
7	42.9%	£75,504	£452,848	£132,848	£92,848	£52,848	£12,848
8	42.9%	£75,504	£528,352	£208,352	£168,352	£128,352	£88,352
9	42.9%	£75,504	£603,856	£283,856	£243,856	£203,856	£163,856
10	42.9%	£75,504	£679,360	£359,360	£319,360	£279,360	£239,360
11	42.9%	£75,504	£754,864	£434,864	£394,864	£354,864	£314,864
12	42.9%	£75,504	£830,368	£510,368	£470,368	£430,368	£390,368

Table 52 AGV's investment options to Valefresco option 1

(Own elaboration)

The final payback period is indicated in the following table:

Payback period	**£320,000**	**£360,000**	**£400,000**	**£440,000**
YEARS	5	5	6	6
MONTHS	2.9	9.2	3.6	10.0

Table 53 Payback period of Valefresco option 1

(Own elaboration)

Therefore, the money to investment on Valefresco can be recovered between the 5th and 6th year.

The second investment is based on 06 AGVs. The cash flow per year will depend on the lettuce sell price of the company. This option is looking for increasing the production rate in 36%. Thus, this increases the production rate from 18 boxes per hour per operator to 24.5 boxes. The final payback period is based on the following information:

Average price (head of lettuce)	0.31
Total heads per KG (Company data)	3
Final price per KG	0.93
Total production cost per KG (60%)	0.558
Profit after expected (pounds per KG)	0.372
Worst scenario to use (85%)	0.3162

Table 54 Potential sell price Valefresco

(Own elaboration)

The price of the head of lettuce was obtained from the UK government website (Wholesale fruit and vegetable prices, November). This data indicates that the lower and higher average price for lettuce is £0.31 to £0.4 per head. To this study, the lower average prices is selected. Therefore, 0.3162 pounds per KG of lettuce is the increment expected by assuming that the production costs is the 60% of the sell price and the "worst case scenario" can drop the expected profit after taxes until 85%.

In this new scenario, 06 AGVs and 07 operators are used, and the harvesting time is 4.5 hours. The other 4.5 hours are used for sowing (as was indicated in previous headings). There are no potential cost to be saved. Therefore, the extra cash flow expected is £ 78.311 per year.

	No automation scenario	Potential Automation scenario (06 AGV)
Boxes / hour	18	306
Lettuces / hour	306	416
Total harvesting time per day (APP)	4.5 hours	
Lettuces per day per operator	1377	1873
Total operator	7	
Total lettuces per day	9639	13109
Lettuces kilo app	3 KG	
Total KG to sell	3213	4369.68
Profit after taxes	0.3162 pounds per KG	
Profit expected per day	1015.95	1381.69
Profit expected per year	£ 264.147	£359.240
Difference per year	**£ 95.093**	

Table 55 Difference on profit after taxes Valefresco

(Own elaboration)

The evaluation is indicated in the following table:

06 AGVS ARE REQUIRED				DIFFERENCE WITH INVESTMENT REQUIRED			
YEAR	**% AGV Reliability**	**Cash flow (increment)**	**CASH FLOW Increment**	**£80,000**	**£90,000**	**£100,000**	**£110,000**
0	**AGV REQUIRED (06)**			**-£480,000**	**-£540,000**	**-£600,000**	**-£660,000**
1	60.0%	£57,056	£57,056	-£422,944	-£482,944	-£542,944	-£602,944
2	80.0%	£76,074	£133,130	-£346,870	-£406,870	-£466,870	-£526,870
3	95.0%	£90,338	£223,468	-£256,532	-£316,532	-£376,532	-£436,532
4	95.0%	£90,338	£313,807	-£166,193	-£226,193	-£286,193	-£346,193
5	95.0%	£90,338	£404,145	-£75,855	-£135,855	-£195,855	-£255,855
6	95.0%	£90,338	£494,483	£14,483	-£45,517	-£105,517	-£165,517
7	95.0%	£90,338	£584,822	£104,822	£44,822	-£15,178	-£75,178
8	95.0%	£90,338	£675,160	£195,160	£135,160	£75,160	£15,160
9	95.0%	£90,338	£765,498	£285,498	£225,498	£165,498	£105,498
10	95.0%	£90,338	£855,837	£375,837	£315,837	£255,837	£195,837
11	95.0%	£90,338	£946,175	£466,175	£406,175	£346,175	£286,175
12	95.0%	£90,338	£1,036,513	£556,513	£496,513	£436,513	£376,513

Table 56 AGV's investment options to Valefresco option 2

(Own elaboration)

The final payback period is indicated in the following table:

Payback period	**£320,000**	**£360,000**	**£400,000**	**£440,000**
YEARS	5	6	7	7
MONTHS	10.1	6.0	2.0	10.0

Table 57 Payback period of Valefresco option 2

(Own elaboration)

Therefore, the money to investment on Valefresco option 2 can be recovered between the 5th and 7th year.

8.4.3 **WD Smith**

The investment for WD Smith is based on 03 AGVs according to the previuos analysis. In this context, the detailed data regarding the cash flow per year is indicated in the following table:

03 AG ARE REQUIRED (TOWING)				DIFFERENCE WITH INVESTMENT REQUIRED			
YEAR	% SAVING FROM TOTAL	SAVING COSTS	CASH FLOW ACC SAVINGS	£80,000	£90,000	£100,000	£110,000
0	AGV REQUIRED (03)			-£240,000	-£270,000	-£300,000	-£330,000
1	25%	£18,468	£18,468	-£221,532	-£251,532	-£281,532	-£311,532
2	50%	£36,937	£55,405	-£184,595	-£214,595	-£244,595	-£274,595
3	75%	£55,405	£110,810	-£129,191	-£159,191	-£189,191	-£219,191
4	75%	£55,405	£166,214	-£73,786	-£103,786	-£133,786	-£163,786
5	75%	£55,405	£221,619	-£18,381	-£48,381	-£78,381	-£108,381
6	75%	£55,405	£277,024	£37,024	£7,024	-£22,976	-£52,976
7	75%	£55,405	£332,429	£92,429	£62,429	£32,429	£2,429
8	75%	£55,405	£387,833	£147,833	£117,833	£87,833	£57,833
9	75%	£55,405	£443,238	£203,238	£173,238	£143,238	£113,238
10	75%	£55,405	£498,643	£258,643	£228,643	£198,643	£168,643

Table 58AGV's investment options to WD Smith

(Own elaboration)

The final payback period is indicated in the following table:

Payback period	£240,000	£270,000	£300,000	£330,000
YEARS	5	5	7	7
MONTHS	4.0	10.5	5.0	11.5

Table 59 Payback period of WD Smith

(Own elaboration)

Therefore, the money to investment on WD Smith can be recovered between the 5th and 7th year.

8.4.4 **Final consideration from the business case:**

The last heading showed the final payback periods required when an AGV technology is introduced. The payback period considered a range of potential investment (£ 80.000 to £ 110.000) and the potential saving cost and/or increment on production (extra cash flow) per company per year. The results shows different behaviour across the companies.

The expected payback period of the investment on manufacturing and automation industries is from 3 to 5 years as maximum. In this study, only Crystal Heart is able to achieve these years across all potential ranges of investment. Valefresco's option 1 and 2, and WD Smith are out of the range of investments, as all its payback periods are over five years. Therefore, Crystal Heart is the direct feasible company to invest from the financial point of view.

However, a final consideration is possible to introduce after the conclusion of the last paragraph. What should be the cost of the AGV in order to get a payback period of 5 year (maximum)? To answer this question, it is required to modify the range of "Investment options". As a result, the following table shows the maximum AGV's sell price that allow to get a payback period of 5 years:

	Valefresco option 1	**WD Smith**
Maximum sell price per AGV	£75.460	£ 73.873
AGV required	04	03
Total investment	£301.840	£ 221.619
Payback Period	**4 years**	
	12 months	

Table 60 Feasible sell price per company

(Own elaboration)

In the case of the option 2 of Valefresco, it is expected two potential options. First, the maximum sell price of the AGV should be £ 66.691. Second, the profit after taxes needs to be incremented from 0.3162 to 0.376. Both options allow to have a payback period of 5 years maximum. The final decision to select (to this option) it is not part of this study.

Therefore, the prices indicated above could be a new constraint to consider during the AGV analysis of next stage, as it can impact on the potential quality of material or in the final profit margin of the future company that could sell the proposed AGV. However, it is expected that the cost of the AGV is cheaper that the range of investment evaluated, as the investment's options was based on assumptions and commercial market prices. The final cost will be obtained on the next stage.

Finally, it is possible to argue that the AGV technology (final conceptual idea) it is feasible from the technical but not from financial perspective for the all companies. The financial analysis evaluated a range of investment from £80.000 to £ 110.000 per AGV, as this options consider the potential modularity required such as, sensors, robotic arms, lifter, etc. As a result, only Crystal heart is feasible from both perspectives.

However, the range of investment was re-evaluated to understand the maximum investment feasible for all companies. This new maximum sell price needs to include all the required specification per company. The sell price for WD smith was reduced in 7.6%. In the case of Valefresco, two option can be adopted, nevertheless, the final decision depends on the owners.

9. Conclusion

To conclude, this feasibility study has the purpose of analyzing in detail the processes of each company, as well as analyzing from the perspective of the horticultural market and its impact on the productive development related to the agricultural sector. In addition, we sought to analyze the perspective of the automation market in terms of identifying available solutions that could be considered as viable alternatives within the present study.

Therefore, in main terms it can be said that the development of a base AGV is feasible under the view of modularity, versatility that is complemented by an increase in performance and efficiency in relation to the productive processes for each company. In addition, this development will focus on the following stages in defining in detail and designing a AGV prototype that meets the functional requirements of each company.

In this context, to conclude this study, the following conclusions depending on the analysis prepared will be delineated:

1. With the analysis the current production cycle from the companies, with the focus on determine the future scenario for automation systems.
    - The amount of AGVs required for each company was determined to avoid bottlenecks and wasted time in other manual processes.
    - For Crystal heart Salad the quantity of AGV’s required to Improve the transport trays cycle is **03 AGVs for complete the total operations**.
    - For Valefresco the quantity of AGV’s required to use people only to sow and harvest in order to avoid wasting time is **04 AGVs for complete the total operations, or 06 AGVs to get more productivity.**
    - For WD Smith the quantity of AGV’s required to reduce the queue at the production line area is **02 AGVs for complete the total operations.**

2. With the identification of commonalties and differences amongst the usage scenarios to help specify and later develop a base-level solution potentially applicable in a wide range of similar businesses.
   - Through this study, it was possible to identify certain similarities in relation to the current development of the respective processes of each company. Thus, the main similarity is related to transporting and delivering point-to-point products.
   - As for the differences, these were analyzed in the mapping of their processes detailed in heading 5. These are based on relation to travel distances and times to transport and dispatch products within their production lines.
   - Also, there are other diference in terms of the weight required to transport as well as the type of the frames uses by each company, while Crystal Heart uses a 30 tray in horizontal batch, Valefresco can use a danish trolley in the same way that WD Smith used to transport flowers.

3. The elaboration of a concept design for each company, contributes to identify the functional requirement in order to achieve their current production volume.

   - With focus on to desing a conceptual solution in direct collaboration with the customers.
   - The concept design aims to get a clear figure to analyse the detailed specification for the next stage in order to build a modular versatile and low cost prototype.
   - The concepts presented within this study require manual loading and unloading from their production lines and to storage areas. Also, in order to automate the manual process are out of the scope.

4. The identification of the most suitable AGV prototype from the conceptual design with the involvement of expert team from WMG-ASG, as well as the customer involvement in order to validate our findings and concept design for each case.

- Regarding to the market overview, there are many companies which develop AGV solutions. But, they provide fixed solutions and as a result of this Feasibility study it is crucial to build an AGV prototype following the autonomous and modular vehicle to meet the functional requirements to achieve the companies production processes.

5. The business case analysis provide a cost perspective in term to determine the investment level and payback period.

- To introduce the automation technology had some benefit regarding to reduce the labour costs, increasing the productivity, reducing operational risks and human safety, providing a modular, outdoor and funtional technology will improve the waste time and continuous operation .
- If the processes and tasks are efficiently planned, therefore, the only disadvantage can be the initial investment, but can be faced by achieving the efficiency snd cost savings that the AGV could bring to aech company.
- The payback period considered a range of potential investment (£ 80.000 to £ 110.000) and the potential saving cost and/or increment on production (extra cash flow) per company per year.
- The payback period for Crystal Heart is in 3 years, for Valefresco is in 5 to 6 years, and for WD Smith is in 5 to 7 years.
- The expected payback period of the investment on manufacturing and automation industries is from 3 to 5 years as maximum. In this study, only Crystal Heart is able to achieve these years across all potential ranges of investment.
- Other case is reducing maximum sell price per AGV bellow of £80K the payback period for Valefresco and WD smith is about 4 years.

Overall, taking in consideration the analysis conducted from the production process mapping and performance review, also according to the concept design criteria and the consequent the Preliminary specification is possible to infer that the solutions presented for each company are technically feasible for automation use to transport and deliver products within their production cycle. However, it is required that more work be done in order to increase the overall system in terms of functionality which will be covered by the project team in the next stage.

Finally, at this feasibility study has provided four concept design that are feasible able to deliver empty or full filled trolleys within the repsctively production lines. And, the next stage will be to down-select these solutions, modify the if is nececessary, transform the preliminary specifications in to a detailed specification in order to build the cost structure to construct a prototype for testing purposes.

10. Recommendations and next stage

10.1 Recomendations

From the present study, certain opportunities were identified within the framework of the current processes of each company. Thus, these opportunities represent the possibility of developing future projects that allow somehow complete automation or perhaps part of it as required by each company. In addition, it can be said that their future analysis in implementation is not part of the present study.

However, it can be recommended that if a future analysis, development, and implementation are feasible they can be fully integrated with the solutions presented in the plague study. Thus, it is recommended to consider the following future gaps or opportunities detected according to the analysis of each company.

- **Crystal Heart**

  - Introduce AGV to move empty trays to conveyor at production area.
  - Automate conveyor in stacking process at production area.
  - Integrate AGVs to move stacked trays from production to germination room.
  - Integrate RFID to increase traceability of trays.
  - Introduce wrap machine at refrigeration room and link this technology with AGV.

- **Valefresco**

  - Introduce wrap machine at refrigeration room and link this technology with the AGV solution presented within this study.

- **WD Smith**

  - Introduce "Good to person" technology to load trolleys at production area.
  - Introduce "Good to person" technology at packing area (Despatch process).
  - Introduce AGV to move trolleys from packing area to lorries.

In summary, the decision to consider these future opportunities as feasible is not part of this study. However, there are some developments by the Automation system group that may be integrated, as is the case with the development related to Good to Person

10.2 Next stage

According to the methodology proposed at the beginning of this detailed feasibility study according to Appendix I, and before beginning the development stage of the selected prototype that meets the requirements for the companies, the planning stage must be started first, in which The following deliverables are established (see figure 27):

- Final product design
- Financial report
- Technical report
- Prototype mockup

Therefore, the active involvement of the customers and stakeholders will be considered in terms of acceptance of the detailed specifications for the design of the required AGV prototype. as well as, according to the Quality Function Deployment (QFD) level 1, the performance specifications will be defined by breaking up the AGV into systems, subsystems, and factors that will allow defining the acceptance criteria and functional requirements.

With this information, we will outline the performance criteria required for this stage, which will allow us in the second level of analysis a detailed part deployment in terms of components and main characteristics. In addition, in this second level, the high-level architecture will be delineated in relation to integration at the software level.

Finally, this analysis will lead us to determine the options available in the market to prepare the final list of materials needed for the development stage. As well as, it will allow us to establish a cost structure that will help to finalize the financial report determining key points such as ROI and the funds required for the development stage.

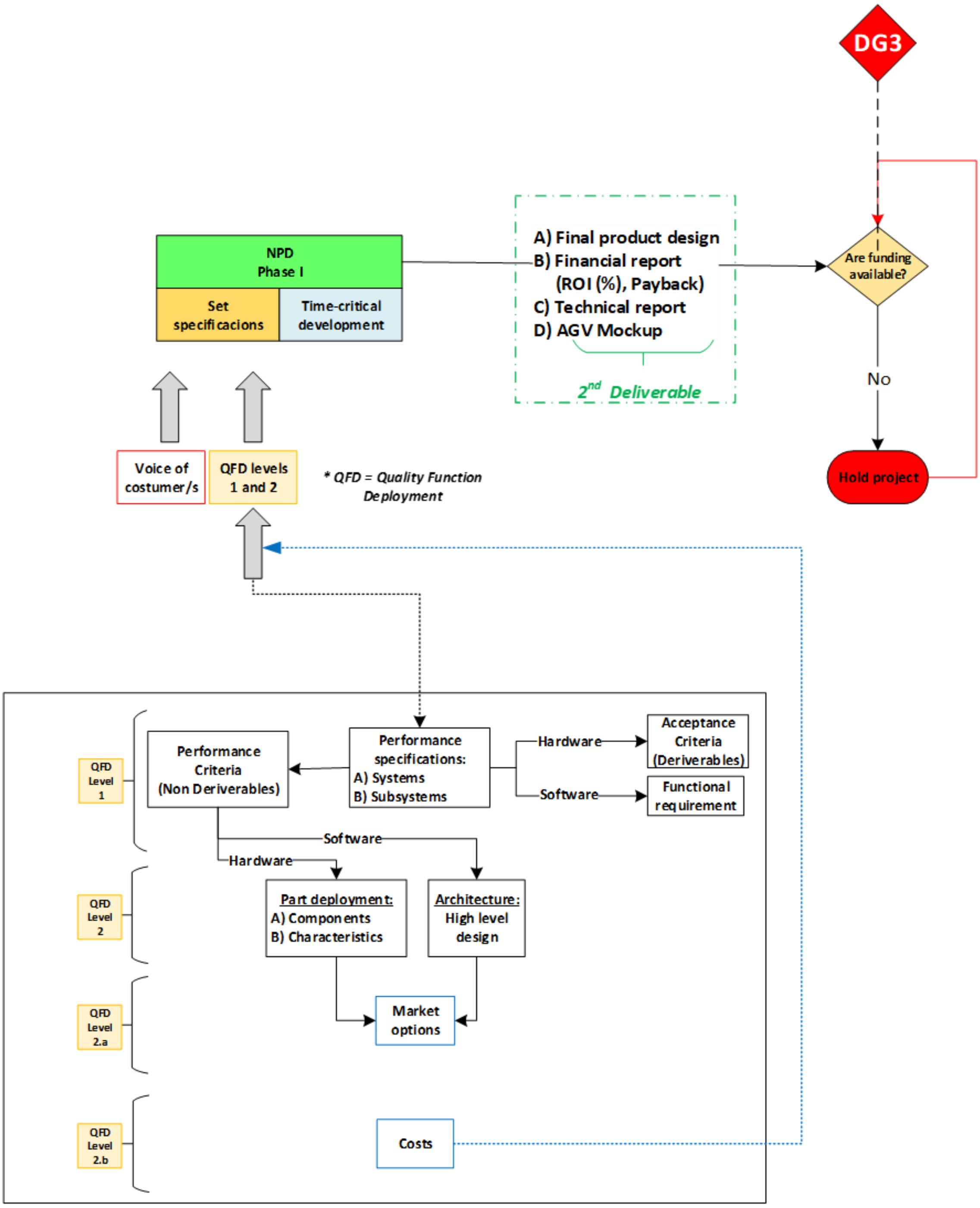


Fig. 27 " Next project stage methodology"

