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Project Report

WMG- University of Warwick

Advanced automation in horticulture project

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This is the final report of a 24 month project which started in March 2019. The work was funded by AHDB and a contract for £45k.

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1. Abstract

The SmartHort Automation project is an innovative project to develop a solution for UK growers which was jointly funded by Agriculture and Horticulture Development Board (AHDB) and the High-Value Manufacturing Catapult, with an in-kind collaboration with WMG-Automation System Group. The project also benefitted from collaboration with three businesses with overlapping technology needs and selected from a wider number of businesses who submitted proposals to join the project in response to an open call to growers to.

A feasibility study was developed and delivered during the first year of the project, which considered an exhaustive analysis of the internal production processes of each company. However, this report includes a discrete event simulation (DES) and a 3D model representation for Crystal Heart Salad Co. This company grows lettuce from seed to plant to sell to other companies and located in East Yorkshire. They use plastic trays as a logistic unit to move and handle the products around the facility.

The company has a future vision to automate the complete production process from sowing to despatch. This idea involves automation technologies that have to be applied at different stages to obtain the necessary reliability to operate with low operational risks. The company detected that the main operational inefficiencies are present in the internal logistical processes.

Therefore, this report focuses on improving the efficiency of the logistical processes of Crystal Heart Lettuce. The current approach relies on forklift operators to move the product through the different growing stages; there is potential scope here for an automation solution to replace the manual operations in transporting trays around the facility. The analysis of the current logistical process is through Discrete Event Simulation (DES).

2. Introduction

This report proposes and evaluates AGVs (Autonomous Guided vehicles) as a method for delivering logistical improvements to the system. The vehicle specification and technical details were presented in the Feasibility report in December 2019 (please refer to this document for further technical information). Due to the significant customisation required for each use case, we envisage looking at one application in terms of AGV in physical form. The subsequent phases of the project will involve understanding the functional requirements for each scenario, critical technical review of state of the art, and looking at commercially available robots and subassemblies to consider whether to buy or build the system and its subassemblies.

However, the Feasibility study report established that AGVs are the proper technological solution to be evaluated in the current logistical processes of horticulture companies that carry pallets and boxes and/or tow trolleys around the facility. However, it is necessary to establish: 1. How could AGVs deliver better operational performance to the internal logistical processes? 2. How many AGVs are required? 3. What is the cost performance and ROI (Return of Interest) related to introducing this technology?

The primary purpose of this report is to give answers to the mentioned questions through 1. It is developing a DES of the company's process that includes AGVs as a proposed solution, and 2—virtually representing AGVs operating in a proposed future scenario in a 3D environment.

The report consists of two parts; the first part describes the evaluation and DES of the current logistical process and the evaluation and DES of the proposed automation solutions. Based on the analysis, the recommendations for Crystal Heart can be made. The second part details the 3D modelling of a proposed AGV, including renders of a potential attachment to enable higher levels of automation. A 3D modelled process of Crystal Heart was used to use the newly proposed AGV.

3. Current Process Performance Analysis and DES

3.1. Current Logistical Process

Crystal Heart Lettuce grows lettuce crops from seeds and despatches lettuce plants to other companies. The process starts with the Sowing machine, where the seeds are planted into pots of compost carried in trays. The trays then spend three days in Germination before being moved into the Greenhouse for where they spend 7-14 days growing. Finally, the crops are moved outside to Harden Off until they are ready to despatch. An outline of this process is shown in figure 1.

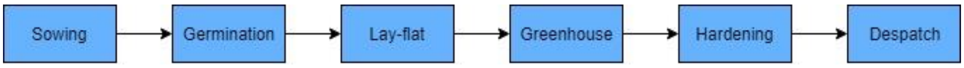

Figure 1 - Crystal Heart Logistical Process

Forklifts are the primary method for moving trays through the system. Forklifts are used to load and unload trays on and off the carrying platforms and transfer the platforms between steps in the process. Trays are stacked in batches after leaving the sowing machines, and they are stored this way in the germination room. After leaving Germination, the batches need to be "laid-flat" so all the trays can get sunlight while growing; this is done by the Lay-flat machine, which lays out the trays in a grid which the forklift is given a specialised tool to be able to pick them up.

3.1.1. Internal logistic performance

Crystal Heart Lettuce provided operational performance data. A simulation of the current logistical process was created in the Witness Software, and the simulation data was validated against company data. The validation aimed to develop a model that could be built upon to test automated logistical scenarios.

From conducting simulations, the current operational performance of the process is presented in Table 1; this shows the number of trays passing through a station and the rate of tray production depending on the seasonal demand of trays. Table 2 shows a comparison of selected simulation data against Crystal Heart data to verify the model.

Intensity of Production	Process	Trays/Week (7 Days)	Trays/Day	Ratio (Trays/Hour)	Ratio (Trays/Min)
MIDDLE SEASON	Sowing	27510	3930	342	5.70
	Germination	27510	3930	358	5.97
	Laying Flat	27510	3930	354	5.90
	Greenhouse	27510	3930	392	6.53
	Hardening	27510	3930	320	5.33
	Despatch	27510	3930	129	2.15
PEAK SEASON	Sowing	27510	3930	347	5.78
	Germination	39480	5640	359	5.98
	Laying Flat	39480	5640	356	5.93
	Greenhouse	39480	5640	391	6.52
	Hardening	39480	5640	321	5.35
	Despatch	39480	5640	139	2.32
LOW SEASON	Sowing	15540	2220	344	5.73
	Germination	15540	2220	357	5.95
	Laying Flat	15540	2220	350	5.83
	Greenhouse	15540	2220	392	6.53
	Hardening	15540	2220	319	5.32
	Despatch	15540	2220	128	2.13

Table 1 - Simulated Rate of Production

In order to identify potential bottlenecks present in the logistical system, the wait times at keys stations were measured and are shown in Table 2. For example, trays wait on average 1.86 minutes at the Lay-flat process to be collected by a forklift.

Location	Average Waiting Time (Minutes)
Sowing	0
Lay-flat	1.86
Greenhouse	0
Despatch	14.54

Table 2 - Average Wait Times

In order to measure the transportation "wastes" present in the system, the forklift travel time was collected from the simulation. The percentage of time spent traveling is considered a "waste," which aims to reduce this by automation. The loading/unloading time is not considered "waste"; optimization of the system would remove the need for the forklift to travel long distances and instead focus on the specialised loading tasks. The average time taken for a forklift to complete specific routes in the system is shown in Table 3.

Journey	Average Time (Minutes)	Percentage Travelling	Percentage Unloading/Loading
Lay-flat to Greenhouse	1.43	30%	70%
Greenhouse to Hardening	5.34	68%	32%
Hardening to Despatch	2.53	52%	48%

Table 3 -Simulated Average Route Times

3.2. Potential "Waste" Present in the System

The literature indicates eight sources of "waste" specified in Lean Manufacturing [1]. Table 4 shows these "wastes" with a description and evaluating their presence in the Crystal Heart process.