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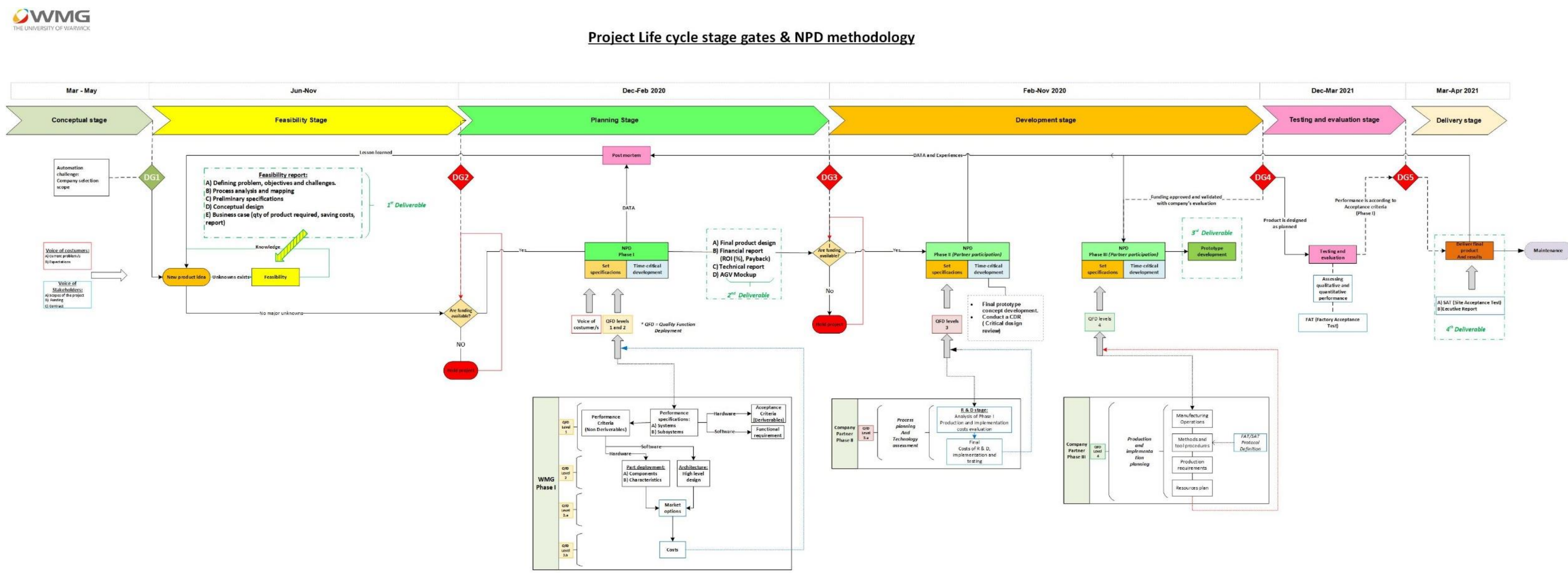
Appendix

I. Project methodology



Project team-ASG	
Robert Harrison	Head ASG
Bilal Ahmad	Project Lead
Ronald Pfeng	Project Manager
Emilio Loo	Lead Engineer
Sergey Konstantinov	Project Engineer
Dave Urqurhart	Project Engineer
Nuno Navegas	Graduate Engineer Trainee

Decision Gates:

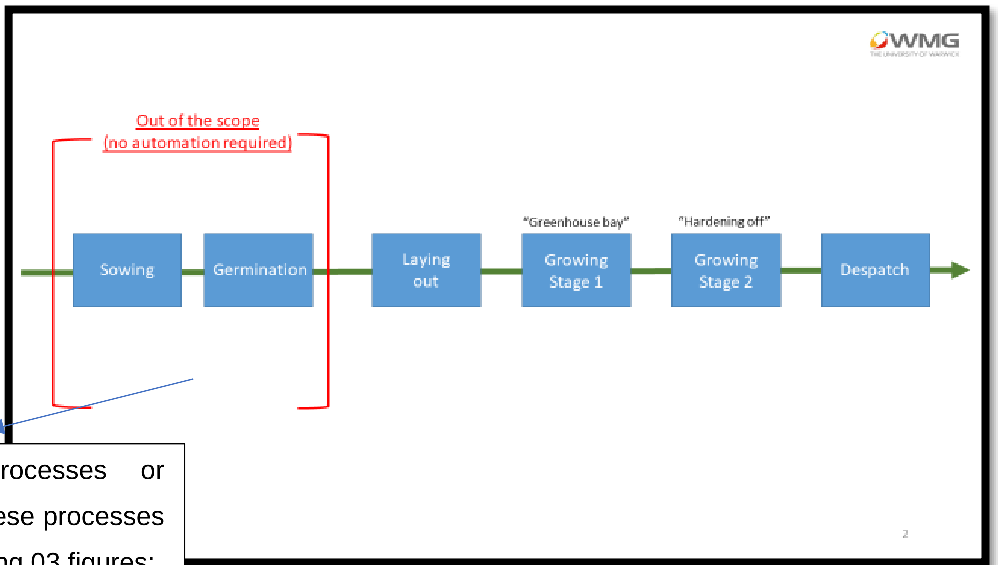
- DG1 = Go to Feasibility
- DG2 = Go to Project planning
- DG3 =Go to Development
- DG4 = Go to Testing
- DG5 = Go to Deliver

II. AGV's market overview

Automation Solution	Agriculture Activities										
	Live Stock			Field Crop							
	Feeding	Handling	Activity Specific	Sowing	Monitoring	Hoeing	Crop nutrition	Pest & Diseases	Harvesting	Transportation	Pruning & Mowing
DeLavalOptiDuo	✓										
Lely Vector	✓										
Octopus Basics			✓								
Boar Bot		✓									
Carré Antis					✓	✓					
Robocrop InRow Weeder						✓					
Robovator						✓					
Ecorobotics AGV					✓	✓					
Iron Ox Lettuce Robot								✓		✓	
Agrobot E series									✓	✓	
3100 Cucumber Harvester									✓		
WP5 Robot									✓		
Octinion Xenion					✓			✓			
Octinion Titanion					✓			✓			
Octinion Rubion									✓		
Hortibot						✓		✓			
The Asterix project								✓			✓
AgBot II					✓	✓		✓			
Hamster Bot					✓						
Rowbot				✓							
Autonomous Robot Tractor						✓		✓		✓	✓
Oz						✓			✓	✓	
Kompano DeLeaf											✓
LettuceBot					✓			✓			
DJI Matrice 200					✓						
Qii-Jet TAV-342								✓			
Trakür								✓			
Wall-Ye					✓						✓
FFRobotics									✓		
Aquarius							✓				
Vision Robotics Grapevine Pruner											✓
Prospero				✓							
Armadillo					✓			✓			
HV-100										✓	
Ladybird										✓	
Vine robot										✓	
Insect Control Robot for Controlled Agriculture								✓			
Conic System Pro-300				✓							
Gripper Inspired by Octopus											
Grizzly						✓		✓		✓	
ASI Forge Platform						✓		✓		✓	✓
BoniRob						✓				✓	
Thorvald							✓	✓	✓	✓	
Robotnik RB-SHERPA											
Oceaneering UniMOVER										✓	
Robosynthesis ARMOURDILLO						✓			✓	✓	
Jaltest AGV									✓	✓	✓

Automation Solution	Commercial	Location	Modular AGV Plataform	Company	Description
DeLavalOptiDuo	Yes	Sweden - EU	No	DeLaval	AGV capable of pushing and redistributing the animal meal
Lely Vector	Yes	Netherlands - EU	No	Lely	AGV capable of allocating animal meal stored in the AGV
Octopus Basics	Yes	France - EU	Yes	Octopus Robots	AGV turns and ventilates litters to prevent bacterria and mprove animal welfare
Boar Bot	Yes	USA	No	Swine Robotics	Remote controlled robot that is used to leash and guide live stock
Carré Antis	Yes	France - EU	No	Carre	AGV assists the farmer in his daily life, realizing in complete autonomy the maintenance of the crops by hoeing and by providing a decision aid in the monitoring of the cultures by acquisition and treatment of key indicators
Robocrop InRow Weeder	Yes	UK - EU	No	Garford	Robot that requires to be towed, automatically weeds out unwanted weeds all around the crop
Robovator	Yes	USA	No	Robovator	Robot that requires to be towed, automatically weeds out unawanted weeds from crop
Ecorobotics AGV	Yes	Switzerland - EU	Yes	Ecorobotix	AGV platform for scouting and phenotyping applications, capable of integrating sensors and applications from different manufacturers.
Iron Ox Lettuce Robot	No	USA	No	Ironnox	Autonamous robot arm, capable of performing delicate tasks in a control environment
Agrobot E series	No	USA	No	Agrobot	Fully autonamous AGV, capable of working in any farm with aisles
3100 Cucumber Harvester	Yes	USA	No	PikRite	Robot that requires to be towed, automatically harvests cucumber
WP5 Robot	No	Netherlands - EU	No	Sweeper & Wageningen Univ	AGV prototype capable of performing delicate tasks in a control environment
Octinion Xenion	Yes	Belgium - UK	Yes	Octinion	AGV indoor farming platafrom, capable of scouting, ensuring crop wellness
Octinion Titanion	Yes	Belgium - UK	Yes	Octinion	AGV outdoor farming platafrom, capable of scouting, ensuring crop wellness
Octinion Rubion	Yes	Belgium - UK	No	Octinion	AGV capaple of harvesting delicate crops
Hortibot	No	Danish - EU	No	Aarhus University	AGV plataform capable of nursing crops depending on the attachments
The Asterix project	No	Norway - EU	No	Adigo	AGV outdoor farming assistant
AgBot II	No	Australia	Yes	ACRV	AGV plataform capable of nursing crops depending on the attachments
Hamster Bot	No	Spain - EU	No	University of Madrid	Prototype small robot capable of collecting soil data
Rowbot	No	UK - EU	No	RowBot Systems	AGV capable of navigating in field aisles and planting seeds
Autonomous Robot Tractor	Yes	Japan	No	Yanmar	Tractor AGV capable of towing attachments
Oz	Yes	France - EU	No	Naio	AGV capable of hoewing, harvesting and aiding in load transport
Kompano DeLeaf	Yes	Netherlands - EU	No	Priva	Robot capable of precisly pruning and deleafing crop plants
LettuceBot	Yes	USA	No	John Deere	Tractor AGV capable monitoring and apply pesticides
DJI Matrice 200	Yes	USA	No	Precision Hawk	Drone capable of monitoring field crops
Qii-Jet TAV-342	Yes	Belgium - UK	No	Bogaerts	AGV capable of operating in aisles and spray pesticide
Trakür	No	Argentina	No	Instituto de Tecnología Agro	Low cost AGV that sprays crops
Wall-Ye	Yes	France - EU	No	Burgundy	Mobile Robot capable of navigating and pruning crop plants
FFRobotics	No	Israel	No	Ffrobotics	Robot arm capable of picking
Aquarius	No	USA	No	Dorhout R&D	AGV that waters crop in a greenhouse
Vision Robotics Grapevine Pruner	No	USA	No	Vison Robotics	Robotic arms capable of pruning delicate crops
Prospero	No	USA	No	Ffrobotics	AGV capable of navigaing in a outdoor field and plant seeds at optimal locations
Armadillo	No	USA	No	FroboMind	The Armadillo is a robot used in various applications such as crop scouting, mechanical and chemical weeding.
HV-100	Yes	USA	Yes	Harvest Automation	Nursery Bot is the solution to automate move potted plants around. The robot uses wheels, gripper arms, trays and sensors move the plants to the desired location.
Ladybird	No	Australia	No	University of Sydney	Ladybird feature tools and systems that make it able to perform autonomous tasks. The robot is used for surveillance, mapping, classification and detection for different vegetables.
Vine robot	No	Spain - EU	No	University of Valencia	Available as a prototype, the robot uses advanced sensors and artificial intelligence to manage the vineyards. The robot provides data about water status, production, vegetable development or grape composition.
Insect Control Robot for Controlled Agricu	No	Korea	No	Kiria	This is an autonomous insect control system able to move on a rail in greenhouses
Conic System Pro-300	Yes	Spain - EU	No	Comic Systems	Conic is a specialized sowing robot for greenhouses able to sow 1,000 trays an hour.
Gripper Inspired by Octopus	No	USA	No	Soft Robotics	Somewhere in a corner of a laboratory, this robot arm moves vegetables back and forth on a party tray. It has blue fingers that curl around any piece of broccoli and lift it up to an a
Grizzly	Yes	Canada	Yes	Clearpath Robotics	Grizzly is an autonomous utility vehicle with a strong body that can host a wide range of equipment for agricultural chores. The platform was developed especially to reduce the grass between crops by spraying chemicals. Also, the platform can perform delicate tasks such as r
ASI Forge Platform	Yes	USA	Yes	ASI	The ASI platform is designed for use with over 100 attachments. All these tools are useful in farming chores like in orchards and vineyards.
BoniRob	No	German	Yes	Bosh	BoniRob is a modular platform that can host a large variety of tools for agricultural chores.
Thorvald	Yes	Norway - EU	Yes	Saga Robotics	Can perform tasks such as UV-treatment, picking fruits and vegetables, phenotyping, in-field transportation, cutting grass for forage, spraying and data collection/crop prediction.
Robotnik RB-SHERPA	Yes	Spain - EU	Yes	Robotnik	RB-SHERPA is suitable for indoor and outdoor logistics applications due to its versatility and high mobility.
Oceaneering UniMOVER	Yes	USA	No	Oceaneering	The UniMover Mini offer a haigh capability in a compact design with an exceptional maneuverability required to transport high to medium loads. Also, includes a superfrog supervisory software system control fleet and traffic amangement collecting performance data, battery
Robosynthesis ARMOURDILLO	Yes	UK - EU	Yes	Robosynthesis	Robosynthesis is a flexible, robust and cost effective industrial modular robotic delivery platform for inspection & maintenance operations
Jaltest AGV	Yes	Spain - EU	No	Jaltest	The standard chassis configuration consists of two 50 Mile range LiPo batteries, charged via induction powering a 50KWh motor to the rear wheels. All L.O.A.D vehicles can be optioned with either Lidar or single-color camera to follow specially pigmented route lines on factory