Name of "Waste"	Description	In Crystal Heart Simulation
Defects	"Waste" from a product or service failing to meet customer expectations	Not involved in simulation, the growing process does not usually have defects. (Assumed to be negligible)
Overproduction	"Waste" from making more product than customers demand	Crops produced to customer order; therefore, overproduction is assumed to be negligible
Waiting	"Waste" from time spent waiting for the next process step to occur	Could occur at forklift unload and loading locations, machine waiting for forklift, forklift waiting for a machine, buffer waiting for forklift
Underutilised talent	"Wastes" due to underutilization of worker's talents, skills, and knowledge	Not measured in the simulation but the ultimate aim of automation will be a reduction in unskilled tasks carried out by skilled workers
Transportation	"Wasted" time, resources, and costs when unnecessarily moving products and materials	This "waste" is present in the system by the time the forklifts spend in motion moving crops around instead of loading or unloading
Inventory	"Wastes" resulting from excess products and materials that aren't processed	This is not relevant to crop-growing as stored plants grow when in storage, so nothing in storage goes unprocessed.
Motion	"Wasted" time and effort related to unnecessary movements by people	This "waste" is present in the system if there is a requirement for operators to move around and support different scenarios.
Extra-Processing	"Wastes" related to more work or higher quality than is required	The lay-flat or stacking machines could be considered overprocessing if they can be eliminated with an easy solution and the logistical system has similar operational performance without them. If there is no cost-effective or readily available solution, the machines and processes should remain and are not considered "waste."

Table 4 - Table of Production "Wastes"

Of the eight "wastes," five are identified as being present in the current process. The unskilled labor "waste" will be reduced by meeting the aim of introducing an automation solution to the process. Extra-processing "wastes" would be present in the lay-flat stage, and the decision to remove this process is based on weighing up the cost of improvement vs. the benefit. Waiting “wastes” can be analysed and measured in the simulation. Both motion and transportation “wastes” will be identified and evaluated in the simulation.

3.2.1. Cost Performance

A cost analysis was performed in the Feasibility Report and was updated during the project's final stage to develop the DES. Therefore, Table 5 is derived from simulation and presents the required hours in each season. The hours are broken down into different categories, full-time hours, full-time overtime hours, agency regular work hours, and agency overtime hours.

Intensity of Production	Process	Hours of Work / Week	Total Hours	Full Time Workers	Full Time Hours	Full Time Over Time	Agency Workers Required	Agency Work	Agency Overtime	Total Hours Provided
MIDDLE SEASON	Sowing	77.7	376.14	6	234	36	3	117	0	387
	Laying-Flat	85.94								
	Despatch	212.5								
PEAK SEASON	Sowing	111.05	506.33	6	234	36	6	234	0	504
	Laying-Flat	119.09								
	Despatch	276.19								
LOW SEASON	Sowing	44.41	216.26	6	234	0	0	0	0	234
	Laying-Flat	49.08								
	Despatch	122.77								

Table 5 - Hours Required to Maintain Production

Based on the assumption that each season lasts 15 weeks and that the full-time hours are paid the entire year, the cost breakdown can be calculated, which is shown in Table 6. The six forklifts (including the despatch forklift) cost £3,600 a year each (to cover fuel, maintenance, spare parts), and the lay-flat machine costs £3,000 a year to run. Adding these to the wage costs gives a total annual cost of **£234,891.** The importance of calculating this data is to determine the value of the automation solution in terms of cost reduction.

LOW SEASON		
Full Time Hours	6 x 39 x £12	£2,808
TOTAL		**£2,808**
MIDDLE SEASON		
Full Time Hours	6 x 39 x £12	£2,808
Overtime Hours	36 x £18	£648
Temporary Workers Hours	117 x £9	£1,053
TOTAL		**£4,509**
PEAK SEASON		
Full Time Hours	6 x 39 x £12	£2,808
Overtime Hours	36 x £18	£648
Temporary Workers Hours	234 x £9	£2,106
TOTAL		**£5,562**
FULL YEAR*		
Full Time Hours	6 x 39 x 52 x £12	£146,016
Overtime Hours	72 x £18	£19,440
Temporary Workers Hours	351 x £9	£47,385
TOTAL		**£212,841**

Table 6 - Annual Wage Calculation

3.3. The Challenge

3.3.1. Suggested Solution

The main challenge stated by the business is the opportunity to eliminate the transportation and motion “wastes” (identified during the analysis) by introducing an autonomous solution to the internal logistic activities. In this way, two automation solutions have been devised to deliver both operational and cost benefits to Crystal Heart Lettuce. The two differ by the level of automation used, as greater automation will require a more significant initial investment. However, the long-term savings of the more automated solution are more important. Both proposed solutions are analysed as new alternative scenarios to the company's current performance that was developed through DES and previously explained. These two scenarios are also evaluated through DES.

Scenario 1 - Semi-Autonomous Solution

AGVs will be added to the system to take over the role of the forklifts in moving the trays between stations, and the forklifts will remain for loading and unloading the trays. The introduction of the AGVs in this role will reduce the transportation "wastes" in the system and utilize the talents of the workers better; forklift operators can be used to focus on skilled loading and unloading tasks rather than moving the worker's forklifts long distances. The waiting "waste" can also be reduced as the forklift can be quicker for loading and unloading machines. The movement of batches from Hardening-Off to Despatch remains controlled by forklift as the automation of loading despatch lorries is outside the project's scope. The process is presented in Figure 2.

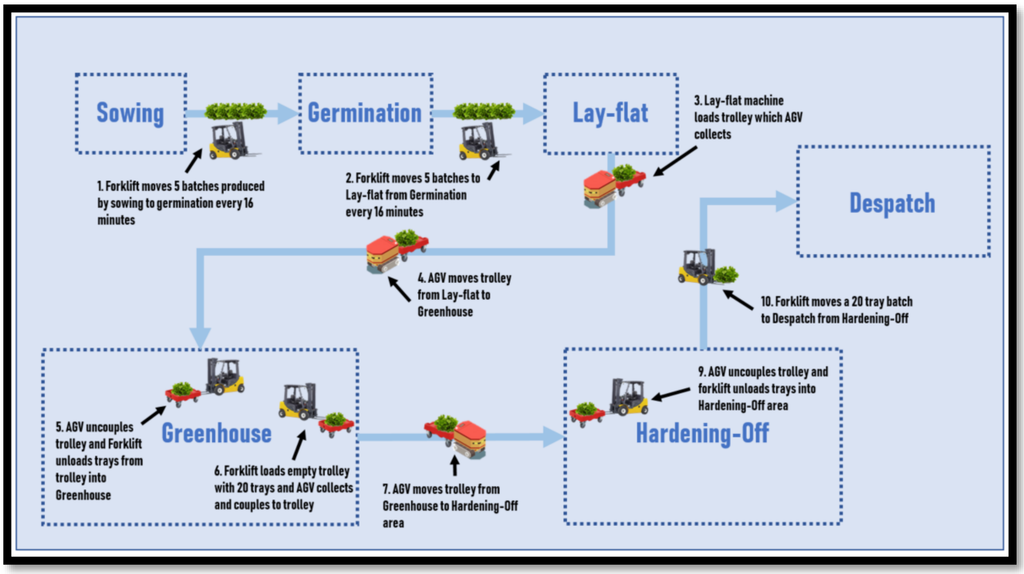

Figure 2 - Semi-Autonomous Production

Scenario 2 - Fully-Autonomous Solution

In this scenario, the forklifts in the system are replaced entirely by AGVs. In addition, the lay-flat process is wholly eliminated by the AGVs having the capacity to unstack the trays themselves. This solution addresses the Extra-processing "waste" as well as the other "wastes" (transportation, motion, waiting, and underutilised talent) addressed in the first scenario. The AGVs are fitted with a module that enables them to unload themselves instead of requiring a forklift. As in the semi-autonomous scenario, a forklift is used to move batches to despatch. The process is shown in figure 3.

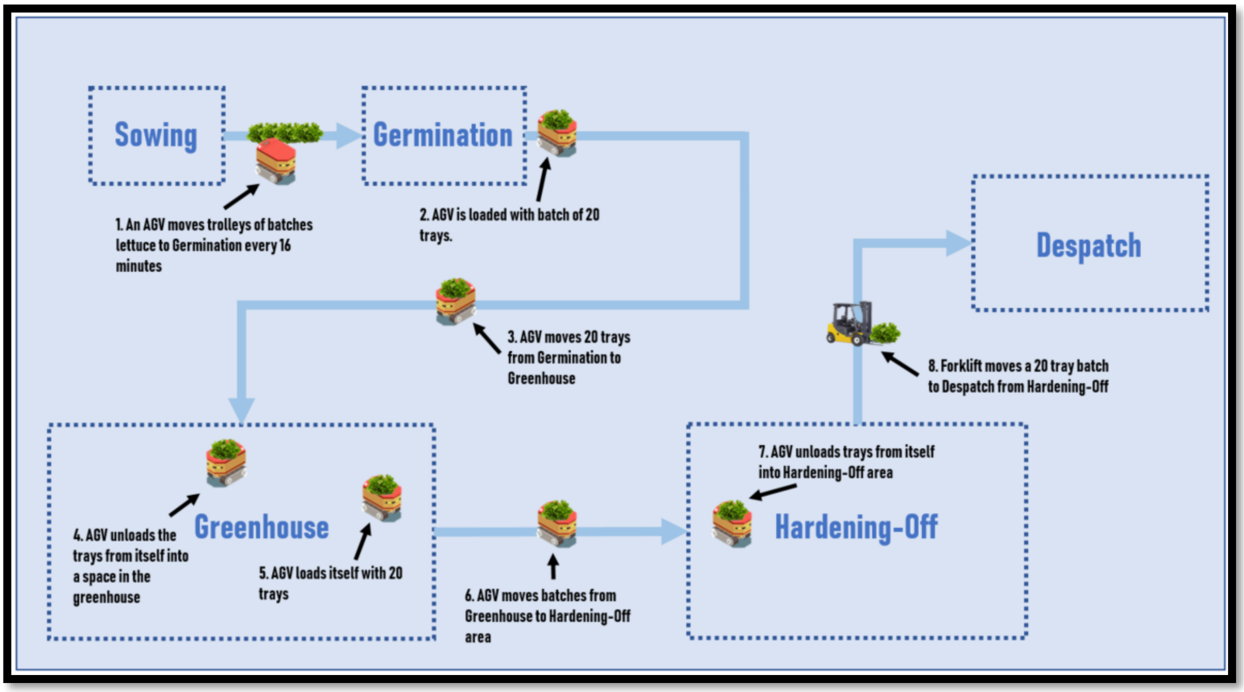

Figure 3 - Fully-Autonomous Production

3.4. Comparison of Simulated Proposed Solution and Current System

Semi-Autonomous Scenario

3.4.1. Resource Allocation

By simulating a semi-autonomous scenario, the number of resources required to sustain this system was calculated.

2 Loading Forklifts - There are three primary tasks for the forklifts: to unload trolleys into the Greenhouse from lay flat, second to load trolleys to leave the Greenhouse for hardening, and the third is to unload trolleys from the Greenhouse into hardening. The forklifts are split between the North Greenhouses and Hardening Area and the South Greenhouses and Hardening Area. Depending on which forklifts have the most significant demand in a day, the least active forklift will be assigned to move the sowing buffer output to the germination store and resupply the lay-flat buffer with five batches trays, respectively. This process occurs every 16 minutes and 40 seconds and takes 3 minutes 30 seconds to complete.

1 Despatch Forklift - Takes completed batches from the Hardening areas to the Despatch area and loads them onto lorries; this forklift could be further supported with more forklifts and labor if the demands were too high to handle.

2 Lay-flat to Greenhouse Transport AGVs - Two AGVs are assigned to move batches from the lay-flat to the selected Greenhouse. They are loaded by the mechanism of the lay-flat machine and uncouple their trolleys at the Greenhouse for the loading forklift to unload when available. The AGV must now collect an empty trolley to be loaded at the lay-flat machine.

2 Greenhouse to Hardening Transport AGVs - Two AGVs are assigned to moving batches from the selected Greenhouse to the hardening area chosen. The AGV collects a trolley preloaded by a loading forklift from the Greenhouse and takes it to the hardening area, where it leaves it to be unloaded later by the forklift. If there are any empty trolleys here, the AGV picks up a trolley and returns it to the Greenhouse to be filled.

The percentage of time a resource spends idle in a day-long shift is shown in Table 7.

Resource	Busy Percentage	Idle Percentage
Loading Forklift 1	83.86%	16.14%
Loading Forklift 2	81.56%	18.44%
Lay-flat to Greenhouse AGV 1	94.32%	5.68%
Lay-flat to Greenhouse AGV 2	94.36%	5.64%
Greenhouse to Harden AGV 1	88.79%	11.21%
Greenhouse to Harden AGV 2	89.01%	10.99%

Table 7 - Resource Utilisation

3.4.2. AGV Task Breakdown

Table 8 shows all the AGV routes in the semi-autonomous scenario. Column two shows the length of the route, then columns 3 to 6 break down the takt time of the route into different processes. The term “takt time” refers to the time taken for one cycle of the process to complete. For example, in the ‘Lay-flat to GH 1’ route, the AGV takes 20 sec to be loaded at the lay-flat, then travels for 198s to the Greenhouse before taking 20s to be unloaded, then another 152s to travel back to lay-flat, this gives a total takt time of 391s with a 5% safety time this takes 411s. As shown in column 9, AGVs are required at lay-flat every 208s. In which case, 1.98 AGVs would be necessary to satisfy the route. The minimum number of the AGVs needed to fulfill the Lay-flat to greenhouse routes is 1.98 as this quantity would be able to meet the requirements of all five routes.