III. Crystal Heart's processes



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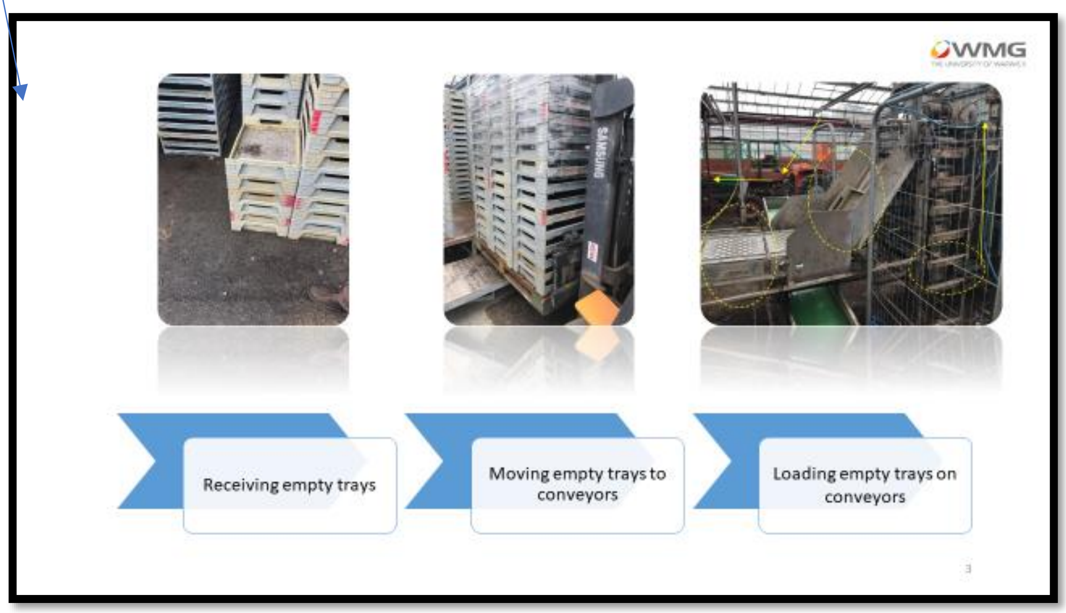
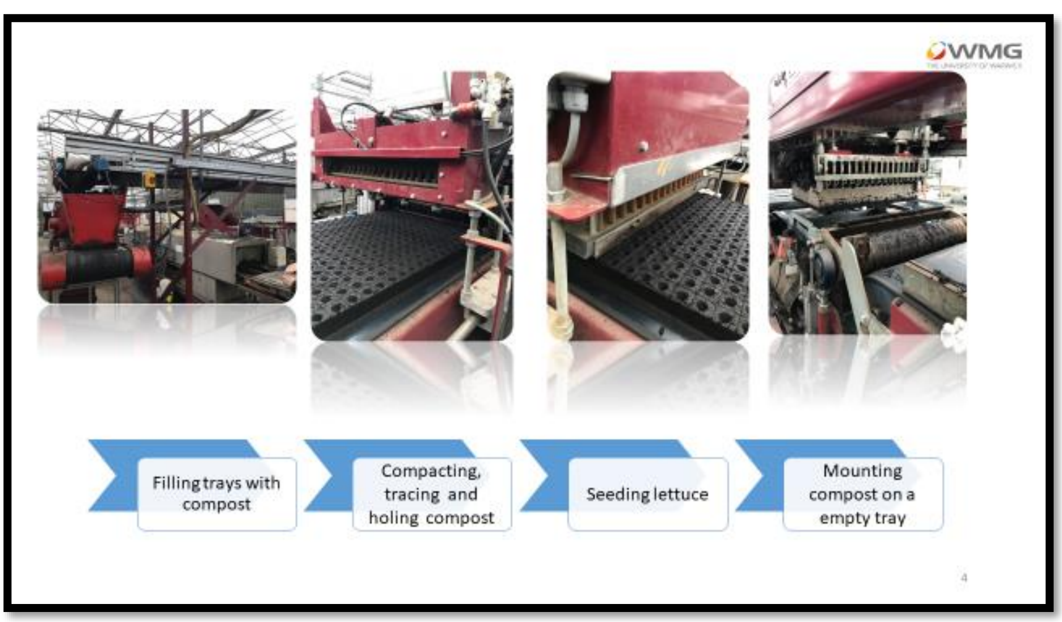
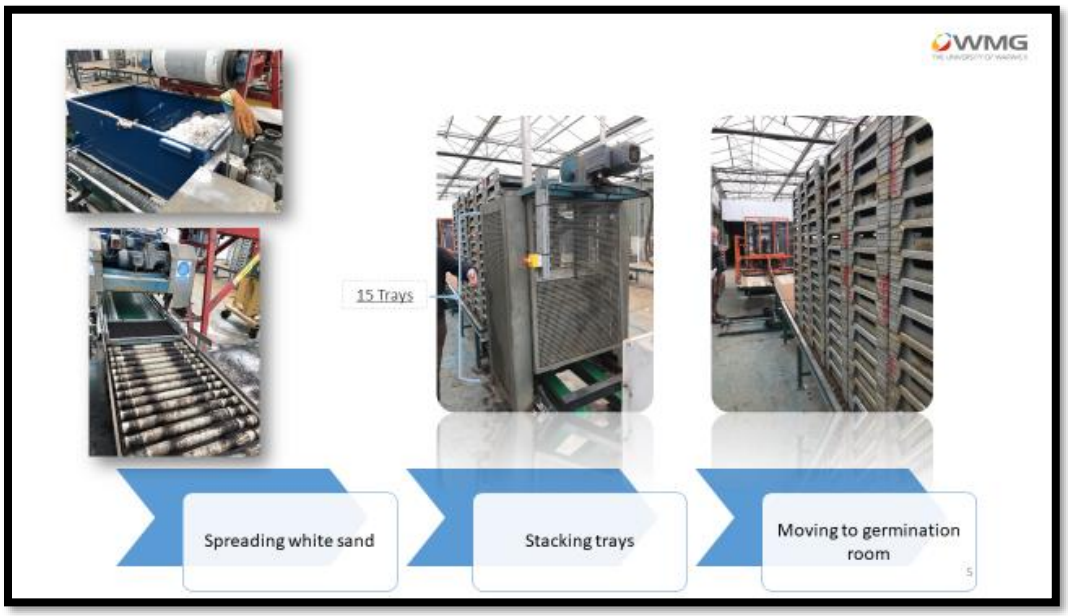
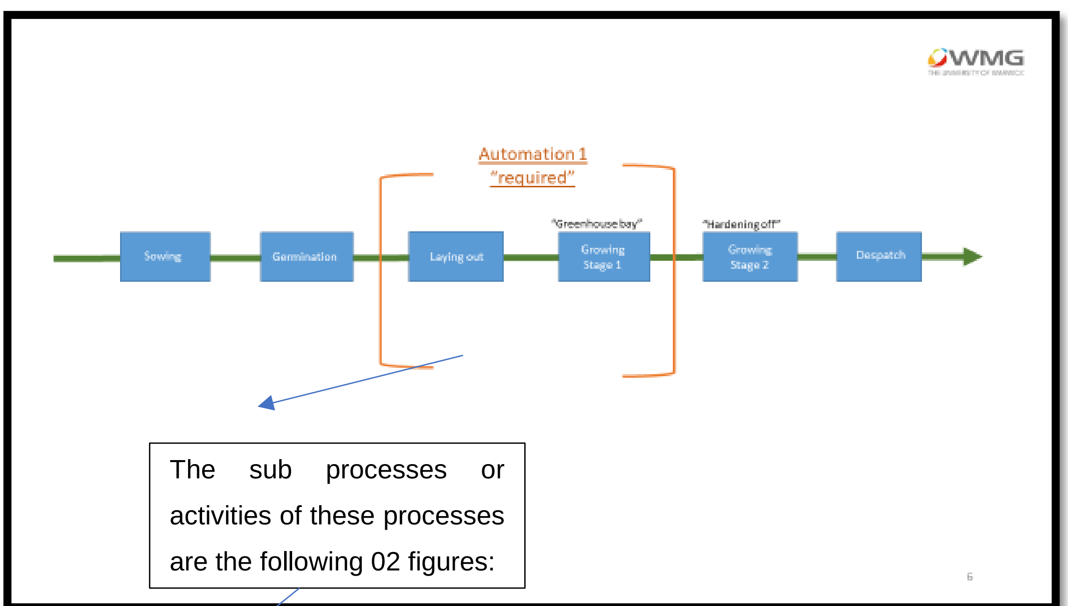
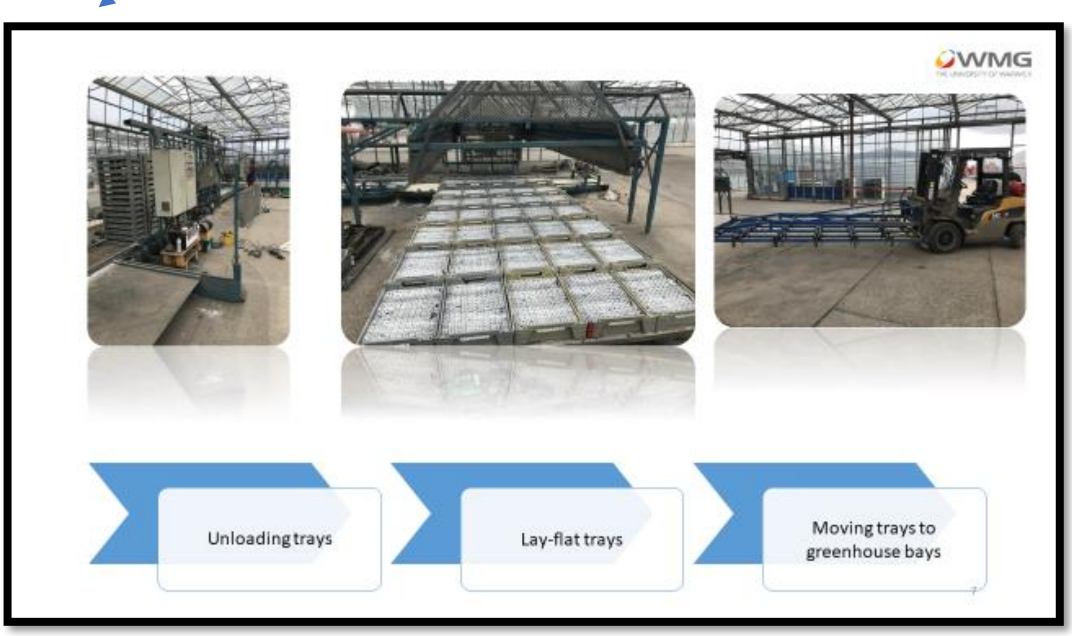
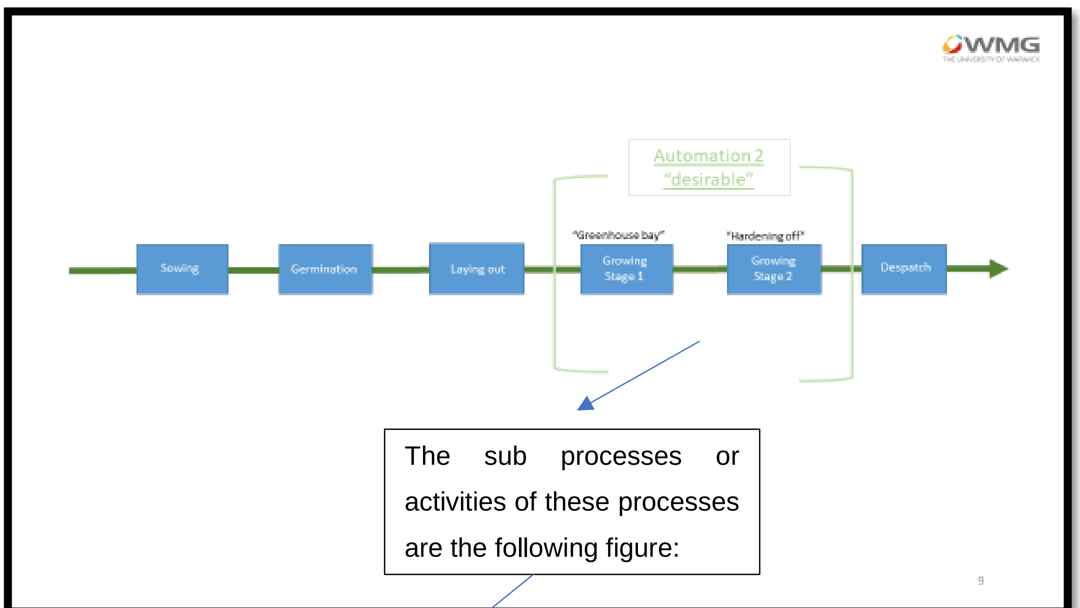




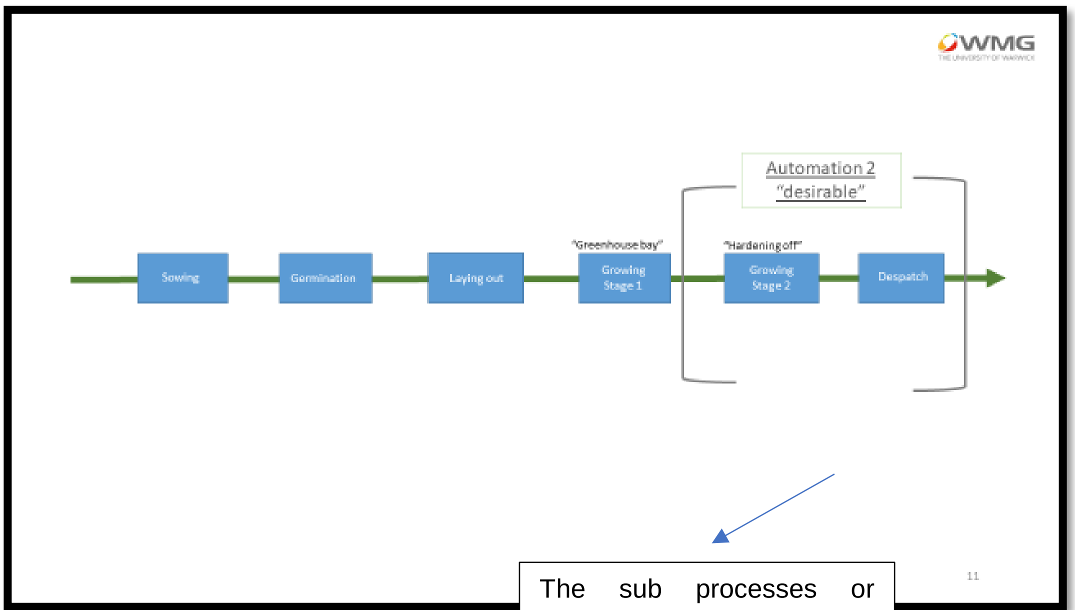

15 Trays
Spreading white sand
Stacking trays
Moving to germination room


Automation 1
"required"
"Greenhouse bay"
"Hardening off"
Sowing
Germination
Laying out
Growing Stage 1
Growing Stage 2
Despatch
The sub processes or activities of these processes are the following 02 figures:


Unloading trays
Lay-flat trays
Moving trays to greenhouse bays

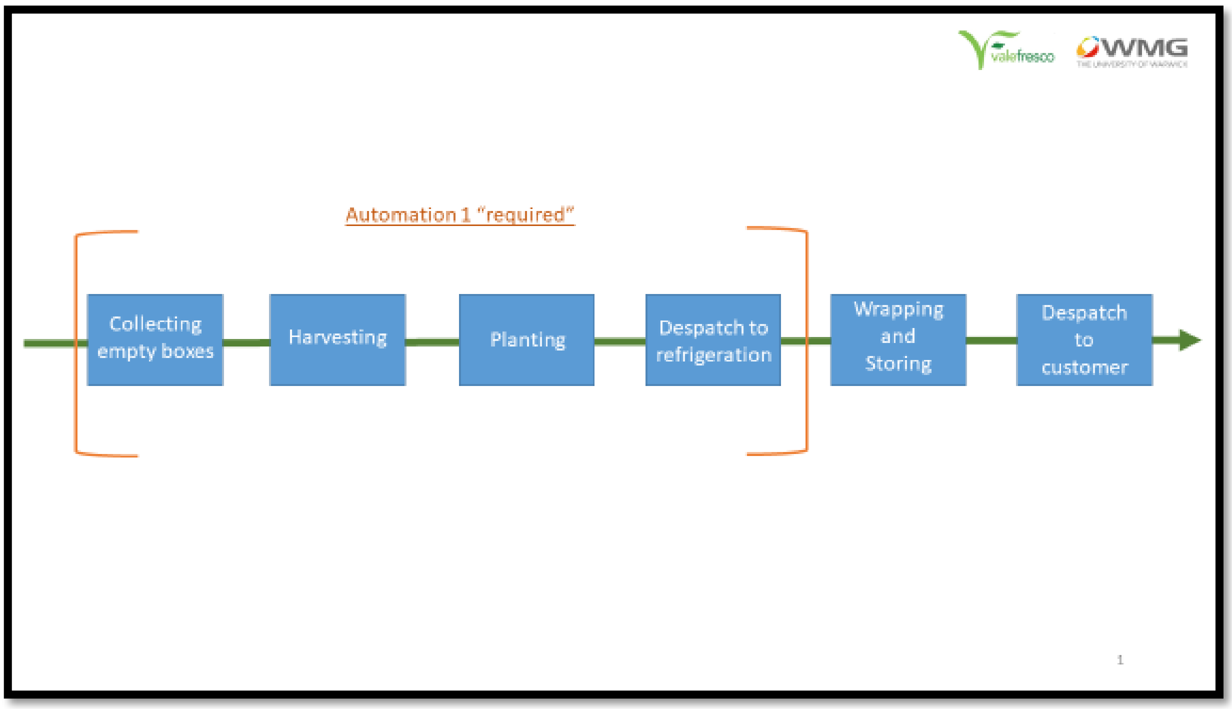


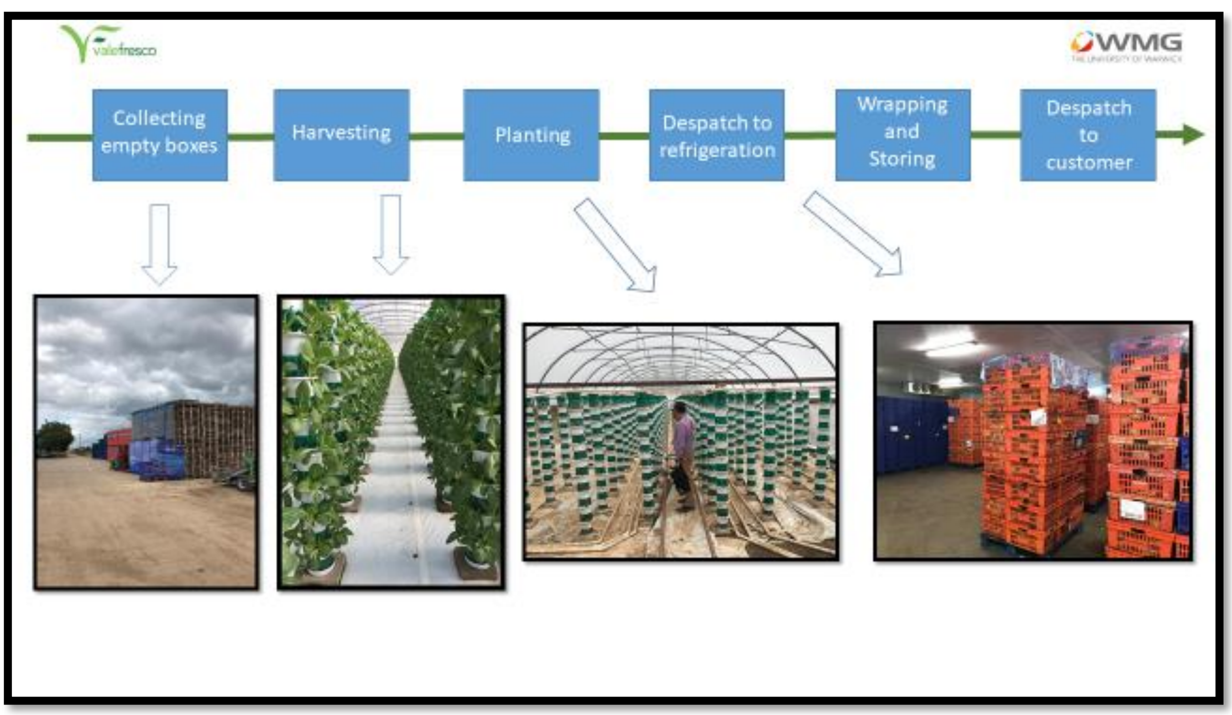
The sub processes or activities of these processes are the following figure:

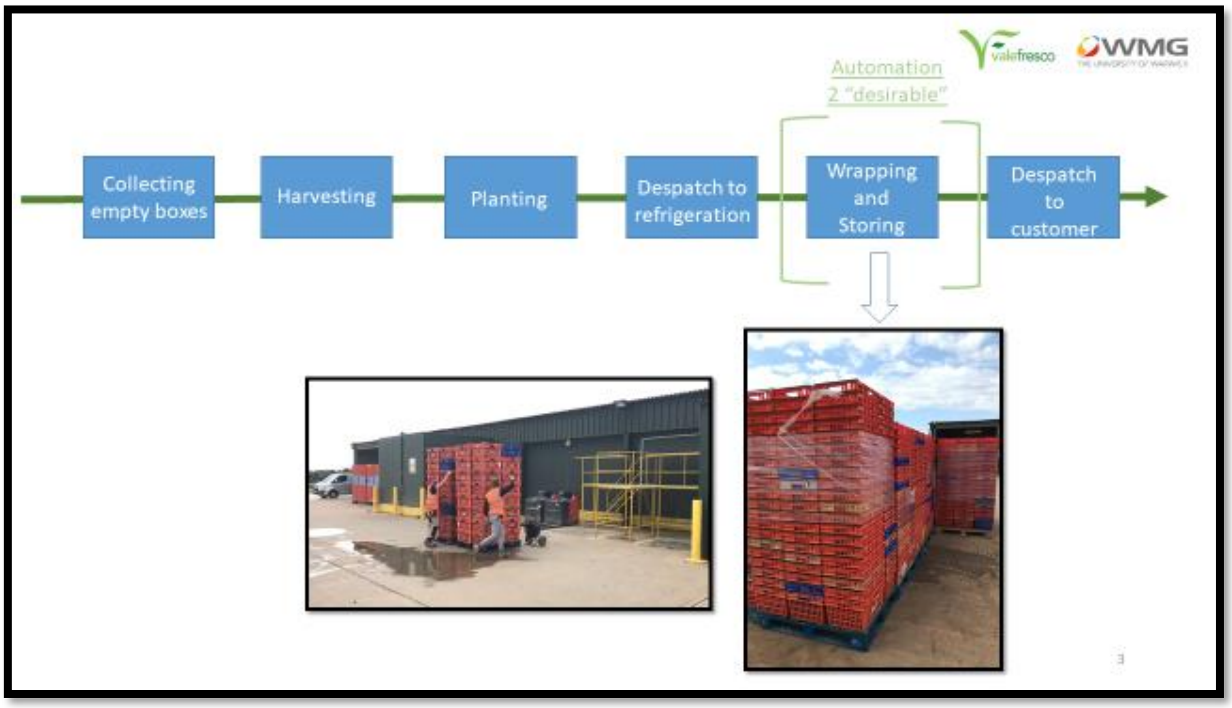


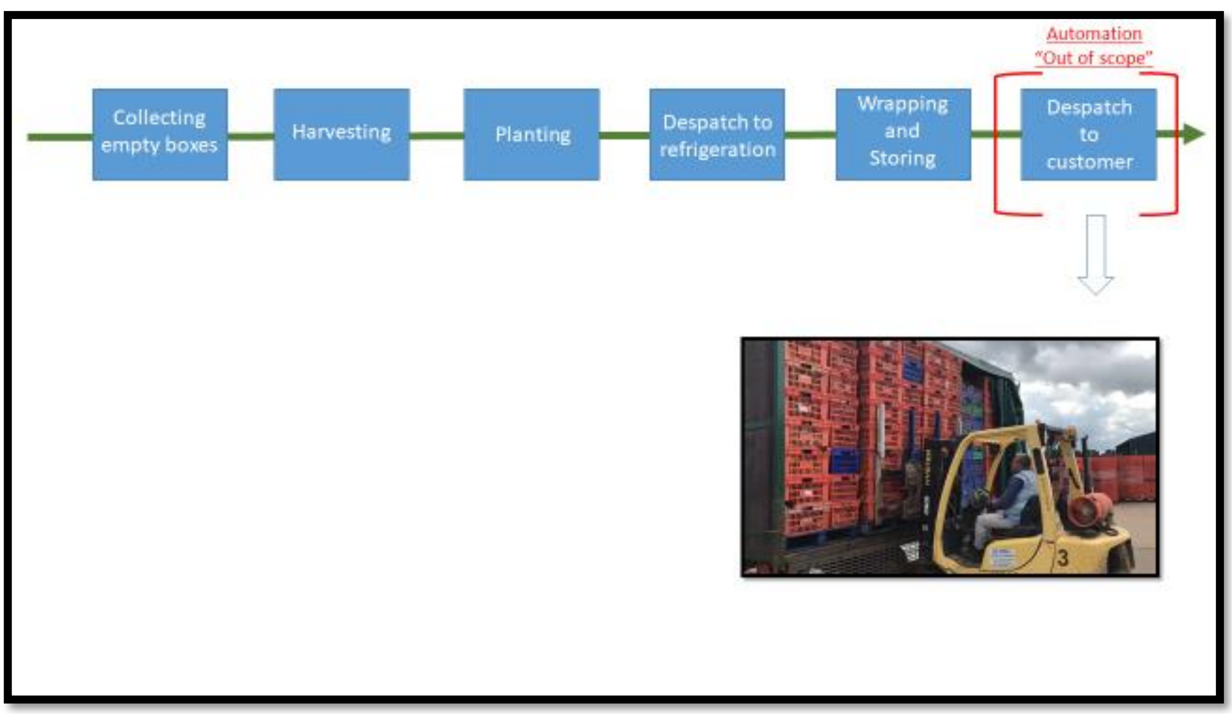
The sub processes or activities of these processes are the following figure:

IV. Valefresco's processes

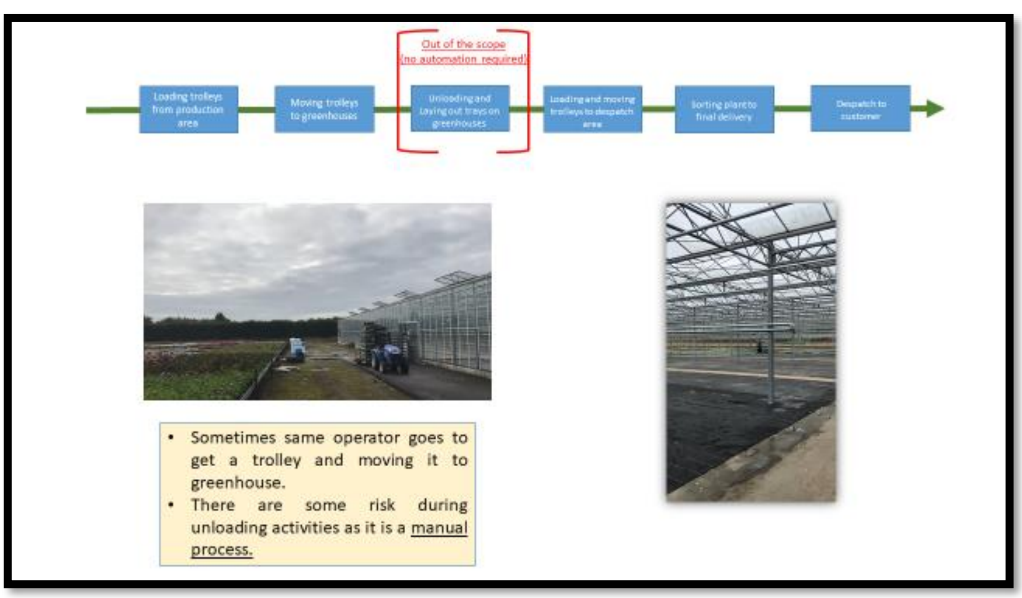


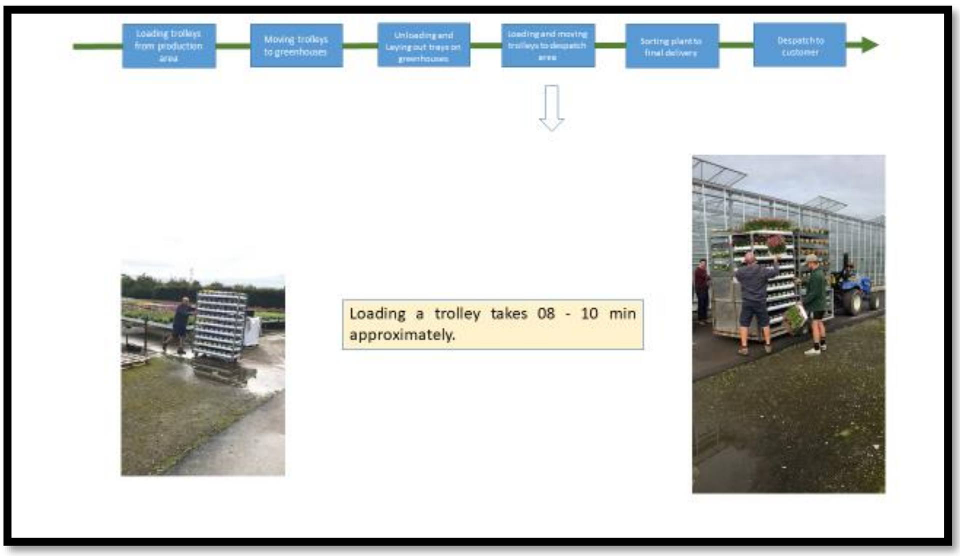



valefresco
WMG
Automation
2 "desirable"
Collecting empty boxes
Harvesting
Planting
Despatch to refrigeration
Wrapping and Storing
Despatch to customer

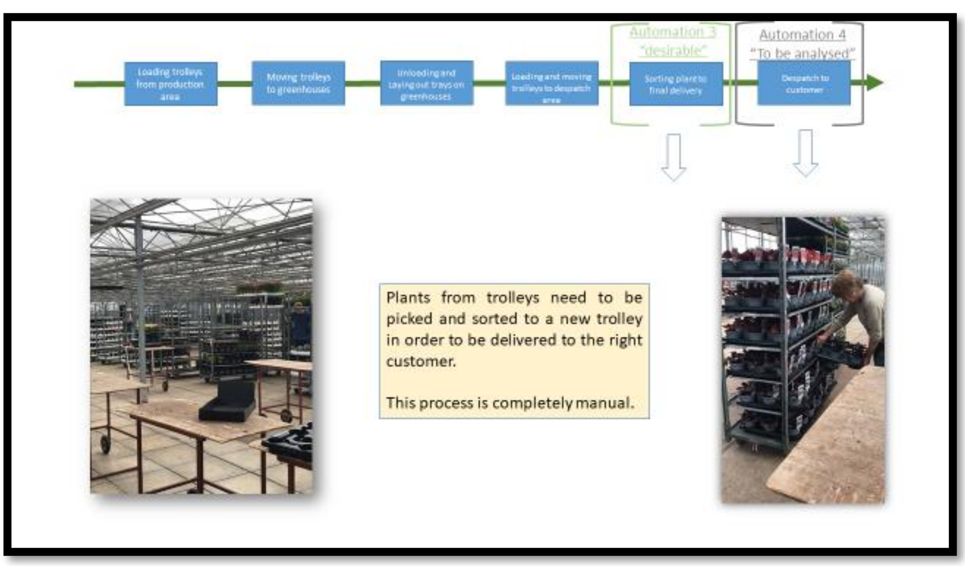

Automation
"Out of scope"
Collecting empty boxes
Harvesting
Planting
Despatch to refrigeration
Wrapping and Storing
Despatch to customer

V. WD Smith's processes

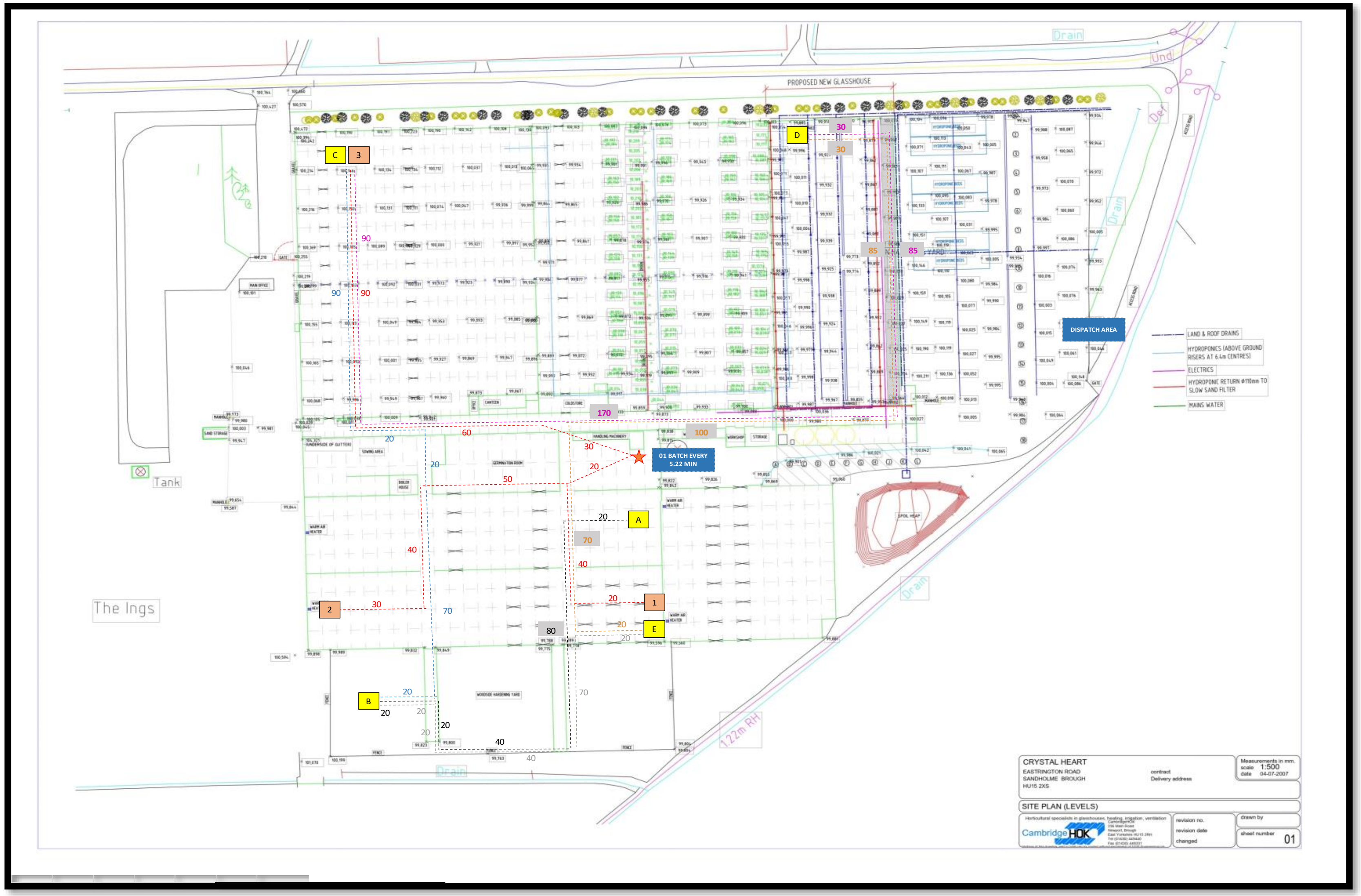



Loading trolleys from production area
Moving trolleys to greenhouses
Unloading and Laying out trays on greenhouses
Loading and moving trolleys to despatch area
Sorting plant to final delivery
Despatch to customer
Loading a trolley takes 08 - 10 min approximately.


Loading trolleys from production area
Moving trolleys to greenhouses
Unloading and Laying out trays on greenhouses
Loading and moving trolleys to despatch area
Sorting plant to final delivery
Despatch to customer
Unloading every par of trolleys take 30 – 45 sec approximately from the trailer and place them on delivery area


Automation 3 "desirable"
Automation 4 "To be analysed"
Loading trolleys from production area
Moving trolleys to greenhouses
Unloading and Laying out trays on greenhouses
Loading and moving trolleys to despatch area
Sorting plant to final delivery
Despatch to customer
Plants from trolleys need to be picked and sorted to a new trolley in order to be delivered to the right customer.
This process is completely manual.

VI. Crystal Heart 's Layout



VII. Crystal Heart's 30 Trays analysis

Using only 01 AGV per process

Safety time of 1.5 min

	INITIAL POINT	FINAL POINT	LOADING TIME sec	DISTANCE (MM)	DISTANCE (MT)	SPEED (MT/S)	MOVING TIME	UNLOADING TIME sec	TOTAL TIME (SEG)	2 WAYS TIME (SEG)	TOTAL TIME (MIN)	BATCH TIME IN MIN(LAY FLAT THROUGHPUT)	GREEN HOUSE THROUGHPUT	DIFFERENCE WITH THROUGHPUT	AGV REQUIRED	FINAL OUTPUT WITH AGV APPLIED	
LAY FLAT ROOM TO GREEN HOUSES	STAR	1	12	80	40	0.8	50.00	20	82.00	132.00	2.20	5.22		3.02	1.15	3.31	
	1	STAR		80	40	0.8	50.00		50.00								
	STAR	2	12	140	70	0.8	87.50	20	119.50	207.00	3.45	5.22		1.77		2.22	
	2	STAR		140	70	0.8	87.50		87.50								
	STAR	3	12	180	90	0.8	112.50	20	144.50	257.00	4.28	5.22		0.94		1.50	
	3	STAR		180	90	0.8	112.50		112.50								
FROM GREEN HOUSES TO HARDENING OFF (OUTSIDE)	A	B	12	180	90	0.8	112.50	20	144.50	282.00	4.70		5.63	0.93	1.85	3.09	
	B	C		220	110	0.8	137.50		137.50								
	C	D	12	375	187.5	0.8	234.38	20	266.38	457.00	7.62		5.63	-1.99		1.51	
	D	E		305	152.5	0.8	190.63		190.63								
	E	B	12	140	70	0.8	87.50	20	119.50	257.00	4.28		5.63	1.35		3.31	
	B	C		220	110	0.8	137.50		137.50								
MIX BOTH PROCESSES	STAR	3 OR C	12	180	90	0.8	112.50	20	144.50	558.38	9.31	5.22		-4.09	2.5	1.50	EXAMPLE 1
	3 OR C	D	12	375	187.5	0.8	234.38	20	266.38								
	D	STAR		236	118	0.8	147.50		147.50								
	STAR	3 OR C	12	180	90	0.8	112.50	20	144.50								
	3 OR C	B	12	220	110	0.8	137.50	20	169.50	558.38	9.31		5.63	-3.68	2.26	1.51	EXAMPLE 2
	B	STAR		160	80	0.8	100.00		100.00	414.00	6.90	5.22		-1.68	1.86	1.51	EXAMPLE 3

Table A.6.1

VIII. Crystal Heart's 20 Trays analysis

Speed can possible be increased to 1.1

Using only 01 AGV per process

Safety time was reduced to 1.5 min

	INITIAL POINT	FINAL POINT	LOADING TIME sec	DISTANCE (MM)	DISTANCE (MT)	SPEED (MT/S)	MOVING TIME	UNLOADING TIME sec	TOTAL TIME (SEG)	2 WAYS TIME (SEG)	TOTAL TIME (MIN)	BATCH TIME IN MIN(LAY FLAT THROUGHPUT)	GREEN HOUSE THROUGHPUT	DIFFERENCE WITH THROUGHPUT	AGV REQUIRED	FINAL OUTPUT WITH AGV APPLIED	
LAY FLAT ROOM (Area but not machine) TO GREEN HOUSES	STAR	1	7	80	40	1.1	36.36	120	163.36								
	1	STAR		80	40	1.1	36.36		36.36	199.73	3.33	5.75		2.42		2.83	
	STAR	2	7	140	70	1.1	63.64	120	190.64						1.14		
	2	STAR		140	70	1.1	63.64		63.64	254.27	4.24	5.75		1.51		2.03	
	STAR	3	7	180	90	1.1	81.82	120	208.82								
	3	STAR		180	90	1.1	81.82		81.82	290.64	4.84	5.75		0.91		1.50	
FROM GREEN HOUSES TO HARDENING OFF (OUTSIDE)	A	B	7	180	90	1.1	81.82	120	208.82								
	B	C		220	110	1.1	100.00		100.00	308.82	5.15		5.33	0.19		2.62	
	C	D	7	375	187.5	1.1	170.45	120	297.45						1.898		
	D	E		305	152.5	1.1	138.64		138.64	436.09	7.27		5.33	-1.93		1.50	
	E	B	7	140	70	1.1	63.64	120	190.64								
	B	C		220	110	1.1	100.00		100.00	290.64	4.84		5.33	0.49		2.78	
MIX BOTH PROCESSES	STAR	3 OR C	7	180	90	1.1	81.82	120	208.82								
	3 OR C	D	7	375	187.5	1.1	170.45	120	297.45	613.55	10.23	5.75	5.33	-4.48	2.40	1.49	*EXAMPLE 1*
	D	STAR		236	118	1.1	107.27		107.27								
	STAR	3 OR C	7	180	90	1.1	81.82	120	208.82								
	3 OR C	B	7	220	110	1.1	100.00	120	227.00	613.55	10.23	5.75	5.33	-4.89	2.67	1.50	*EXAMPLE 2*
	B	STAR		160	80	1.1	72.73		72.73	508.55	8.48	5.75	5.33	-2.73	2.60	2.07	*EXAMPLE 3*