Route	Distance (m)	Load Time (s)	Travel Time (Loaded) (s)	Unload Time (s)	Travel Time (Unloaded) (s)	Total Time (s)	5% Safety Time	Required Time (s)	AGVs Required	Minimum AGV Number Required
Lay-flat to GH 1	175	20	198.86	20	152.97	391.83	411.42	208	1.98	1.98
Lay-flat to GH 2	140	20	159.09	20	122.38	321.47	337.54	208	1.62	
Lay-flat to GH 3	140	20	159.09	20	122.38	321.47	337.54	208	1.62	
Lay-flat to GH 4	170	20	193.18	20	148.60	381.78	400.87	208	1.93	
Lay-flat to GH 5	105	20	119.32	20	91.78	251.10	263.66	208	1.27	
GH1 to Harden East	170	20	193.18	20	148.60	381.78	400.87	208	1.93	1.93
GH1 to Harden East	125	20	142.05	20	109.27	291.32	305.89	208	1.47	
GH3 to Harden South	160	20	181.82	20	139.86	361.68	379.76	208	1.83	
GH4 to Harden South	170	20	193.18	20	148.60	381.78	400.87	208	1.93	
GH5 to Harden South	120	20	136.36	20	104.90	281.26	295.32	208	1.42	

Table 8 - AGV Route Takt Times

3.4.3. Production Statistics

Table 9 shows the production rate of the system in varying seasons. Notice that the change in demand does not change the production rate; this is because there are bottlenecks, such as the sowing machine limiting the maximum production rate. This means that varying demand varies the length of the day. For example, in the low season, the average day is around 6 hours of work. In an automated system, a 12 hour workday could be used, allowing the number of AGVs required by the system to be halved as the required rate of the system was also split. In terms of costing and ROI calculations in this Use Case, the maximum number of AGVs required to run the system in the Peak Season will be considered.

Intensity of Production	Process	Trays/Week (7 Days)	Trays/Day	Ratio (Trays/Hour)	Ratio (Trays/Min)
MIDDLE SEASON	Laying Flat	28280	4040	347	5.78
	Hardening	28280	4040	315	5.25
	Despatch	28280	4040	132	2.20
PEAK SEASON	Laying Flat	39480	5640	345	5.75
	Hardening	39480	5640	318	5.30
	Despatch	39480	5640	135	2.25
LOW SEASON	Laying Flat	15680	2240	343	5.72
	Hardening	15680	2240	312	5.20
	Despatch	15680	2240	126	2.10

Table 9 - Semi-Autonomous Production Rates

3.4.4. Costs and Return on Investment

The seasonal costs for essential part-time labour is as follows: (Low season: £810 p/w), (Middle Season: £1,620 p/w), (Peak Season: £2,196 p/w). When each season lasts for 15 weeks, the total expense is £69,390 per year. Wages for the three full-time forklift operators are £73,008, and the cost to run the three forklifts £11,000. In addition, the energy cost for the lay-flat machine is £3,000. Therefore the total spend is **£156,498,** which saves **£78,393** a year for the current yearly costs. Considering this saving, for a three-year return of investment for four AGVs, the maximum spend per AGV is **£58,794.** Table 10 shows a breakdown of the return of investment over multiple years depending on the initial cost of each AGV.

Year	Annual Cash Flow (Saving Costs)	Cumulative Cash Flow (Cumulative Savings)	Cost Per AGV (x4 AGVs)				
			£40,000	£ 45,000	£50,000	£55,000	£60,000
4 AGV Investment			-£160,000	-£180,000	-£200,000	-£220,000	-£240,000
1	£78,393	£78,393	-£81,607	-£101,607	-£121,607	-£141,607	-£161,607
2	£78,393	£156,786	-£3,214	-£23,214	-£43,214	-£63,214	-£83,214
3	£78,393	£235,179	£75,179	£55,179	£35,179	£15,179	-£4,821
4	£78,393	£313,572	£153,572	£133,572	£113,572	£93,572	£73,572
5	£78,393	£391,965	£231,965	£211,965	£191,965	£171,965	£151,965

Table 10 - Return of Investment for Semi-Autonomous Scenario

Fully-Autonomous Scenario

3.4.5. Resource Allocation

By simulating a fully autonomous scenario, the number of resources required to sustain this system was calculated.

Removal of Lay-flat machine - The fully autonomous scenario removes the need for a lay-flat machine**,** AGVs carry the trays in stacks, and unloading mechanisms exist that can unload AGVs tray by tray. In this case, trays are collected and transported by AGVs directly from the Germination room.

1 Despatch Forklift - As with the semi-Autonomous scenario, the despatch forklift takes completed batches from the Hardening areas to the Despatch area and loads them onto lorries; this forklift could be further supported with more forklifts and labor if the demands were too high to handle in peak season. The Despatch forklift operates on a standard 8-5 shift while the rest of the system works the whole day.

3 Germination to Greenhouse AGVs - Three AGVs collect stacks of trays from Germination, then take the trays to the Greenhouse, where they autonomously unload themselves.

4 Greenhouse to Hardening AGVs - Four AGVs are assigned the task of moving batches from the selected Greenhouse to the hardening area chosen. They are autonomously loading and unloading themselves.

Moving sowing batches to Germination: Every 16 minutes and 40 seconds, there are five completed batches from the sowing machine. Therefore, an AGV is assigned from either of the two transport routes (germination to Greenhouse or Greenhouse to hardening route) to move these batches to Germination. The process takes no more than 6 minutes to complete before the AGV returns to its original job.

The percentage of time a resource spends idle in a day-long shift is shown in table 11.

Resource	Busy Percentage	Idle Percentage
Lay-flat to Greenhouse AGV 1	97.38%	2.62%
Lay-flat to Greenhouse AGV 2	97.22%	2.78%
Lay-flat to Greenhouse AGV 3	96.53%	3.47%
Greenhouse to Harden AGV 1	87.63%	12.37%
Greenhouse to Harden AGV 2	85.43%	14.57%
Greenhouse to Harden AGV 3	86.21%	13.79%
Greenhouse to Harden AGV 4	87.06%	12.94%

Table 11 - Fully-Autonomous Resource Utilisation

3.4.6. AGV Task Breakdown

Table 12 shows the breakdown of AGV routes in the fully autonomous scenario, which follows the same logic as Table 8.

Route	Distance (m)	Load Time (s)	Travel Time (Loaded) (s)	Unload Time (s)	Travel Time (Unloaded) (s)	Total Time (s)	5% Safety Time	Required Time (s)	AGVs Required	Minimum AGV Number Required
Lay-flat to GH 1	175	30	198.86	200	152.97	581.83	610.92	208	2.94	2.94
Lay-flat to GH 2	140	30	159.09	200	122.38	511.47	537.04	208	2.58	
Lay-flat to GH 3	140	30	159.09	200	122.38	511.47	537.04	208	2.58	
Lay-flat to GH 4	170	30	193.18	200	148.60	571.78	600.37	208	2.89	
Lay-flat to GH 5	105	30	119.32	200	91.78	441.10	463.16	208	2.23	
GH1 to Harden East	170	200	193.18	200	148.60	741.78	778.87	208	3.74	3.74
GH1 to Harden East	125	200	142.05	200	109.27	651.32	683.89	208	3.29	
GH3 to Harden South	160	200	181.82	200	139.86	721.68	757.76	208	3.64	
GH4 to Harden South	170	200	193.18	200	148.60	741.78	778.87	208	3.74	
GH5 to Harden South	120	200	136.36	200	104.90	641.26	673.32	208	3.24	

Table 12 - AGV Route Takt Times

3.4.7. Production Statistics

Intensity of Production	Process	Trays/Week (7 Days)	Trays/Day	Ratio (Trays/Hour)	Ratio (Trays/Min)
MIDDLE SEASON	Hardening	28280	4040	330	5.50
	Despatch	28280	4040	114	1.90
PEAK SEASON	Hardening	39480	5640	337	5.62
	Despatch	39480	5640	111	1.85
LOW SEASON	Hardening	15680	2240	333	5.55
	Despatch	15680	2240	115	1.92

Table 13 - Fully-Autonomous Production Rates

3.4.8. Costs and Return on Investment

The seasonal costs for essential part-time labour is as follows: (Low season: £810 p/w), (Middle Season: £1,620 p/w), (Peak Season: £2,196 p/w). When each season lasts for 15 weeks, the total expense is £69,390 per year. On top of this, wages for the one full-time forklift operator are £24,336, and the cost of running the forklift is £3,700. This leaves a total annual spend of £97,426, which saves £137,465 a year. Therefore, for a three-year return of investment for seven AGVs, the maximum spend per AGV is **£58,912.** Table 14 shows a breakdown of the return of investment over multiple years depending on the initial cost of each AGV.

Year	Annual Cash Flow (Saving Costs)	Cumulative Cash Flow (Cumulative Savings)	Cost Per AGV (x7 AGVs)				
			£40,000	£ 45,000	£ 50,000	£ 55,000	£ 60,000
7 AGV Investment			-£280,000	-£315,000	-£350,000	-£385,000	-£420,000
1	£137,465	£137,465	-£142,535	-£177,535	-£212,535	-£247,535	-£282,535
2	£137,465	£274,930	-£5,070	-£40,070	-£75,070	-£110,070	-£145,070
3	£137,465	£412,395	£132,395	£97,395	£62,395	£27,395	-£7,605
4	£137,465	£549,860	£269,860	£234,860	£199,860	£164,860	£129,860
5	£137,465	£687,325	£407,325	£372,325	£337,325	£302,325	£267,325

Table 14 - Return of Investment for Fully-Autonomous Scenario

3.5. Solution Recommendations

The semi-autonomous scenario saves £78,393 a year for a 3-year return of investment of four AGVs these must cost a maximum of £58,794 each. The fully autonomous scenario saves £137,465 a year; for a 3-year return of investment of seven AGVs, these must cost a maximum of £58,912 each. The recommendation is to take on the semi-autonomous solution initially as the return of investment and productivity of the system is comparable. Then after a period of 1-2 years, the fully autonomous solution could be selected to expand upon the existing semi-autonomous solution based on the success of the initial investment.

As shown in the cost analysis, there are considerable savings to be made by adopting an automation solution in Crystal Heart; the fully autonomous scenario offers more significant saving potential and requires more investment. The conclusion is that the main barrier to adopting automation technology for agricultural SMEs is the initial price of investment. The main cost of the investment is the AGV cost; therefore, by designing a lower cost AGV, SMEs will be able to make greater levels of automation investments.

4. 3D Modelling of AGV and Potential Attachments

4.1. AGV Design

The designed AGV is shown in Figure 4. The AGV is designed to be low-cost and can be used in multiple different sectors. A detailed rendering of the AGV was created in Blender software, shown in Figure 4.

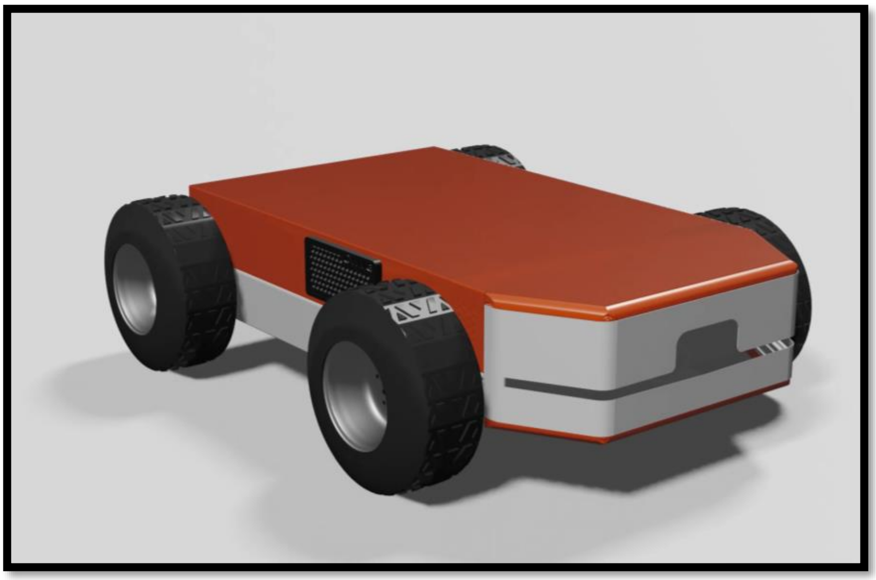

Figure 4 - AGV Rendering

4.1.1. AGV Benefits

There are several reasons for the choice of using an AGV over an alternative automation technology. The primary reason is the flexibility of implementation, AGVs could be integrated into a logistical process with minimal infrastructure development required, and different levels of automation could then be introduced later on either with more investment or more technological development.
Other benefits of AGVs are their low carbon emissions compared to the use of forklifts and the potential of an AGV fleet to be used for a full 24 hour day compared to a human workforce which would require increased wages for night shifts.

4.2. Agricultural Attachment Model

Figure 5 shows a rendering of a potential agricultural attachment that could be used with the AGV. The proposed agricultural attachment would enable the development of the fully autonomous scenario. It is leading to a reduction of both the motion and transport “wastes.” The attachment removes the need for the AGV to be unloaded by a forklift as it is able to self-unload onto floor level. There is a redundancy for the lay-flat room as there is no need for this process due to the capabilities of the AGV to received stacked trays and lift trays off the carried stack.

A 3D model of the Crystal Heart Lettuce process was created in Visual Components; Figures 5-11 show the modelled stages of the process. Creating a 3D model was used to visualise the potential implementation of a fully autonomous scenario and understand how the agricultural attachment might function.