Table A.7.1

IX. Crystal Heart's 10 Trays analysis

Speed can possible be increased to 1.1

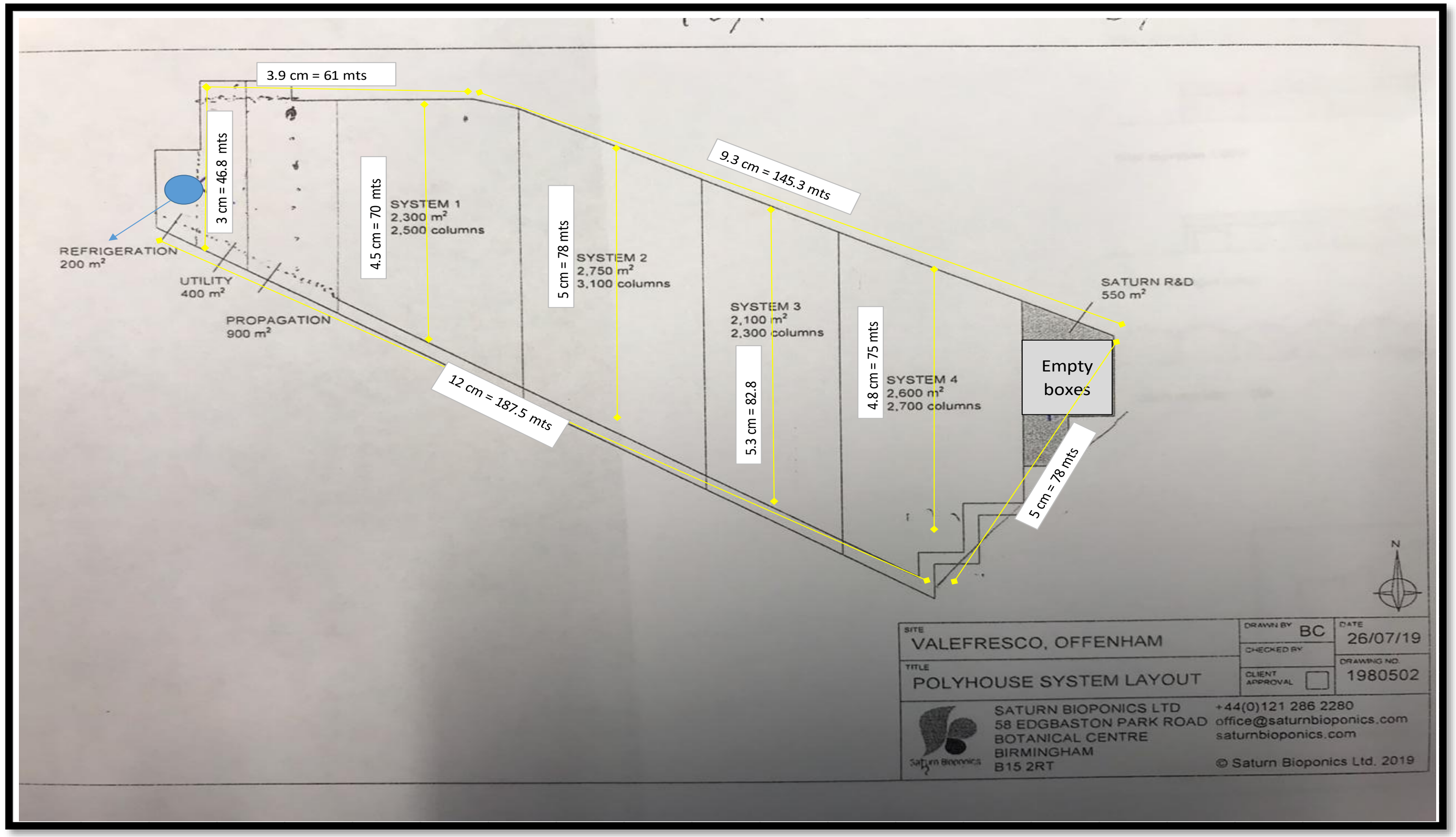
Using only 01 AGV per process

Safety time was reduced to 1.5 min

	INITIAL POINT	FINAL POINT	LOADING TIME sec	DISTANCE (MM)	DISTANCE (MT)	SPEED (MT/S)	MOVING TIME	UNLOADING TIME sec	TOTAL TIME (SEG)	2 WAYS TIME (SEG)	TOTAL TIME (MIN)	BATCH TIME IN MIN(LAY FLAT THROUGHPUT)	GREEN HOUSE THROUGHPUT	DIFFERENCE WITH THROUGHPUT	AGV REQUIRED	FINAL OUTPUT WITH AGV APPLIED	
LAY FLAT ROOM (Area but not machine) TO GREEN HOUSES	STAR	1	7	80	40	1.1	36.36	60	103.36								
	1	STAR		80	40	1.1	36.36		36.36	139.73	2.33	3.48		1.15		2.28	
	STAR	2	7	140	70	1.1	63.64	60	130.64						1.94		
	2	STAR		140	70	1.1	63.64		63.64	194.27	3.24	3.48		0.24		1.81	
	STAR	3	7	180	90	1.1	81.82	60	148.82								
	3	STAR		180	90	1.1	81.82		81.82	230.64	3.84	3.48		-0.37		1.50	
FROM GREEN HOUSES TO HARDENING OFF (OUTSIDE)	A	B	7	180	90	1.1	81.82	60	148.82								
	B	C		220	110	1.1	100.00		100.00	248.82	4.15		3.75	-0.40		2.26	
	C	D	7	375	187.5	1.1	170.45	60	237.45						2.79		
	D	E		305	152.5	1.1	138.64		138.64	376.09	6.27		3.75	-2.52		1.50	
	E	B	7	140	70	1.1	63.64	60	130.64								
	B	C		220	110	1.1	100.00		100.00	230.64	3.84		3.75	-0.09		2.37	
MIX BOTH PROCESSES	STAR	3 OR C	7	180	90	1.1	81.82	60	148.82								
	3 OR C	D	7	375	187.5	1.1	170.45	60	237.45	493.55	8.23	3.48	3.75	-4.75	4.15	1.50	EXAMPLE 1
	D	STAR		236	118	1.1	107.27		107.27								
	STAR	3 OR C	7	180	90	1.1	81.82	60	148.82								
	3 OR C	B	7	220	110	1.1	100.00	60	167.00	493.55	8.23	3.48	3.75	-4.48	3.65	1.50	EXAMPLE 2
	B	STAR		160	80	1.1	72.73		72.73	388.55	6.48	3.48	3.75	-3.00	3.28	1.50	EXAMPLE 3

Table A.8.1

X. New Valefresco's facility Layout



XI. Valefresco process’s analysis current performance

Quantity of AGVs applied to current performance

Time constraint: **30 MIN**

		QTY OF OPERATORES AND 01 AGV PER SIDE (EMPTY AND FULL)					
TIME FROM SYSTEM "X" TO REFRIGERATOR (WITH RETURN IN MIN)		5	6	7	8	9	
SYSTEM 1	4.24	21.21	25.45	29.70	33.94	38.18	TOTAL AGVS REQUIRED: 02
SYSTEM 2	6.01	30.04	36.05	42.05	48.06	54.07	
SYSTEM 3	7.24	36.18	43.42	50.65	57.89	65.13	
SYSTEM 4	8.05	40.25	48.29	56.34	64.39	72.44	
TIME FROM SYSTEM "X" TO EMPTY BOXES AND RETURN (MIN)		5	6	7	8	9	
SYSTEM 1	7.33	36.67	44.00	51.33	58.67	66.00	
SYSTEM 2	6.25	31.25	37.50	43.75	50.00	56.25	
SYSTEM 3	5.30	26.48	31.78	37.08	42.38	47.67	
SYSTEM 4	4.03	20.17	24.20	28.24	32.27	36.31	

Time constraint: **30 MIN**

TIME FROM SYSTEM X TO REFRIGERATOR (WITH RETURN IN MIN)		QTY OF OPERATORES AND 02 AGV PER SIDE (EMPTY AND FULL)					
		5	6	7	8	9	
SYSTEM 1	4.24	10.61	12.73	14.85	16.97	19.09	TOTAL AGVS REQUIRED: 04
SYSTEM 2	6.01	15.02	18.02	21.03	24.03	27.03	
SYSTEM 3	7.24	18.09	21.71	25.33	28.95	32.56	
SYSTEM 4	8.05	20.12	24.15	28.17	32.20	36.22	
TIME FROM SYSTEM X TO EMPTY BOXES AND RETURN (MIN)		5	6	7	8	9	
SYSTEM 1	7.33	18.33	22.00	25.67	29.33	33.00	
SYSTEM 2	6.25	15.63	18.75	21.88	25.00	28.13	
SYSTEM 3	5.30	13.24	15.89	18.54	21.19	23.84	
SYSTEM 4	4.03	10.08	12.10	14.12	16.14	18.15	

Time constraint: **30 MIN**

TIME FROM SYSTEM X TO REFRIGERATOR (WITH RETURN IN MIN)		QTY OF OPERATORES AND 03 AGV PER SIDE (EMPTY AND FULL)					
			6	7	8	9	
SYSTEM 1	4.24	7.07	8.48	9.90	11.31	12.73	TOTAL AGVS REQUIRED: 06
SYSTEM 2	6.01	10.01	12.02	14.02	16.02	18.02	
SYSTEM 3	7.24	12.06	14.47	16.88	19.30	21.71	
SYSTEM 4	8.05	13.42	16.10	18.78	21.46	24.15	
TIME FROM SYSTEM X TO EMPTY BOXES AND RETURN (MIN)		5	6	7	8	9	
SYSTEM 1	7.33	12.22	14.67	17.11	19.56	22.00	
SYSTEM 2	6.25	10.42	12.50	14.58	16.67	18.75	
SYSTEM 3	5.30	8.83	10.59	12.36	14.13	15.89	
SYSTEM 4	4.03	6.72	8.07	9.41	10.76	12.10	

Table A.10.1

XII. Valefresco process's analysis new potential performance

Quantity of AGVs applied to the new potential performance when picking and walking time waste are eliminated.

Time constraint: **18 MIN**

TIME FROM SYSTEM "X" TO REFRIGERATOR (WITH RETURN IN MIN)		QTY OF OPERATORES AND 01 AGV PER SIDE (EMPTY AND FULL)				
		5	6	7	8	9
SYSTEM 1	4.24	21.21	25.45	29.70	33.94	38.18
SYSTEM 2	6.01	30.04	36.05	42.05	48.06	54.07
SYSTEM 3	7.24	36.18	43.42	50.65	57.89	65.13
SYSTEM 4	8.05	40.25	48.29	56.34	64.39	72.44
TIME FROM SYSTEM "X" TO EMPTY BOXES AND RETURN (MIN)		5	6	7	8	9
SYSTEM 1	7.33	36.67	44.00	51.33	58.67	66.00
SYSTEM 2	6.25	31.25	37.50	43.75	50.00	56.25
SYSTEM 3	5.30	26.48	31.78	37.08	42.38	47.67
SYSTEM 4	4.03	20.17	24.20	28.24	32.27	36.31

TOTAL AGVS REQUIRED: 02

Time constraint: **18 MIN**

TIME FROM SYSTEM X TO REFRIGERATOR (WITH RETURN IN MIN)		QTY OF OPERATORES AND 02 AGV PER SIDE (EMPTY AND FULL)				
		5	6	7	8	9
SYSTEM 1	4.24	10.61	12.73	14.85	16.97	19.09
SYSTEM 2	6.01	15.02	18.02	21.03	24.03	27.03
SYSTEM 3	7.24	18.09	21.71	25.33	28.95	32.56
SYSTEM 4	8.05	20.12	24.15	28.17	32.20	36.22
TIME FROM SYSTEM X TO EMPTY BOXES AND RETURN (MIN)		5	6	7	8	9
SYSTEM 1	7.33	18.33	22.00	25.67	29.33	33.00
SYSTEM 2	6.25	15.63	18.75	21.88	25.00	28.13
SYSTEM 3	5.30	13.24	15.89	18.54	21.19	23.84
SYSTEM 4	4.03	10.08	12.10	14.12	16.14	18.15

TOTAL AGVS REQUIRED: 04

Time constraint: **18 MIN**

TIME FROM SYSTEM X TO REFRIGERATOR (WITH RETURN IN MIN)		QTY OF OPERATORES AND 03 AGV PER SIDE (EMPTY AND FULL)				
			6	7	8	9
SYSTEM 1	4.24	7.07	8.48	9.90	11.31	12.73
SYSTEM 2	6.01	10.01	12.02	14.02	16.02	18.02
SYSTEM 3	7.24	12.06	14.47	16.88	19.30	21.71
SYSTEM 4	8.05	13.42	16.10	18.78	21.46	24.15
TIME FROM SYSTEM X TO EMPTY BOXES AND RETURN (MIN)		5	6	7	8	9
SYSTEM 1	7.33	12.22	14.67	17.11	19.56	22.00
SYSTEM 2	6.25	10.42	12.50	14.58	16.67	18.75
SYSTEM 3	5.30	8.83	10.59	12.36	14.13	15.89
SYSTEM 4	4.03	6.72	8.07	9.41	10.76	12.10

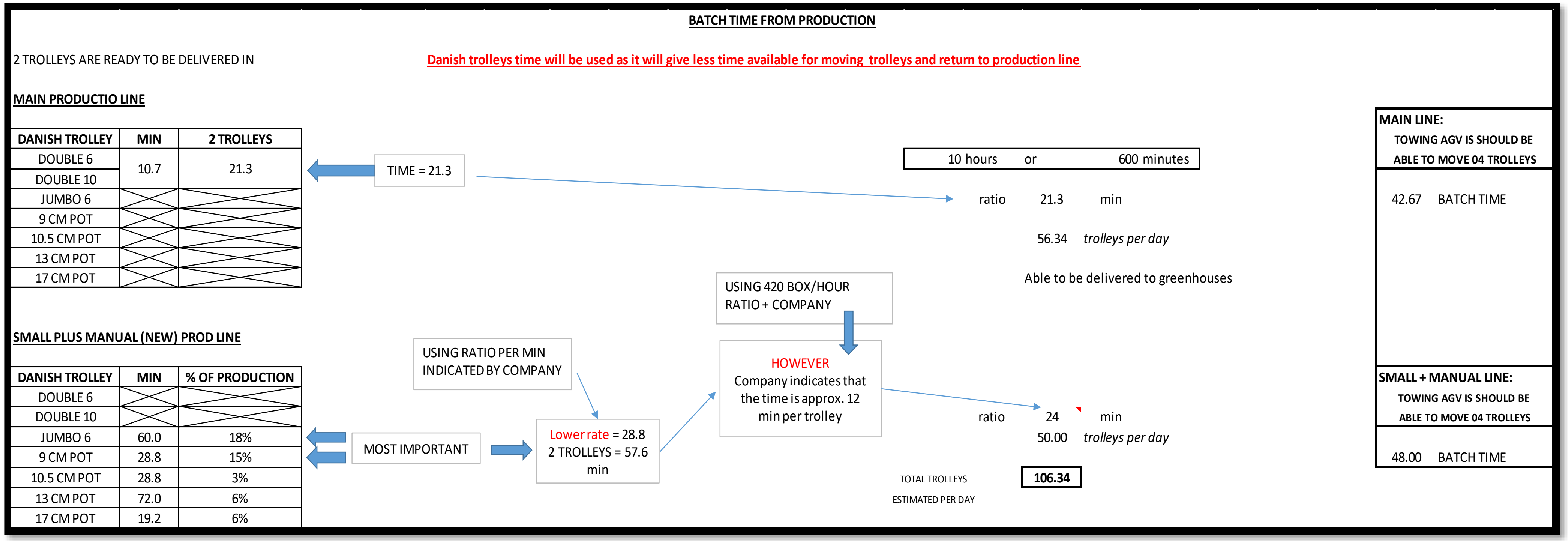
TOTAL AGVS REQUIRED: 06

Table A.11.1

XIII. WD Smith process's analysis

A.) **Batch times:** The following two figures shows the batch times of trolleys from production line and greenhouses respectively.

A.1) Trolley's batch time from production lines:



MAIN PRODUCTIO LINE

DANISH TROLLEY	MIN	2 TROLLEYS
DOUBLE 6	10.7	21.3
DOUBLE 10		
JUMBO 6		
9 CM POT		
10.5 CM POT		
13 CM POT		
17 CM POT		

SMALL PLUS MANUAL (NEW) PROD LINE

DANISH TROLLEY	MIN	% OF PRODUCTION
DOUBLE 6		
DOUBLE 10		
JUMBO 6	60.0	18%
9 CM POT	28.8	15%
10.5 CM POT	28.8	3%
13 CM POT	72.0	6%
17 CM POT	19.2	6%

Table A.12.1

A.2) Trolley's batch time from greenhouses:

BATCH TIME FROM GREENHOUSES

TYPE		DANISH TROLLEYS TOTAL OF BOXES	SECOND TIME FOR LOADING	MINUTES TIME FOR LOADING
DOUBLE 6	BOX	80	400	7
DOUBLE 10	TRAY	80	400	7
JUMBO 6	TRAY	120	600	10
9 CM POT	TRAY	48	240	4
10.5 CM POT	TRAY	48	240	4
13 CM POT	TRAY	60	300	5
17 CM POT	TRAY	16	80	1

85 % OF THE PRODUCTION. AVG 7.78 → IT WILL BE USED AS IT THE WORST CASE SCENARIO

Therefore, if there are enough boxes to load trolleys, the batch time to deliver every trolley will be 7.78 min

Final batch time from greenhouses	
2 trolleys	15.56
4 trolleys	31.11

TYPE		SIX SHELF BARROWS QTY	SECOND TIME FOR LOADING	MINUTES TIME FOR LOADING
DOUBLE 6	BOX	126	630	11
DOUBLE 10	TRAY	126	630	11
JUMBO 6	TRAY	180	900	15
9 CM POT	TRAY	54	270	5
10.5 CM POT	TRAY	54	270	5
13 CM POT	TRAY	60	300	5
17 CM POT	TRAY	0	0	0

85 % OF THE PRODUCTION. AVG 12.00

	TOTAL WORKING TIME	LOADING TIME PER TROLLEY	TOTAL TROLLEYS TO DELIVER
A	600	7.78	77.12
B			
C			
D			
E			
F			
G			
H			
I			

AVG TROLLEYS PER POINTS 8.6

Table A.12.2

B) No mixing processes' analysis: The following tables show the analysis for a "Lifter" AGV and "Towing" AGV when AGVs do not mix different key points.

B.1) Lifter AGV:

B.1.1) From main line to different key points and zones:

FROM PRODUCTION LINE 1 (MAIN LINE):

SAFETY TIME OF 2.5 MIN.