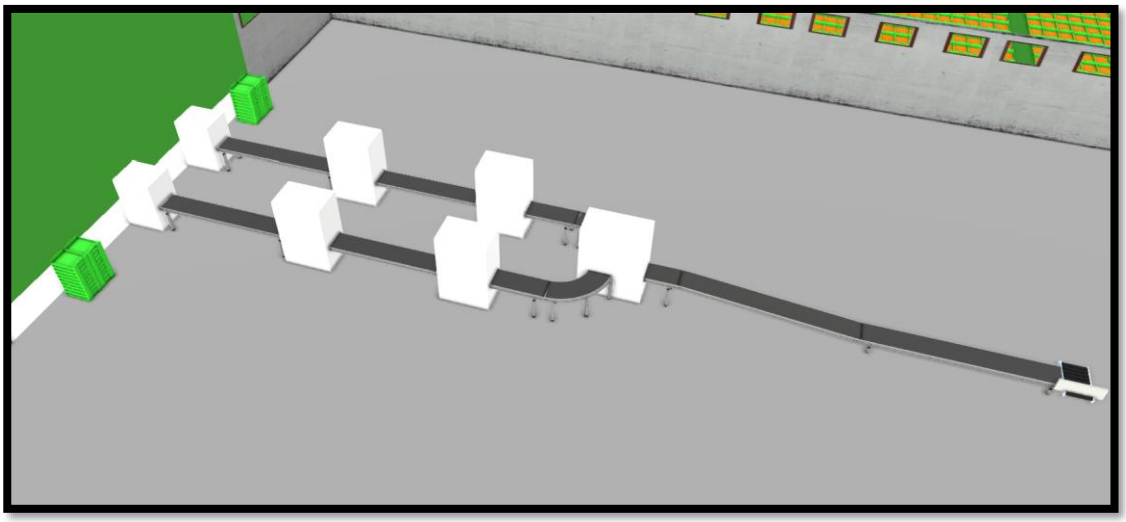

Figure 5 - Sowing Room

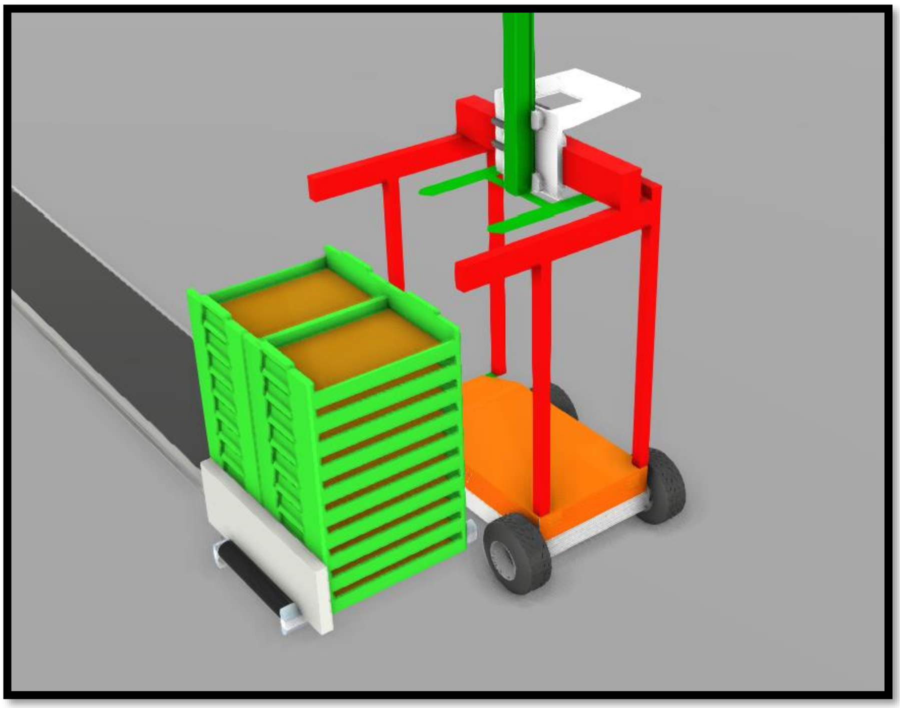

Figure 6 - Loading Mechanism - Retracted

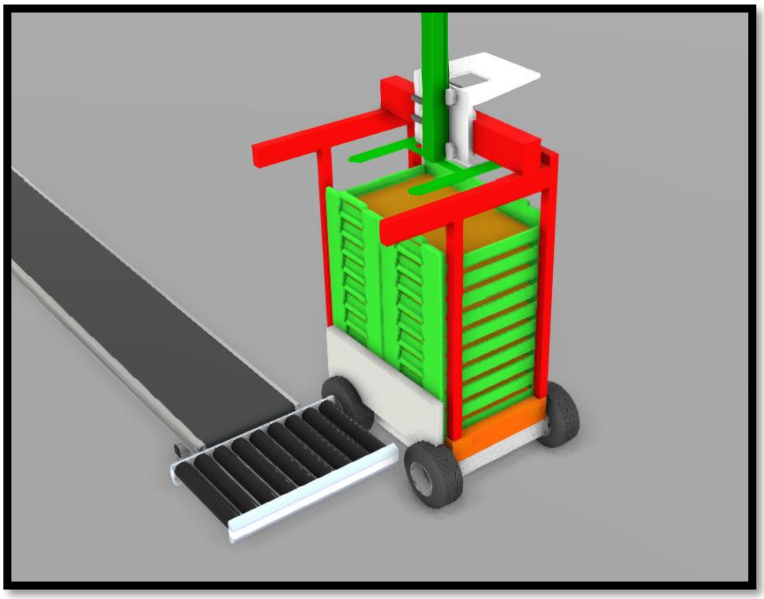

Figure 7 - Loading Mechanism - Extended

Figure 5 shows the sowing room process, and the two sowing machines can be seen which fill trays with compost and sow with seeds, the machine stacks trays into ten high stacks, which can then be pushed onto the AGV with the mechanism shown in Figures 6 and 7.

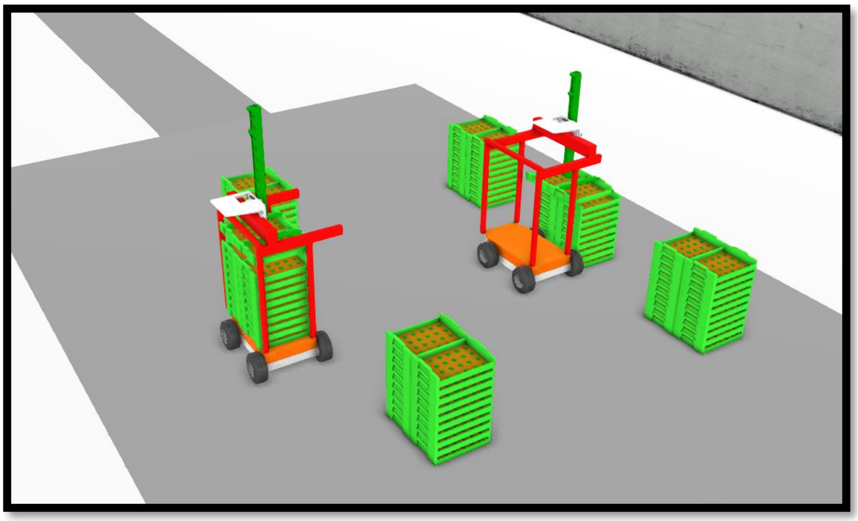

Figure 8 - Germination Room

Figure 8 shows the germination room; as in the current scenario, trays are stored in stacks then the AGV comes to load the trays from a stack onto itself. The trays from Germination are taken to the lay-flat room in the current system, but this process is eliminated, and trays are instead taken directly to greenhouses.