	INITIAL POINT	FINAL POINT	LOADING TIME sec	DISTANCE (MT)	AVG SPEED (MT/S)	MOVING TIME	UNLOADING TIME sec	TOTAL TIME (SEG)	2 WAYS TIME (SEG)	TOTAL TIME (MIN)	BATCH TIME IN MIN (2 TROLLEYS)	DIFFERENCE WITH THROUGHPUT	AGV REQUIRED	FINAL OUTPUT WITH AGV	TOTAL AGV
ZONE 1	STAR	A	10	165	1.1	150.00	10	170.00					0.28		1
	A	STAR	0	165	1.1	150.00	0	150.00	320.00	5.33	21.33	16.00		2.50	
	STAR	B	10	70	1.1	63.64	10	83.64					0.13		1
	B	STAR	0	70	1.1	63.64	0	63.64	147.27	2.45	21.33	18.88		2.50	
	STAR	C	10	135	1.1	122.73	10	142.73					0.23		1
	C	STAR	0	135	1.1	122.73	0	122.73	265.45	4.42	21.33	16.91		2.50	
	STAR	D	10	190	1.1	172.73	10	192.73					0.32		1
	D	STAR	0	190	1.1	172.73	0	172.73	365.45	6.09	21.33	15.24		2.50	
ZONE 2	STAR	E	10	210	1.1	190.91	10	210.91					0.36		1
	E	STAR	0	210	1.1	190.91	0	190.91	401.82	6.70	21.33	14.64		2.50	
	STAR	F	10	267	1.1	242.73	10	262.73					0.45		1
	F	STAR	0	267	1.1	242.73	0	242.73	505.45	8.42	21.33	12.91		2.50	
	STAR	G	10	317	1.1	288.18	10	308.18					0.53		1
	G	STAR	0	317	1.1	288.18	0	288.18	596.36	9.94	21.33	11.39		2.50	
ZONA 3	STAR	H	10	343	1.1	311.82	10	331.82					0.57		1
	H	STAR	0	343	1.1	311.82	0	311.82	643.64	10.73	21.33	10.61		2.50	
	STAR	I	10	378	1.1	343.64	10	363.64					0.63		1
	I	STAR	0	378	1.1	343.64	0	343.64	707.27	11.79	21.33	9.55		2.50	
	STAR	DISPATCH	10	260	1.1	236.36	10	256.36					0.44		1
	DISPTACH	STAR	0	260	1.1	236.36	0	236.36	492.73	8.21	21.33	13.12		2.50	

Table A.12.3

B.1.2) From small + manual lines to different key points and zones:

SAFETY TIME OF 2.5 MIN.

	INITIAL POINT	FINAL POINT	LOADING TIME sec	DISTANCE (MT)	AVG SPEED (MT/S)	MOVING TIME	UNLOADING TIME sec	TOTAL TIME (SEG)	2 WAYS TIME (SEG)	TOTAL TIME (MIN)	BATCH TIME IN MIN (2 TROLLEYS)	DIFFERENCE WITH THROUGHPUT	AGV REQUIRED	FINAL OUTPUT WITH AGV APPLIED	TOTAL AGV
ZONE 1	STAR	A	10	290	1.1	263.64	10	283.64					0.42	2.50	1
	A	STAR	0	290	1.1	263.64	0	263.64	547.27	9.12	24.00	14.88			
	STAR	B	10	196	1.1	178.18	10	198.18					0.29	2.50	1
	B	STAR	0	196	1.1	178.18	0	178.18	376.36	6.27	24.00	17.73			
	STAR	C	10	256	1.1	232.73	10	252.73					0.38	2.50	1
	C	STAR	0	256	1.1	232.73	0	232.73	485.45	8.09	24.00	15.91			
	STAR	D	10	319	1.1	290.00	10	310.00					0.47	2.50	1
	D	STAR	0	319	1.1	290.00	0	290.00	600.00	10.00	24.00	14.00			
ZONE 2	STAR	E	10	50	1.1	45.45	10	65.45					0.09	2.50	1
	E	STAR	0	50	1.1	45.45	0	45.45	110.91	1.85	24.00	22.15			
	STAR	F	10	103	1.1	93.64	10	113.64					0.16	2.50	1
	F	STAR	0	103	1.1	93.64	0	93.64	207.27	3.45	24.00	20.55			
	STAR	G	10	152	1.1	138.18	10	158.18					0.23	2.50	1
	G	STAR	0	152	1.1	138.18	0	138.18	296.36	4.94	24.00	19.06			
ZONA 3	STAR	H	10	180	1.1	163.64	10	183.64					0.27	2.50	1
	H	STAR	0	180	1.1	163.64	0	163.64	347.27	5.79	24.00	18.21			
	STAR	I	10	211	1.1	191.82	10	211.82					0.31	2.50	1
	I	STAR	0	211	1.1	191.82	0	191.82	403.64	6.73	24.00	17.27			
	STAR	DISPATCH	10	100	1.1	90.91	10	110.91					0.16	2.50	1
	DISPTACH	STAR	0	100	1.1	90.91	0	90.91	201.82	3.36	24.00	20.64			

Table A.12.4

B.1.3) From greenhouses key points to delivery area:

2.5 min safety time

	INITIAL POINT	FINAL POINT	LOADING TIME sec	DISTANCE (MT)	AVG SPEED (MT/S)	MOVING TIME	UNLOADING TIME sec	TOTAL TIME (SEG)	TOTAL TIME (MIN)	TOTAL TIME (MIN)	BATCH TIME IN MIN (2 TROLLEYS)	DIFFERENCE WITH THROUGHPUT	AGV REQUIRED	FINAL OUTPUT WITH AGV APPLIED	TOTAL AGV
ZONE 1	A	DELIVERY	10	350	1.1	318.18	10	338.18	5.64		15.56		0.91	✓ 2.50	1
	DELIVERY	D	0	410	1.1	372.73	0	372.73	6.21	11.85	15.56	✓ 3.71			
	D	DELIVERY	10	410	1.1	372.73	10	392.73	6.55		15.56		0.90	✓ 2.50	1
	DELIVERY	C	0	340	1.1	309.09	0	309.09	5.15	11.70	15.56	✓ 3.86			
	C	DELIVERY	10	340	1.1	309.09	10	329.09	5.48		15.56				
	DELIVERY	B	0	280	1.1	254.55	0	254.55	4.24	14.30	15.56	! 1.25	1.10	! 2.50	2
	B	DELIVERY	10	280	1.1	254.55	10	274.55	4.58		15.56				
ZONE 2	DELIVERY	E	0	61	1.1	55.45	0	55.45	0.92						
	E	DELIVERY	10	61	1.1	55.45	10	75.45	1.26						
	DELIVERY	F	0	59	1.1	53.64	0	53.64	0.89						
	F	DELIVERY	10	59	1.1	53.64	10	73.64	1.23						
	DELIVERY	G	0	114	1.1	103.64	0	103.64	1.73						
	G	DELIVERY	10	114	1.1	103.64	10	123.64	2.06	15.33	15.56	✗ 0.22	1.17	✓ 2.50	1
ZONA 3	DELIVERY	H	0	89	1.1	80.91	0	80.91	1.35						
	H	DELIVERY	10	89	1.1	80.91	10	100.91	1.68						
	DELIVERY	I	0	128	1.1	116.36	0	116.36	1.94						
	I	DELIVERY	10	128	1.1	116.36	10	136.36	2.27						

Table A.12.5

B.2.) Towing AGV:

B.2.1) From main line to different key points and zones:

FROM PRODUCTION LINE 1 (MAIN LINE): **TOWING AGV**

SAFETY TIME OF 2.5 MIN.

	INITIAL POINT	FINAL POINT	LOADING TIME sec	DISTANCE (MT)	AVG SPEED (MT/S)	MOVING TIME	UNLOADING TIME sec	TOTAL TIME (SEG)	2 WAYS TIME (SEG)	TOTAL TIME (MIN)	BATCH TIME IN MIN **(4 TROLLEYS)**	DIFFERENCE WITH THROUGHPUT	AGV REQUIRED	FINAL OUTPUT WITH AGV APPLIED	TOTAL AGV
ZONE 1	STAR	A	40	165	0.8	206.25	40	286.25					0.20	✓ 2.50	1
	A	STAR	0	165	0.8	206.25	0	206.25	492.50	8.21	42.67	✓ 34.46			
	STAR	B	40	70	0.8	87.50	40	167.50					0.11	✓ 2.50	1
	B	STAR	0	70	0.8	87.50	0	87.50	255.00	4.25	42.67	✓ 38.42			
	STAR	C	40	135	0.8	168.75	40	248.75					0.17	✓ 2.50	1
	C	STAR	0	135	0.8	168.75	0	168.75	417.50	6.96	42.67	✓ 35.71			
	STAR	D	40	190	0.8	237.50	40	317.50					0.23	✓ 2.50	1
	D	STAR	0	190	0.8	237.50	0	237.50	555.00	9.25	42.67	✓ 33.42			
ZONE 2	STAR	E	40	210	0.8	262.50	40	342.50					0.25	✓ 2.50	1
	E	STAR	0	210	0.8	262.50	0	262.50	605.00	10.08	42.67	✓ 32.58			
	STAR	F	40	267	0.8	333.75	40	413.75					0.31	✓ 2.50	1
	F	STAR	0	267	0.8	333.75	0	333.75	747.50	12.46	42.67	✓ 30.21			
	STAR	G	40	317	0.8	396.25	40	476.25					0.36	✓ 2.50	1
	G	STAR	0	317	0.8	396.25	0	396.25	872.50	14.54	42.67	✓ 28.13			
ZONA 3	STAR	H	40	343	0.8	428.75	40	508.75					0.39	✓ 2.50	1
	H	STAR	0	343	0.8	428.75	0	428.75	937.50	15.63	42.67	✓ 27.04			
	STAR	I	40	378	0.8	472.50	40	552.50					0.43	✓ 2.50	1
	I	STAR	0	378	0.8	472.50	0	472.50	1025.00	17.08	42.67	✓ 25.58			
	STAR	DISPATCH	40	260	0.8	325.00	40	405.00					0.30	✓ 2.50	1
	DISPTACH	STAR	0	260	0.8	325.00	0	325.00	730.00	12.17	42.67	✓ 30.50			

Table A.12.6

B.2.2) From small + manual lines to different key points and zones:

SAFETY TIME OF 2.5 MIN.

	INITIAL POINT	FINAL POINT	LOADING TIME sec	DISTANCE (MT)	AVG SPEED (MT/S)	MOVING TIME	UNLOADING TIME sec	TOTAL TIME (SEG)	2 WAYS TIME (SEG)	TOTAL TIME (MIN)	BATCH TIME IN MIN **(04 TROLLEYS)**	DIFFERENCE WITH THROUGHPUT	AGV REQUIRED	FINAL OUTPUT WITH AGV APPLIED	TOTAL AGV
ZONE 1	STAR	A	10	290	0.8	362.50	10	382.50					0.27		1
	A	STAR	0	290	0.8	362.50	0	362.50	745.00	12.42	48.00	35.58		2.50	
	STAR	B	10	196	0.8	245.00	10	265.00					0.19		1
	B	STAR	0	196	0.8	245.00	0	245.00	510.00	8.50	48.00	39.50		2.50	
	STAR	C	10	256	0.8	320.00	10	340.00					0.24		1
	C	STAR	0	256	0.8	320.00	0	320.00	660.00	11.00	48.00	37.00		2.50	
	STAR	D	10	319	0.8	398.75	10	418.75					0.30		1
	D	STAR	0	319	0.8	398.75	0	398.75	817.50	13.63	48.00	34.38		2.50	
ZONE 2	STAR	E	10	50	0.8	62.50	10	82.50					0.05		1
	E	STAR	0	50	0.8	62.50	0	62.50	145.00	2.42	48.00	45.58		2.50	
	STAR	F	10	103	0.8	128.75	10	148.75					0.10		1
	F	STAR	0	103	0.8	128.75	0	128.75	277.50	4.63	48.00	43.38		2.50	
	STAR	G	10	152	0.8	190.00	10	210.00					0.15		1
	G	STAR	0	152	0.8	190.00	0	190.00	400.00	6.67	48.00	41.33		2.50	
ZONA 3	STAR	H	10	180	0.8	225.00	10	245.00					0.17		1
	H	STAR	0	180	0.8	225.00	0	225.00	470.00	7.83	48.00	40.17		2.50	
	STAR	I	10	211	0.8	263.75	10	283.75					0.20		1
	I	STAR	0	211	0.8	263.75	0	263.75	547.50	9.13	48.00	38.88		2.50	
	STAR	DISPATCH	10	100	0.8	125.00	10	145.00					0.10		1
	DISPTACH	STAR	0	100	0.8	125.00	0	125.00	270.00	4.50	48.00	43.50		2.50	

Table A.12.7

C) Mixing processes' analysis: The following tables show the analysis for a "Lifter" AGV and "Towing" AGV when AGVs are mix different key points (production lines, greenhouses and delivery area).

C.1) Lifter AGV:

(This analysis continue in next table)

	INITIAL POINT	FINAL POINT	LOADING TIME sec	DISTANCE (MT)	AVG SPEED (MT/S)	MOVING TIME	UNLOADING TIME sec	TOTAL TIME (SEG)	TOTA TIME (MIN) PER STAGE	TOTA TIME (MIN) TOTAL TRAVEL	BATCH TIME IN MIN **(2 TROLLEYS)**	DIFFERENCE WITH THROUGHPUT	AGV REQUIRED	FINAL OUTPUT WITH AGV APPLIED	TOTAL AGV
Lifter AGV	STAR	D	40	190	1.1	172.7	40.0	252.7	4.21	25.53	21.33	-4.20	1.36	2.50	2
	D	A	0	124	1.1	112.7	0.0	112.7	1.88						
	A	DELIVERY	40	350	1.1	318.2	40.0	398.2	6.64						
	DELIVERY	I	40	128	1.1	116.4	40.0	196.4	3.27						
	I	DELIVERY	40	128	1.1	116.4	40.0	196.4	3.27						
	DELIVERY	STAR	40	325	1.1	295.5	40.0	375.5	6.26						
	6 (above) and 8 points (below) travel														
	STAR	D	40	190	1.1	172.7	40.0	252.7	4.21	40.62	21.33	-19.29	2.16	2.50	3
	D	A	0	124	1.1	112.7	0.0	112.7	1.88						
	A	DELIVERY	40	350	1.1	318.2	40.0	398.2	6.64						
	DELIVERY	I	40	128	1.1	116.4	40.0	196.4	3.27						
	I	DELIVERY	40	128	1.1	116.4	40.0	196.4	3.27						
	DELIVERY	D	40	410	1.1	372.7	40.0	452.7	7.55						
	D	DELIVERY	40	410	1.1	372.7	40.0	452.7	7.55						
	DELIVERY	STAR	40	325	1.1	295.5	40.0	375.5	6.26						

IN MIXING PROCESS THE PRODUCTION TIME BATCH IS USED AS THE BOTTLENECK TO AVOID It FROM PRODUCTION PERSPECTIVE.

TO 6 POINTS TRAVEL	2	ARE REQUIRED
TO 8 POINTS TRAVEL	3	ARE REQUIRED

Table A.12.8

(It comes from the last table)

Lifter AGV

INITIAL POINT	FINAL POINT	LOADING TIME sec	DISTANCE (MT)	AVG SPEED (MT/S)	MOVING TIME	UNLOADING TIME sec	TOTAL TIME (SEG)	TOTA TIME (MIN) PER STAGE	TOTA TIME (MIN) TOTAL TRAVEL	BATCH TIME IN MIN **(2 TROLLEYS)**	DIFFERENCE WITH THROUGHPUT	AGV REQUIRED	FINAL OUTPUT WITH AGV APPLIED	TOTAL AGV
STAR 1	D	40	190	1.1	172.7	40	252.7	4.21	36.52	21.33	-15.18	1.94	2.50	2
D	A	0	124	1.1	112.7	0	112.7	1.88						
A	DELIVERY	40	350	1.1	318.2	40	398.2	6.64						
DELIVERY	STAR 2	40	100	1.1	90.9	40	170.9	2.85						
STAR 2	D	40	319	1.1	290.0	40	370.0	6.17						
D	A	0	124	1.1	112.7	0	112.7	1.88						
A	DELIVERY	40	350	1.1	318.2	40	398.2	6.64						
DELIVERY	STAR 1	40	325	1.1	295.5	40	375.5	6.26						

08 points travel based on zone 2. Just 02 are required

Mixing 8 points travel (star 1) with star 2 (other prod lines) and checking 16 points travel agv's requirements

INITIAL POINT	FINAL POINT	LOADING TIME sec	DISTANCE (MT)	AVG SPEED (MT/S)	MOVING TIME	UNLOADING TIME sec	TOTAL TIME (SEG)	TOTA TIME (MIN) PER STAGE	TOTA TIME (MIN) TOTAL TRAVEL		BATCH TIME IN MIN **(2 TROLLEYS)**	DIFFERENCE WITH THROUGHPUT (Total 16 points)	DIFFERENCE WITH THROUGHPUT (Per prod. line stages)	AGV REQUIRED		FINAL OUTPUT WITH AGV APPLIED		TOTAL AGV	
STAR 1	D	40	190	1.1	172.7	40	252.7	4.2	74.38	36.52	21.33	-53.05	-15.18	3.95	1.94	2.50	2.50	4	2
D	A	0	124	1.1	112.7	0	112.7	1.9											
A	DELIVERY	40	350	1.1	318.2	40	398.2	6.6											
DELIVERY	STAR 2	40	100	1.1	90.9	40	170.9	2.8											
STAR 2	D	40	319	1.1	290.0	40	370.0	6.2											
D	A	0	124	1.1	112.7	0	112.7	1.9											
A	DELIVERY	40	350	1.1	318.2	40	398.2	6.6											
DELIVERY	STAR 1	40	325	1.1	295.5	40	375.5	6.3											
STAR 1	D	40	190	1.1	172.7	40	252.7	4.2		40.33	24.00		-16.33		1.88		2.50		2
D	STAR 2	40	319	1.1	290.0	40	370.0	6.2											
STAR 2	D	40	319	1.1	290.0	40	370.0	6.2											
D	A	0	124	1.1	112.7	0	112.7	1.9		37.86	21.33		-16.53		2.01		2.50		3
A	DELIVERY	40	350	1.1	318.2	40	398.2	6.6											
DELIVERY	I	40	128	1.1	116.4	40	196.4	3.3											
I	DELIVERY	40	128	1.1	116.4	40	196.363636	3.3											
DELIVERY	STAR 1	40	325	1.1	295.5	40	375.454545	6.3											

In order to analyse them independently, the time is splited to the differents production lines

If we use the mixing points as 16 different points before back to star 1. This could be the difference. this helps to check the real requirement of AGV by mixing different areas

Table A.12.9

C.2) Towing AGV:

(This analysis continue in next table)

	INITIAL POINT	FINAL POINT	LOADING TIME sec	DISTANCE (MT)	AVG SPEED (MT/S)	MOVING TIME	UNLOADING TIME sec	TOTAL TIME (SEG)	TOTA TIME (MIN) PER STAGE	TOTA TIME (MIN) TOTAL TRAVEL	BATCH TIME IN MIN **(4 TROLLEYS)**	DIFFERENCE WITH THROUGHPUT	AGV REQUIRED	FINAL OUTPUT WITH AGV APPLIED	TOTAL AGV
Towing AGV	STAR	D	40	190	0.8	237.5	40	317.5	5.29	32.60	42.67	10.06	0.81	2.50	1
	D	A	0	124	0.8	155	0	155	2.58						
	A	DELIVERY	40	350	0.8	437.5	40	517.5	8.63						
	DELIVERY	I	40	128	0.8	160	40	240	4.00						
	I	DELIVERY	40	128	0.8	160	40	240	4.00						
	DELIVERY	STAR	40	325	0.8	406.25	40	486.25	8.10						
	6 (above) and 8 points (below) travel														
	STAR	D	40	190	0.8	237.5	40	317.5	5.29	52.35	42.67	-9.69	1.30	2.50	2
	D	A	0	124	0.8	155	0	155	2.58						
	A	DELIVERY	40	350	0.8	437.5	40	517.5	8.63						
	DELIVERY	I	40	128	0.8	160	40	240	4.00						
	I	DELIVERY	40	128	0.8	160	40	240	4.00						
	DELIVERY	D	40	410	0.8	512.5	40	592.5	9.88						
	D	DELIVERY	40	410	0.8	512.5	40	592.5	9.88						
	DELIVERY	STAR	40	325	0.8	406.25	40	486.25	8.10						

Maximum quantity of travel points (JUST 01 AGV)	*8*	*points*

IN MIXING PROCESS THE PRODUCTION TIME BATCH IS USED AS THE BOTTLENECK TO AVOID

Table A.12.10

(It comes from the last table)

TOWING AGV

INITIAL POINT	FINAL POINT	LOADING TIME sec	DISTANCE (MT)	AVG SPEED (MT/S)	MOVING TIME	UNLOADING TIME sec	TOTAL TIME (SEG)	TOTA TIME (MIN) PER STAGE	TOTA TIME (MIN) TOTAL TRAVEL	BATCH TIME IN MIN **(4 TROLLEYS)**	DIFFERENCE WITH THROUGHPUT	AGV REQUIRED	FINAL OUTPUT WITH AGV APPLIED	TOTAL AGV
STAR 1	D	40	190	0.8	237.5	40	317.5	5.29	47.21	42.67	-4.54	1.18	2.50	2
D	A	0	124	0.8	155.0	0	155.0	2.58						
A	DELIVERY	40	350	0.8	437.5	40	517.5	8.63						
DELIVERY	STAR 2	40	100	0.8	125.0	40	205.0	3.42						
STAR 2	D	40	319	0.8	398.8	40	478.8	7.98						
D	A	0	124	0.8	155.0	0	155.0	2.58						
A	DELIVERY	40	350	0.8	437.5	40	517.5	8.63						
DELIVERY	STAR 1	40	325	0.8	406.3	40	486.3	8.10						

Mixing 8 points travel (star 1) with star 2 (other prod lines) and checking 16 points travel agv's requirements

INITIAL POINT	FINAL POINT	LOADING TIME sec	DISTANCE (MT)	AVG SPEED (MT/S)	MOVING TIME	UNLOADING TIME sec	TOTAL TIME (SEG)	TOTA TIME (MIN) PER STAGE	TOTA TIME (MIN) TOTAL TRAVEL		BATCH TIME IN MIN **(4 TROLLEYS)**	DIFFERENCE WITH THROUGHPUT		AGV REQUIRED		FINAL OUTPUT WITH AGV APPLIED		TOTAL AGV	
STAR 1	D	40	190	0.8	237.5	40	317.5	5.29				Total 16 points	Per prod. line stages						
D	A	0	124	0.8	155.0	0	155.0	2.58											
A	DELIVERY	40	350	0.8	437.5	40	517.5	8.63											
DELIVERY	STAR 2	40	100	0.8	125.0	40	205.0	3.42		47.21	42.67		-4.54		1.18		2.50		2
STAR 2	D	40	319	0.8	398.8	40	478.8	7.98											
D	A	0	124	0.8	155.0	0	155.0	2.58											
A	DELIVERY	40	350	0.8	437.5	40	517.5	8.63											
DELIVERY	STAR 1	40	325	0.8	406.3	40	486.3	8.10	95.77			-53.10		2.3843		2.50		3	
STAR 1	D	40	190	0.8	237.5	40	317.5	5.29											
D	STAR 2	40	319	0.8	398.8	40	478.8	7.98		51.96	48		-3.96		1.14		2.50		2
STAR 2	D	40	319	0.8	398.8	40	478.8	7.98											
D	A	0	124	0.8	155.0	0	155.0	2.58											
A	DELIVERY	40	350	0.8	437.5	40	517.5	8.63											
DELIVERY	I	40	128	0.8	160.0	40	240.0	4.00		48.56	42.67		-5.90		1.21		2.50		2
I	DELIVERY	40	128	0.8	160.0	40	240	4											
DELIVERY	STAR 1	40	325	0.8	406.3	40	486.25	8.10											

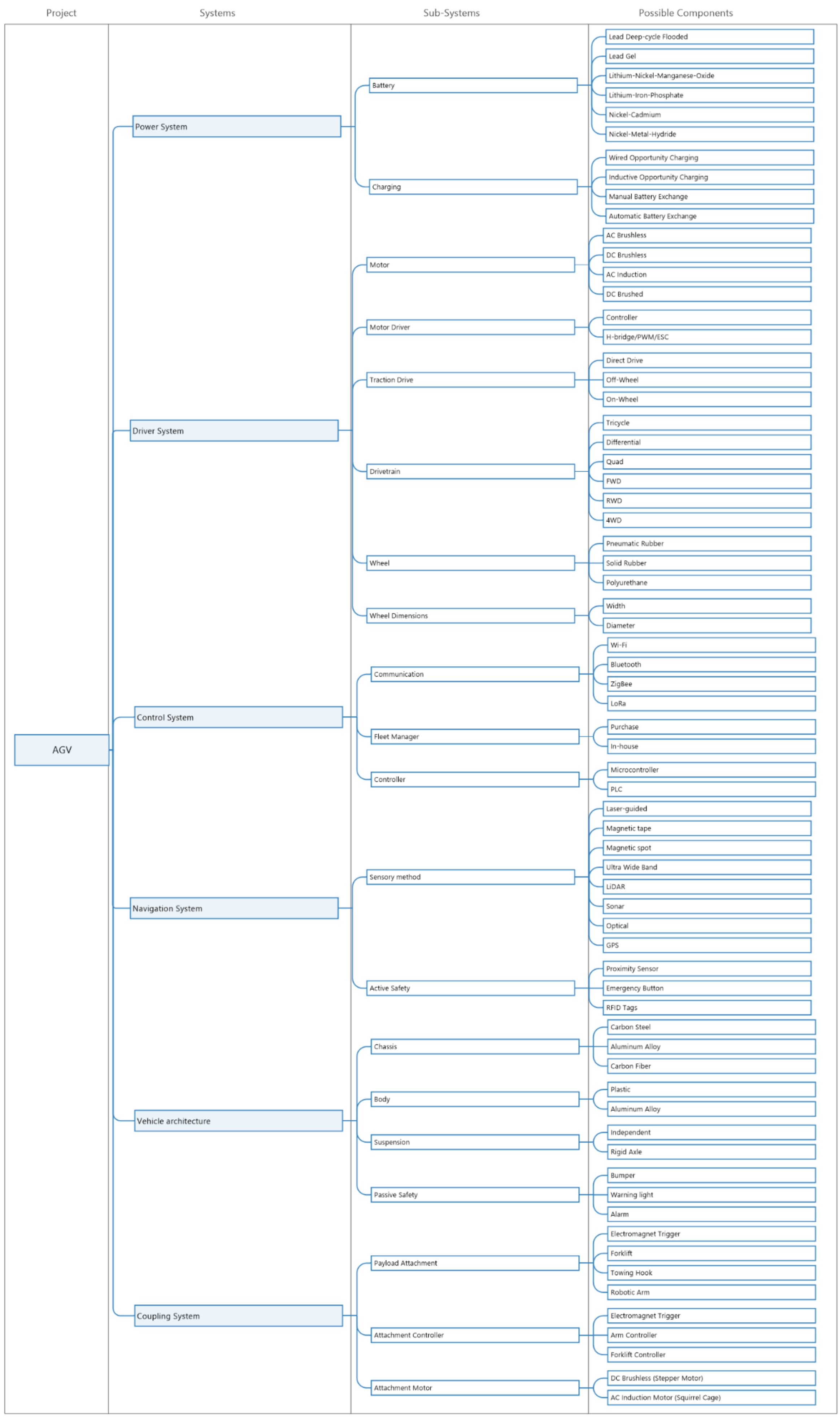
Spliting time to the differents production lines. In order to analyse them independently

If we use the mixing points as 16 different points before back to star 1. This could be the difference. this helps to check the real requirement of AGV by mixing different areas

Table A.12.11

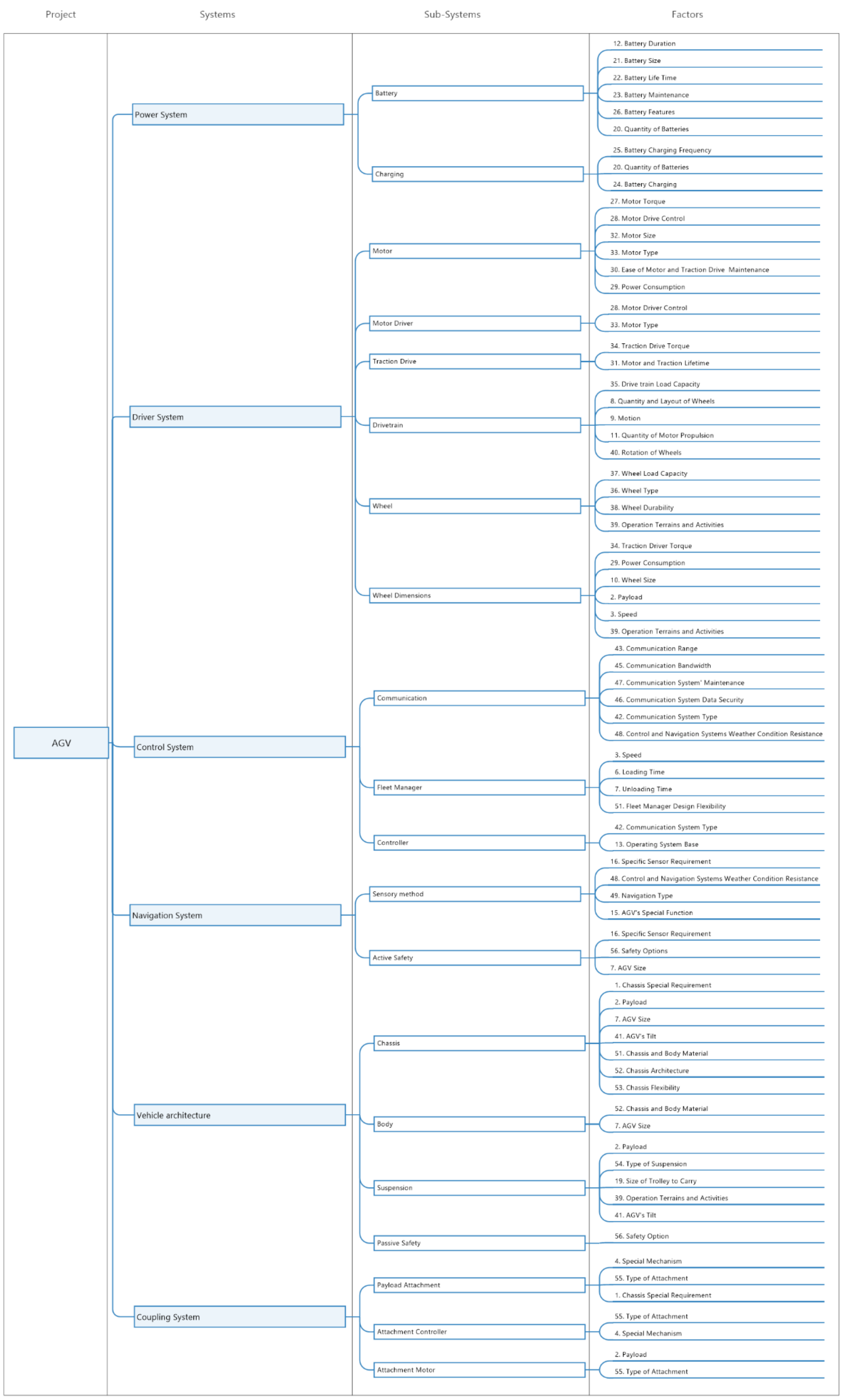
XIV. Breakdown of the AGV’s conceptual idea

AGV Breakdown Flow Diagram to Components



XV. Linkage between AGV systems and sub systems and the critical factors identified.

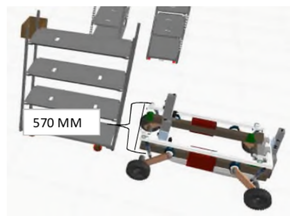
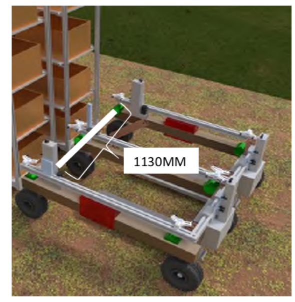
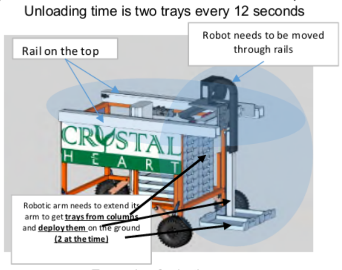
AGV Breakdown Flow Diagram to Factors

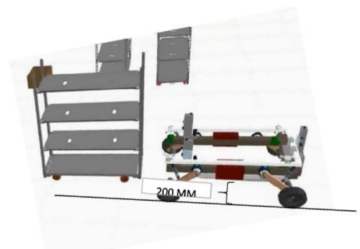


XVI. Preliminary specifications

General Description: *The conceptual design is an Offroad AGV which will be used generally outside buildings and for agriculture purpose.*

The following table shows the different factor or variables that need to be included, considered and/or evaluated/reevaluated during the next stage in order to define the final AGV to prototype. However, the conceptual design of this stage was designed according to the vision of the researchers that was based on the following data/information (If it is applicable):

N°	Variable / factor	Crystal heart salad	Valefresco	WD smith
1	***Chassis special requirement:*** *AGV needs to move object from its front. In this scenario, AGV cannot be closed at the front as normal AGVs.*	890 MM / 89 CM	57 cm  	113 cm 
2	***Payload:*** *the load carried by a vehicle exclusive of what is necessary for its operation especially*	220 KG	120 KG	240 KG
3	***Speed:*** *This speed needs to be considered either agv is loaded or unloaded*	1.1 m/s	1.1 m/s	1.1 m/s (Not towing AGV), Towing AGV speed is **<u>0.8 m/s</u>**
4	***Special Mechanisms:*** *Some companies require special mechanism or system in order to work properly on their processes*	**Robotic arm at the top of the AGV.** It will required an special frame where rails and robotic arm will be placed. Unloading time is two trays every 12 seconds  Example of robotic arm: https://www.youtube.com/watch?v=yn5ejzbrj_s	<u>"AGV CALLER" DEVICE AND SYSTEM:</u> This device will allow operators to call for an agv. The fleet manager will synchrosnise calls according to the production schedule, timing of harvesting, etc. This device could be a button, software aplications, weight sensor on the rails, etc.	**Towing capacity**: It is required a **<u>towing capacity of 550 KG</u>**. The AGV needs to be able to pull a trailer with 04 danish trolleys. 
		Lift mechanism: All companies require a lift mechanism at the bottom to loading boxes/trays		
		Lift mechanism required yes Payload 220 KG Height to lift 100 mm (10 cm)	Lift mechanism required yes Payload 120 KG Height to lift 100 mm (10 cm)	Lift mechanism required yes Payload 240 KG Height to lift 100 mm (10 cm)
		<u>Example of lifting mechanism can be found here:</u> https://www.youtube.com/watch?v=uvsvrf-eB4g https://www.youtube.com/watch?v=AvfqYOtyYZM		
5	***Loading time:*** *This is the time expected to load boxes or trays to AGV*	10 seconds two columns of 10	Full trolley (01) = 10 seconds	lo towing = 10 seconds ; Towing AGV = 40 second
6	***Unloading time:*** *This is the time expected to unload boxes or trays from AGV*	12 seconds each par of trays	10 boxes in 20 seconds (this is a manual process. Operator needs to unload boxes)	lo towing = 10 seconds ; Towing AGV = 40 second
7	***AGV SIZE:*** *AGV measures*	Length: 1330 mm (133 cm) + frame ; Width: 890 mm 89 (CM) + frame ; height: 1100 mm (110 cm)	Length: 1350 mm (135 cm) + frame ; Width: 620 mm (62 cm) + frame ; height: **<u>TO BE CHECKED IN THE NEXT STAGE</u>**	Length: 1350 mm (135 cm) + frame ; Width: 1130 mm (113 cm) + frame ; height: **<u>TO BE CHECKED IN THE NEXT STAGE</u>**

8	***Quantity and layout of wheels:*** *Qty of wheel required and its layout at the bottom of the agv*	4 wheels required. Layout of wheels will be defined at next stage.	4 wheels required. Layout of wheels will be defined at next stage.	4 wheels required. Layout of wheels will be defined at next stage.
9	***Motion:*** *Type of traction required*	Drive and steering = 4 x 4 (traction)	Drive and steering = 4 x 4 (traction)	Drive and steering = 4 x 4 (traction)
10	***Wheel size***	100 mm (10 cm) radio	100 mm (10 cm) radio	100 mm (10 cm) radio
11	***Qty Motor Propulsion:*** *Qty of propulsion required*	4 propulsion required. 01 motor propulsion per wheel	4 propulsion required. 01 motor propulsion per wheel	4 propulsion required. 01 motor propulsion per wheel
12	***Battery duration:*** *Qty of hours that agv needs to operate without charging*	10 hours	10 hours	10 hours
13	***Operating system:*** *Base platform of the AGV's control system*	ROS (Robotic Operating System)	ROS (Robotic Operating System)	ROS (Robotic Operating System)
14	***Ground clearence:*** *the height of the lowermost part of the vehicle with respect to ground*	200 mm (20 cm)	200 mm (20 cm) 	200 mm (20 cm)
15	***AGV's special function:*** *Special features required per company*	Stack & unestack columns and trays // Lift 02 columns of 10 trays	Lift and put down 01 Danish trolley // Drive through narrow aisles // Short turnover radio required // Carry load in height (180 CM)	Lift and put down 021 Danish trolleys // - Drive on low inclination angles // Carry load in height (180 CM)
16	***Specific sensor requirement:*** *Special sensor's features required by company*	**A) Positioning of AGVs in order to load columns from ground:** How agv needs to approach to tray's column in order to lift them properly. **B) Get right column from a group of columns:** AGV needs to be able to choose the right column from the store place. **C) Proximity sensor:** In order to avoid collision. Sensors need to be located at front and on the sides. **D) Other sensors**: Inclination/tilt warning, gravity centre accuracy, temperature, emergency system.	**A) Positioning of AGVs in order to load trolleys from ground and from the right places (POIs):** How agv needs to approach to tray's column in order to lift them properly. (Synch Trolleys - AGV) **B) Get right trolley from a group of trolleys:** AGV needs to be able to choose the right trolley from POIs. **C) Proximity sensor**: It is useful for transiting through asiles and to avoid collision. Sensors need to be located at front and on the sides. **D) Other sensors**: Inclination/tilt warning, gravity centre accuracy, temperature, emergency system.	**A) Positioning of AGVs in order to load trolleys from ground and from the right places (POIs):** How agv needs to approach to tray's column in order to lift them properly. (Synch Trolleys - AGV) **B) Get right trolley from a group of trolleys:** AGV needs to be able to choose the right trolley from POIs. **C) Proximity sensor**: In order to avoid collision. Sensors need to be located at front and on the sides. **D) Other sensors**: Inclination/tilt warning, gravity centre accuracy, temperature, emergency system.
17	***Product to be carried:*** *Dimension and type of product that will c arry the load*	Trays  L = 665 mm (66.5 cm) W = 445 mm (44.5 cm) H = 1200 mm (120 cm) 1100 mm (110 cm) when	Boxes L = 600 mm (60 cm) W = 400 mm (40 cm) H = 300 mm (30 cm) 	Boxes - different sizes (* see WD smith excel spreadsheet analysis) 
18	***Special Tasks:*** *Special features required per company*	Waterproof - Mud & Dust resistence - Stack & unestack load - Lift 02 columns of 10 trays	Waterproof - Mud & Dust resistence - Stack & unestack load - drive on narrow aisles - pick 01 danish trolley	Waterproof - Mud & Dust resistence - Stack & unestack load - drive on narrow aisles - pick 02 danish trolley
19	***Size of trolley to carry:*** *The trolley to carry is a Danish trolley as it is broadly used for agriculture purpose.*	This company do not use Danish trolleys or other kind of trolleys.	L = 135 mm (135.5 cm) W = 565 mm (56.5 cm) H = 1800 mm (180 cm)	L = 135 mm (135.5 cm) W = 565 mm (56.5 cm) H = 1800 mm (180 cm)