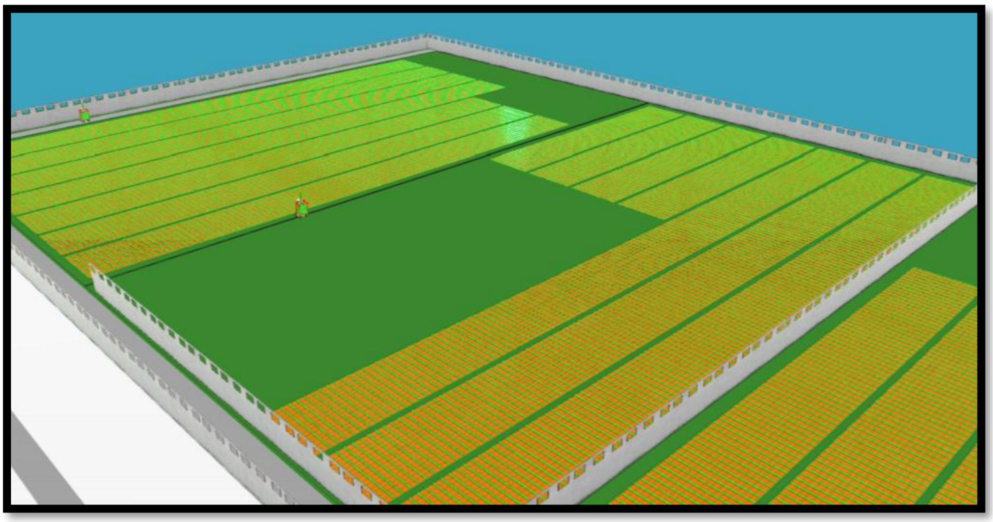

Figure 9 - Greenhouse Stage

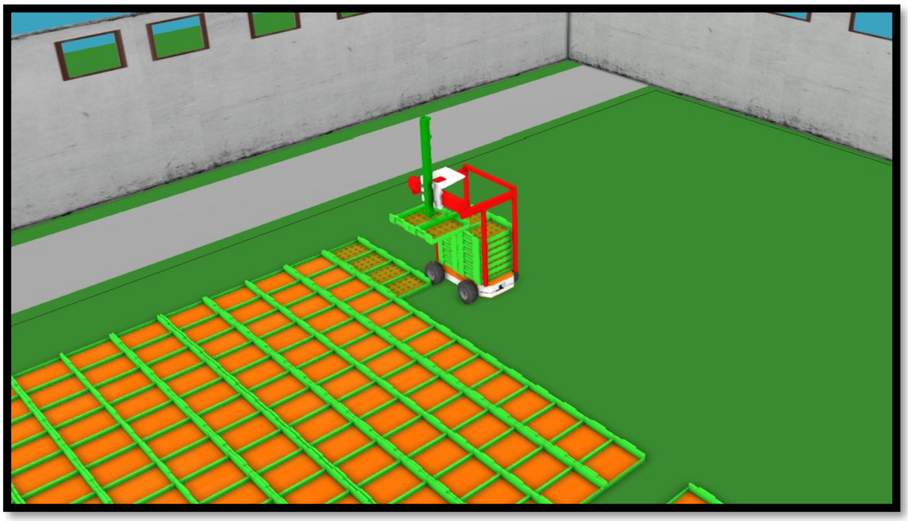

Figure 10 - Loading and Unloading Process

Figure 9 shows the greenhouse stage; here, trays are loaded and unloaded with the same process, shown in Figure 10. The AGV drives parallel to the line of trays stopping at each tray location and places or picks up a tray depending on the current task.

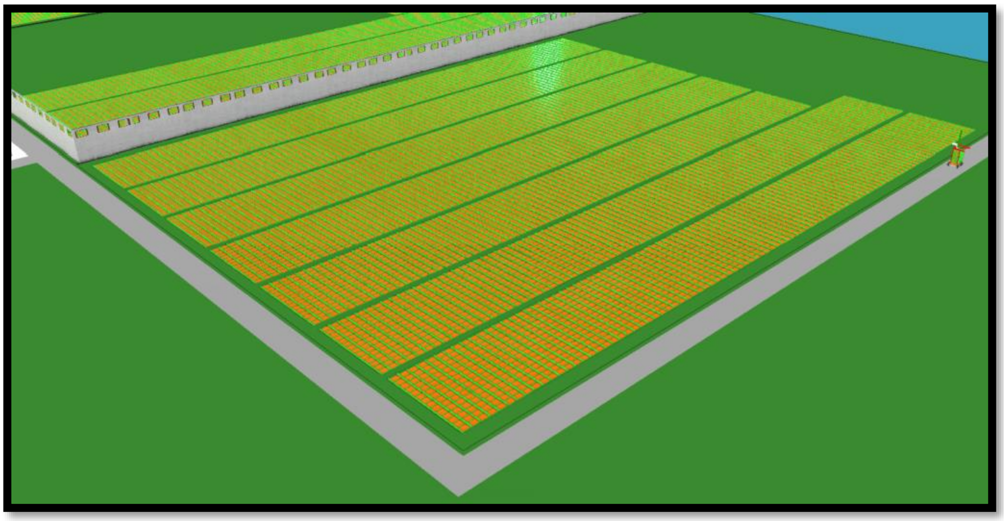

Figure 11 - Hardening Off

Figure 11 shows the outdoor hardening-off area; the processes here are the same as in the Greenhouse, where the trays are laid out, as shown in Figure 10.

4.3. Further Attachment Modelling

The analysis and research applied to this report show that there is scope for further attachment development; these attachment designs are indicated in Figures 12-15. Although the attachments are shown in an industrial application, there is potential to find uses for these attachments in the agriculture sector, be it the Crystal Heart application or other companies.