20	***Quantity of batteries:*** *Quantity of slots available to locate batteries*	02 slots for batteries on the sides. Size of slots need to be defined on next stage	02 slots for batteries on the sides. Size of slots need to be defined on next stage	02 slots for batteries on the sides. Size of slots need to be defined on next stage
21	***Battery size:*** *Size of the battery according to AGV design*	**Pending. It needs to be discussed next stage.** However, it is required that battery is flexible to different sizes in order to fit with agv's frame design	**Pending. It needs to be discussed next stage.** However, it is required that battery is flexible to different sizes in order to fit with agv's frame design	**Pending. It needs to be discussed next stage.** However, it is required that battery is flexible to different sizes in order to fit with agv's frame design
22	***Battery life time:*** *Total life expected*	3 years. It needs to be discussed next stage	3 years. It needs to be discussed next stage	3 years. It needs to be discussed next stage
23	***Battery maintenance:*** *Level of battery's maintenance required*	Medium - Low	Medium - Low	Medium - Low
24	***Battery charging:*** *Type and qty of battery charging option*	**Type:** Charging station. **QTY**: 01 charging station with the same qty of slots as agv are required.	**Type:** Charging station. **QTY:** 01 charging station with the same qty of slots as agv are required.	**Type:** Charging station. **QTY:** 01 charging station with the same qty of slots as agv are required.
25	***Battery charging frequency:*** *How often battery needs to be charged and how long it will take*	**Charging activitites**: It is planned to be done overnight. **Charging duration:** It needs to be calculated next stage	**Charging activitites:** It is planned to be done overnight. **Charging duration:** It needs to be calculated next stage	**Charging activitites:** It is planned to be done overnight. **Charging duration:** It needs to be calculated next stage
26	***Battery features:*** *Power, ampers, volts, etc that will be required to the AGV*	Pending. It needs to be discussed next stage	Pending. It needs to be discussed next stage	Pending. It needs to be discussed next stage
27	***Motor Torque***	Pending. It needs to be discussed next stage	Pending. It needs to be discussed next stage	Pending. It needs to be discussed next stage
28	***Motor driver control:*** *How AGV will regulate speed and linear directions*	Pending. It needs to be discussed next stage	Pending. It needs to be discussed next stage	Pending. It needs to be discussed next stage
29	***Power consumption:*** *Energy estimated that motors will consume from batteries.*	Pending. It needs to be discussed next stage	Pending. It needs to be discussed next stage	Pending. It needs to be discussed next stage
30	***Ease of motor and traction drive maintenance:*** *How often is necessary to maintain motor and traction drive and its components*	Pending. It needs to be discussed next stage	Pending. It needs to be discussed next stage	Pending. It needs to be discussed next stage
31	***Motor and traction drive lifetime:*** *Total life expected of agv motor, traction drive and its components*	Pending. It needs to be discussed next stage	Pending. It needs to be discussed next stage	Pending. It needs to be discussed next stage
32	***Motor size:*** *maximum size required to be placed on the AGV*	Pending. It needs to be discussed next stage	Pending. It needs to be discussed next stage	Pending. It needs to be discussed next stage
33	***Motor type:*** *Type of motor required according to the company's processes*	Pending. It needs to be discussed next stage	Pending. It needs to be discussed next stage	Pending. It needs to be discussed next stage
34	***Traction driver torque***	Pending. It needs to be discussed next stage	Pending. It needs to be discussed next stage	Pending. It needs to be discussed next stage
35	***Drive train load capacity:*** *Maximum payload accepted*	To be calculated at next stage. AGV weight + accessories + payload	To be calculated at next stage. AGV weight + accessories + payload	To be calculated at next stage. AGV weight + accessories + payload
36	***Wheel type:*** *Type of wheels required according with the terrain where agv will be used*	Outdoor	Outdoor	Outdoor
37	***Wheel load capacity:*** *Maximum payload accepted for wheels*	To be calculated at next stage. AGV weight + accessories + payload	To be calculated at next stage. AGV weight + accessories + payload	To be calculated at next stage. AGV weight + accessories + payload
38	***Wheels durability:*** *Frecuency of wheels replacement. It will depends of the type of activities and ground where AGV will be operating.*	To be calculated at next stage. AGV weight + accessories + payload + Friction factors	To be calculated at next stage. AGV weight + accessories + payload + Friction factors	To be calculated at next stage. AGV weight + accessories + payload + Friction factors

39	***Operation terrains and activities:*** *Type of activity and terrain where the agv will operate*	**Type of activity**: Agriculture - Horticulture. **Terrain**: Cold (less than 0 degrees), muddy, dirty, and wet. AGV should face mud / water up to 10 cm deep.	**Type of activity**: Agriculture - Horticulture. **Terrain:** Cold (less than 0 degrees), muddy, dirty, and wet. AGV should face mud / water up to 10 cm deep.	**Type of activity**: Agriculture - Horticulture. **Terrain:** Cold (less than 0 degrees), muddy, dirty, and wet. AGV should face mud / water up to 10 cm deep.
40	***Rotation of Wheels:*** *Maximum angle for wheels rotation*	Pending. It needs to be discussed next stage	Pending. It needs to be discussed next stage	Pending. It needs to be discussed next stage
41	***AGV's tilt:*** *Maximum tilt forward/backward and by sides when AGV is operating at full load.*	Pending. It needs to be discussed next stage	Pending. It needs to be discussed next stage	Pending. It needs to be discussed next stage
42	***Communication system type:*** *Type of communication system to be used*	Pending. It needs to be discussed next stage	Pending. It needs to be discussed next stage	Pending. It needs to be discussed next stage
43	***Communication range:*** *Maximum distance of communication data beetween AGV and server*	Pending. It needs to be discussed next stage	Pending. It needs to be discussed next stage	Pending. It needs to be discussed next stage
44	***AGV's controller system:*** *Type of controller system to be used on AGV*	Pending. It needs to be discussed next stage	Pending. It needs to be discussed next stage	Pending. It needs to be discussed next stage
45	***Comunnication bandwidth:*** *Amount of data to transfer between AGV and server*	Pending. It needs to be discussed next stage	Pending. It needs to be discussed next stage	Pending. It needs to be discussed next stage
46	***Communication system data security:*** *This indicates if it is necessary security protocol in data transfer and what kind of security is required (if it is applicable)*	Pending. It needs to be discussed next stage	Pending. It needs to be discussed next stage	Pending. It needs to be discussed next stage
47	***Communication system 's maintenance:*** *Level of maintenance required to communication system*	Low	Low	Low
48	***Control and navigation systems weather condition resistance:*** *Boundaries of weather condition for a safety AGV operations*	Yes. Control system needs to be able to operate under raining, wind, and cold temperature. Levels/boundaries of operations will be defined at next stage	Yes. Control system needs to be able to operate under raining, wind, and cold temperature. Levels/boundaries of operations will be defined at next stage	Yes. Control system needs to be able to operate under raining, wind, and cold temperature. Levels/boundaries of operations will be defined at next stage
49	***Navigation type:*** *Type of sensor method require for positioning AGV while it is moving.*	Pending. It needs to be discussed next stage	Pending. It needs to be discussed next stage	Pending. It needs to be discussed next stage
50	***Fleet Manager design flexibility:*** *Ease to access, to programm and to modify the fleet manager software*	Fleet manager capabilities will be defined at the next stage. Some of the capabilities are: Production scheduling // low level of maintenance // route planning // automate reports // mapping layout // early warnings etc.	Fleet manager capabilities will be defined at the next stage. Some of the capabilities are: Production scheduling // low level of maintenance // route planning // automate reports // mapping layout // early warnings etc.	Fleet manager capabilities will be defined at the next stage. Some of the capabilities are: Production scheduling // low level of maintenance // route planning // automate reports // mapping layout // early warnings etc.
51	***Chassis and body material:*** *Type of material suitable to AGV requirement*	Pending. It needs to be discussed next stage. A material resistance and vector decomposition analysis is required.	Pending. It needs to be discussed next stage. A material resistance and vector decomposition eanalysis is required.	Pending. It needs to be discussed next stage. A material resistance and vector decomposition analysis is required.
52	***Chassis architecture:*** *Frame design suitable to AGV' s requirement*	Pending. It needs to be discussed next stage	Pending. It needs to be discussed next stage	Pending. It needs to be discussed next stage
53	***Chassis flexibility:*** *Easy to assembly and modify*	Modular AGV. It will be possible to add different variances in order to increase versatilty. Frame/ chassis is the main support of accessories and variances. Different variables such as terrain, type of activities, inclination level, speed and payload will need to be included to define the suitable agv's modularity to use.	Modular AGV. It will be possible to add different variances in order to increase versatilty. Frame/ chassis is the main support of accessories and variances. Different variables such as terrain, type of activities, inclination level, speed and payload will need to be included to define the suitable agv modularity to use.	Modular AGV. It will be possible to add different variances in order to increase versatilty. Frame/ chassis is the main support of accessories and variances. Different variables such as terrain, type of activities, inclination level, speed and payload will need to be included to define the suitable agv modularity to use.
54	***Type of suspension:*** *Type of suspension required according to AGV specification*	Pending. It needs to be discussed next stage. Different variables such as frame architecture, terrain, type of activities, inclination level, speed and payload will need to be included to define the suitable suspension to use.	Pending. It needs to be discussed next stage. Different variables such as frame architecture, terrain, type of activities, inclination level, speed and payload will need to be included to define the suitable suspension to use.	Pending. It needs to be discussed next stage. Different variables such as frame architecture, terrain, type of activities, inclination level, speed and payload will need to be included to define the suitable suspension to use.
55	***Type of attachment:*** *Type of attachment required to tow a trailer.*	Not required	Not required	Towing required. Type of attachment will be defined at next stage
56	***Safety Options:*** *Component that make AGV moving safety*	Light // bumper material // stop emergency button // etc. It will be discussed at next stage	Light // bumper material // stop emergency button // etc. It will be discussed at next stage	Light // bumper material // stop emergency button // etc. It will be discussed at next stage

XVII. Cost breakdown grouped per company

The following costs are classified according the information sent by companies.

Cost description PER YEAR												
				CRYSTAL HEART			VALEFRESCO			WD SMITH		
A	**Labour cost:**	**Description**	**Unit of measure**	**Quantity**	**COST (£)**	**Total**	**Quantity**	**COST (£)**	**Total**	**Quantity**	**COST (£)**	**Total**
A.1	Company staff (production area)	People involved in a fix or permanent contract that operate in the area of this study. Please indicate the total annual costs that need to include taxes, vacations, sick leaves, etc.	Operator	5	£33,748	£168,740	7	£25,000	£175,000	4 (peak season, 4 month) + 01 (08 month year)	£15,636	£72,968
A.2	Overtime	Costs related to people who are hired under a "overtime" contract in order to meet demand increment. Please indicate quantity of hours of "overtime" and then the average cost.	Hours			INCLUDED ON A.1			INCLUDED ON A.1			INCLUDED ON A.1
A.3	Health and welfare	Any cost related with health and welfare to people indicated at points A.1 and A.2	Amount per year			INCLUDED ON A.1			INCLUDED ON A.1			INCLUDED ON A.1
B	**Material supply:**	**Description**	**Unit of measure**	**Quantity**	**COST (£)**	**Total**	**Quantity**	**COST (£)**	**Total**	**Quantity**	**COST (£)**	**Total**
B.1	Vehicle Repair parts (material)	Every parts used to repair the current vehicles. Please include any cost if there is some repair external service	Quantity of events per year			£2,000			N/A			£200
B.2	Equipments repair parts (material)	Every parts used to repair the current equipments, Please include any cost if there is some repair external service. **Please consider only equipments where operators are involve regarding the project's scope**	Quantity of events per year			N/A			N/A			N/A
B.3	Machine repair parts (material)	Every parts used to repair the current machines. Please include any cost if there is some repair external service. **Please consider machines where operators are involve regarding the project's scope.**	Quantity of events per year			N/A			N/A			N/A
B.4	Lubricants	Quantity of different lubricants used on vehicles, machine, equipments	Amount per year	1		N/A			N/A	1		£50
B.5	Fuel	Total fuel used on vehicles, machines	Amount per year	1					N/A	1		£50.0
B.6	Other supplies (i.e. tyres)	Please indicate the total amount of other material used during the company's operations. For instance change tyres, hooks, rope, etc.	Amount per year	1		N/A			N/A	1		£30.0
B.6	Personal Protective Equipment (PPE)	Total cost involved to PPE equipment for operators indicated In A.1 and A.2	Amount per year	1		N/A			£1,000	1		£75
C	**Maintenance:**	**Description**	**Unit of measure**	**Quantity**	**COST (£)**	**Total**	**Quantity**	**COST (£)**	**Total**	**Quantity**	**COST (£)**	**Total**
C.1	Vehicle maintenance	Total cost of maintenance (all kind of maintenances)	Quantity of events per year			2000			N/A	1	500	500
C.2	Machines maintenance	Total cost of maintenance (all kind of maintenances). **Please consider only renting machine where operators are involve regarding the project's scope**	Quantity of events per year			N/A			N/A			N/A
C.3	Equipments maintenance	Total cost of maintenance (all kind of maintenances)	Quantity of events per year			N/A			N/A			N/A
C.4	Others	Please indicate other cost related with maintenance and were not indicated above	Quantity of events per year			N/A			N/A			N/A
D	**Rent**	**Description**	**Unit of measure**	**Quantity**	**COST (£)**	**Total**	**Quantity**	**COST (£)**	**Total**	**Quantity**	**COST (£)**	**Total**
D.1	Rent vehicles	Indicate the total cost of renting vehicles during the year	Quantity of events per year			N/A			N/A			N/A
D.2	Rent Machines	Indicate the total cost of renting machines during the year. **Please consider only renting machine where operators are involve regarding the project's scope**	Quantity of events per year			N/A			N/A			N/A
D.3	Rent Equipments	Indicate the total cost of renting equipments during the year (For instance trolleys)	Quantity of events per year			N/A			N/A			N/A
E	**Taxes:**	**Description**	**Unit of measure**	**Quantity**	**COST (£)**	**Total**	**Quantity**	**COST (£)**	**Total**	**Quantity**	**COST (£)**	**Total**
E.1	Vehicle taxes / road taxes	Annual taxes per vehicle	Vehicle			N/A			N/A			N/A
F	**Investments**	**Description**	**Unit of measure**	**Quantity**	**COST (£)**	**Total**	**Quantity**	**COST (£)**	**Total**	**Quantity**	**COST (£)**	**Total**
F.1	Replace current old vehicles (Forklift/trucks)	Please indicate If there are vehicles that need to be replaced within next two years.	Vehicle			N/A			N/A			N/A
G	**Training - qualifications**	**Description**	**Unit of measure**	**Quantity**	**COST (£)**	**Total**	**Quantity**	**COST (£)**	**Total**	**Quantity**	**COST (£)**	**Total**
G.1	Operators qualifications (drivers only)	Please indicate If there are operators who require any renewals of qualification (per year)	Operator			N/A			N/A			N/A
G.2	New special driving licences or renewals	Please indicate If there are operators who require any renewals of special driving licence (per year)	Operator			N/A			N/A			N/A
H	**Depreciation**	**Description**	**Unit of measure**	**Quantity**	**COST (£)**	**Total**	**Quantity**	**COST (£)**	**Total**	**Quantity**	**COST (£)**	**Total**
H.1	Vehicles depreciation	Total annual vehicle's depreciation cost.	Amount per year			N/A			N/A			N/A
I	**Insurances**	**Description**	**Unit of measure**	**Quantity**	**COST (£)**	**Total**	**Quantity**	**COST (£)**	**Total**	**Quantity**	**COST (£)**	**Total**
I.1	Vehicles insurance	Total annual vehicle's insurance cost	Amount per year			N/A			N/A			N/A
J	**Energy**	**Description**	**Unit of measure**	**Quantity**	**COST (£)**	**Total**	**Quantity**	**COST (£)**	**Total**	**Quantity**	**COST (£)**	**Total**
J.1	Machine energy	Electric power consumed by machines **which are in the project's scope**	KWH per YEAR	1	£3,000	£3,000			N/A			N/A
K	**Others**	**Description**	**Unit of measure**	**Quantity**	**COST (£)**	**Total**	**Quantity**	**COST (£)**	**Total**	**Quantity**	**COST (£)**	**Total**
K.1	Other cost	Any other cost that needs to be consider and were not indicated above. **This cost need to be related with the current project scope**	To be define by the company			N/A			N/A			N/A
TOTAL COST PER YEAR						**£175,740**			**£176,000**			**£73,873**

Notes:

1.- Column "Unit of measure" indicates the variable to be considered in order to get data
2.- Column "Quantity" needs to be filled with the quantity of "Unit of measures" **found per year.**
3.- Column "Cost" represent the value of 01 quantity unit (see example above). In the case that the "Unit of measure" indicates "Amount per year" please fill the cell with the total cost.
4.- If it is indicated "Amount per year" or KWH per YEAR please fill with "1" in the row "Quantity"
5.- if applicable, Please define and fill a suitable "Unit of Measure" on "Unit of Measure" cell for point K.1.

Table A.17.1