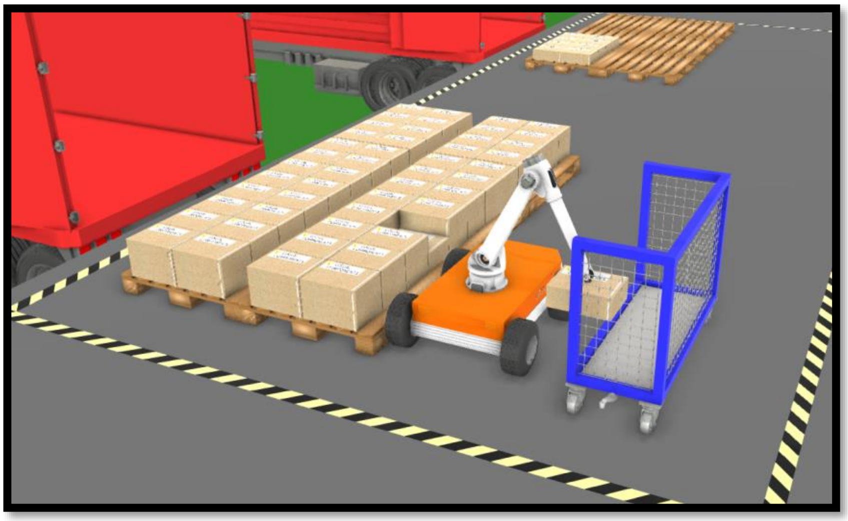

Figure 12 - Robotic Arm Attachment

Figure 12 shows a robotic arm attachment, in the 3D model, the arm is able to pick up boxes with a grabbing mechanism. This example is used to load and unload boxes from supply lorries, but the application could be used to move any regular shaped object that fits the grabbing mechanism.

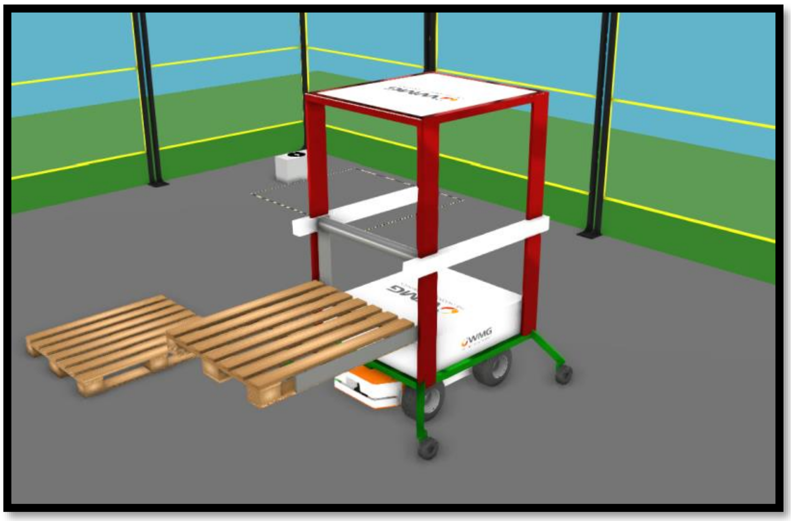

Figure 13 - Pallet Stacking Attachment

Figure 13 shows a pallet stacking attachment; the arms of the attachment are designed to pick up regular industrial pallets by clamping the sides. In the model, the AGV is collecting used pallets ready for later reuse. This could have agricultural and industrial applications as many processes rely on pallets to transport materials.

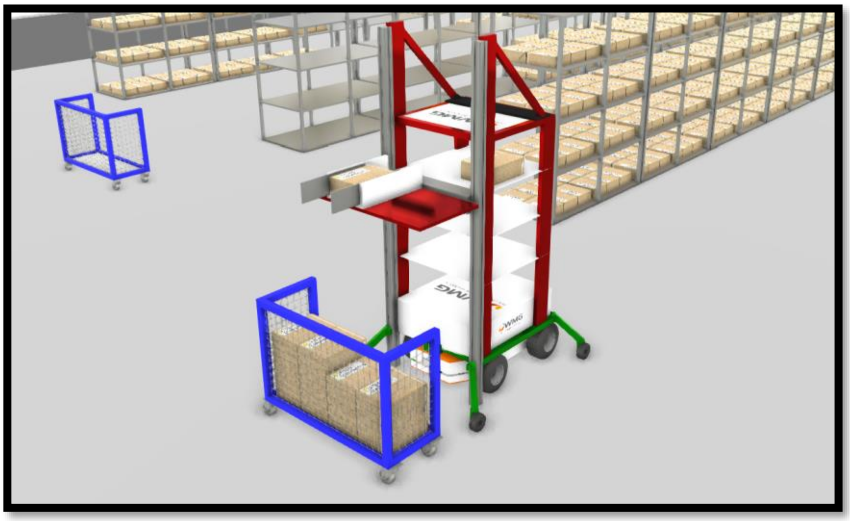

Figure 14 - Self-Stacking Attachment

Figure 15 - Self-Stacking Attachment loading Shelves

Figure 14 shows a self-stacking attachment. This attachment can store items within itself, and the attachment can pick and place on several shelving levels shown in Figure 15. The 3D model is used in an industrial setting, but this attachment could be used to store and carry small trays; perhaps this could have applications in a modified Crystal Heart germination room.

5. Conclusions

The first part of this report focused on analyzing the current logistical process of Crystal Heart. The analysis highlighted the presence of several sources of “waste.” A semi-autonomous scenario was proposed to tackle the most critical transportation “waste,” due to the unnecessary towing tasks of manned forklifts, where AGVs do most of the long-distance transportation, a further fully autonomous scenario was devised tackled the motion “wastes” present. Loading tasks of forklifts are transferred to the AGVs. While both scenarios offer cost savings, the most significant savings come from the fully autonomous, although this required more investment. It was also concluded that there was a requirement for a low-cost AGV in order to reduce the barrier of investment for SMEs, allowing greater levels of automation development.

The second part of the report focuses on the 3D modelling carried out on the project. The AGV designed was presented along with the benefits of AGV technology. An agricultural attachment designed to fit the needs of the Crystal Heart fully autonomous scenario was designed and simulated in a 3D model of the Crystal Heart process. Other extensions suited to different applications both in industry and agriculture were also simulated and modelled in the 3D environment.

The analysed solutions could help with the company’s future vision to automate their processes by initially using AGVs to articulate the moving trays task from production to dispatch. A second technological development should introduce a solution to automate the current production activities in the sowing process and synchronise it with the internal logistical processes performed by AGVs. This is achieved in terms of infrastructure and data collection.

The main recommendation of this report is for Crystal Heart to adopt the proposed semi-autonomous scenario initially. The recommendation for adopting the fully autonomous scenario would be a partial roll-out starting between the greenhouse and hardening stage, then based on the success of this implementation, and a full roll-out can be realised. This gradual implementation allows Crystal Heart to minimise the risks to their production by validating the success of each automation level. The real-life performance can then be evaluated and the feasibility of a fully autonomous scenario reassessed.

Further research should focus on the design of the agricultural attachment; this can include devising a specification based on the requirements of several agricultural companies, assessing a feasible attachment technology, and another 3D modelling of the attachment in practice.

Finally, a new Catapult-funded project is underway, focusing on developing an indoor/outdoor hybrid AGV testbed prototype to assess the performance and efficiency of business logistics operations targeting the manufacturing sectors and horticulture (including Crystal Heart, Valefresco and, WD Smith). Also, this new project represents an open opportunity to explore the real business needs in this market by using a testbed that can provide valuable test conclusions and, therefore, engage companies to scale this project to the third stage, the commercial prototype.

6. References

[1] Nawras Skhmot, The 8 Wastes of Lean, from (https://theleanway.net/The-8-Wastes-of-Lean), accessed 29.04.2021