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SIMULATING THE AUTOMATION OF SORTING CRATES – A STEPWISE APPROACH

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automation, sorting crates, stepwise simulation

ABSTRACT
This paper presents an initial study on the task of automating the sorting of crates. It was paramount in the study that the technology used for the automation process is already existing and available to the client in Norway, therefore an existing pallet sorting system was used as state of the art. The simulation was performed via a stepwise approach, that is, first we simulated the process as it is now. Based on this manual case we simulated the same system under a new automated task at time, until the final case (close to) full automated. A set of KPIs was defined and used in the assessment of all cases, including the manual one. These are Opex [NOK], Capex [NOK], Reliability [Stops over time], Robustness [%, Probability of consequence], and Efficiency [crates per. hour]. Our finding overall is that the time it took to sort a given number of crates decreased with increasing implementation of automation through the various change cases. With reduced time consumption the efficiency and number of crates per hour increased, from 300 in the manual case, to 1200 in the fully automated case. The increase in automation also resulted in increased costs, both capital- and operating costs. If we look at the cost increase in relation to the capacity increase, the cost per sorted crate decreases by about 50%. The manual process sorts 300 crates per hour, and if we look at the cost per sorted crate, the fully automated case must sort 600 crates per hour to breakeven and justify the automation.

SORTING CRATES PROBLEM

The starting point of our work was based on the needs from a real grocery distributor in Norway, supplying supermarkets with food. The food is transported to the grocery stores on pallets and in various reusable plastic crates (Figure 1). Upon delivery, they also take used pallets and crates back, and deliver these to a sorting department. All pallets and crates are visually inspected for damage and defects, before being sorted by type. These are then shipped to the distributor for reuse. The crates studied comes in two sizes, the IFCO6420 and IFCO4314 (half size), Figure 2.

The core of our work was to be able to simulate the benefits of automating a currently manual process. The simulation will be done by identifying the main process and sub- processes of the actual manual case. The available technology for automation is then studied, with a gradual implementation of the automation in the current processes, keep as benchmark the same assumption and constraints.

Figure 1 – Reusable crates returned from grocery stores (above) and crates after the manual sorting process (below)

AUTMATION TECHNOLOGY FOR SORTING

Automatic sorting takes place in several different industries, typically industries with high volumes like food processing (sorting), parcel sorting, and waste

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management. Although much robotic technology is already developed, the true integration in sorting is still in its infant stage. While most of the system is made of standardized parts, the integration of all the parts, the software that controls the system and in many cases the grippers, are custom made for each case. (Automated parcel sorting - An introductory guide, 2021)

Figure 2 - Unfolded crate IFCO6420 (above) and two crates folded and stacked (below).

In food processing, automation is found in high volume sorting jobs, like finding and picking small pits or stalks in fruits and nuts. Increasingly, they are also used in fruit and vegetable harvesting, where robots can select perfectly ripe fruit accurately and fast. (Industrial automation : TOMRA, 2021). In waste management sorting is often done for recycling purposes, where the different waste types can be carboard, electronics, organic, metal, different types of plastic, and glass, and among these there is a large variation in sizes and shapes. (Bonello, Saliba and Camilleri, 2017). We comment in the following subsections the solutions currently available, divided into the functions that are relevant for the crate problem, that is,movement of objects, sensors and gripping

Movement of objects

The most used technology for transporting objects in a production and sorting environment are belt conveyor or roller conveyor. Belt conveyor systems are some of the most universally used and recognized machines in any industrial setting. (Conveyor Types & Configurations, 2021) The belt conveyors use a series of powered pulleys to move a continuous belt. This belt can be made of natural or synthetic fabrics such as polyester or nylon. In extreme temperatures or aggressive parts, a wire mesh or fiberglass belting can be used. In the modular belt conveyors, the belting is made of individual, interlocked segments, usually made of hard plastic. These are easier to repair than flat belts models, easier to wash, and more resilient to sharp, abrasive, or otherwise problematic materials. Conveyor belt systems can be configured with back-lit belts for visual inspection and quality control, and vacuum belts for holding flat products to the belts surface. (*Conveyor Types & Configurations*, 2021)

Roller conveyors are a series of rollers supported within a frame where objects can be moved either manually, by gravity, or by power. Because of their adaptability roller conveyors are used widely in numerous industries, but mostly in logistics and manufacturing.

Gravity roller conveyors are useful as they use gravity force to move objects by putting the conveyor at a decline angle. This is a cost-effective solution, requires no power source which reducing the cost of operation, the need for maintenance, and time in maintaining the conveyor. This also provides a more environmentally friendly solution compared to a powered roller conveyor.
It is generally harder to control the conveyor speed, especially with heavy objects on the conveyor. Powered roller conveyors are more suitable when transporting object over a longer distance, there is a need to control the speed, or split the conveyor in zones with different speeds. The motion can also be controlled by sensors.
Powered systems are more expensive and needs more maintenance than passive systems.

Sensors

In automatic sorting, different sensors are used, either alone or in combination. The choice of sensors is dependent on what feature to identify, material, shape, or colour. A combination of sensors can identify both material and colour/shape of the same object. In the (MRF) material recovery facility in Marsaskala, Malta, they combine a NIR sensor (Near-infrared) with visual imaging (2D) to identify PET plastic and to differentiate between withe and clear versions. Near-infrared (NIR) spectroscopy is effective, and a common technology to identify various materials like paper, cardboard, metallic objects, plastic, and various foam products. (Bonello, Saliba and Camilleri, 2017)

Gripping

While the technology used for gripping is standardized, how it is used, in which combination and in what shape, can differ from project to project. Often the grippers are specially made for the object(s) to be handled, and even a combination of technologies is used like the universal gripper design proposed in (Bonello, Saliba and Camilleri, 2017) and seen in the picture below. Here both mechanical jaws and a retracting vacuum tube is used both individually and simultaneously, depending on the object to be lifted.

To extract the metallic objects, magnets or electromagnets can be used on ferrous objects, while eddy current separation technology sorts out 90% of non-ferrous metallic objects. Some objects can be sorted by air stabilization systems that pins the object to the conveyer and allows it to exit through dedicated outlets. In some cases, a cooperation between man and machine is a good solution, where some objects can be extracted manually to increase sensing precision. Figure 3 summarizes the automation techonoly found relevant for our study.

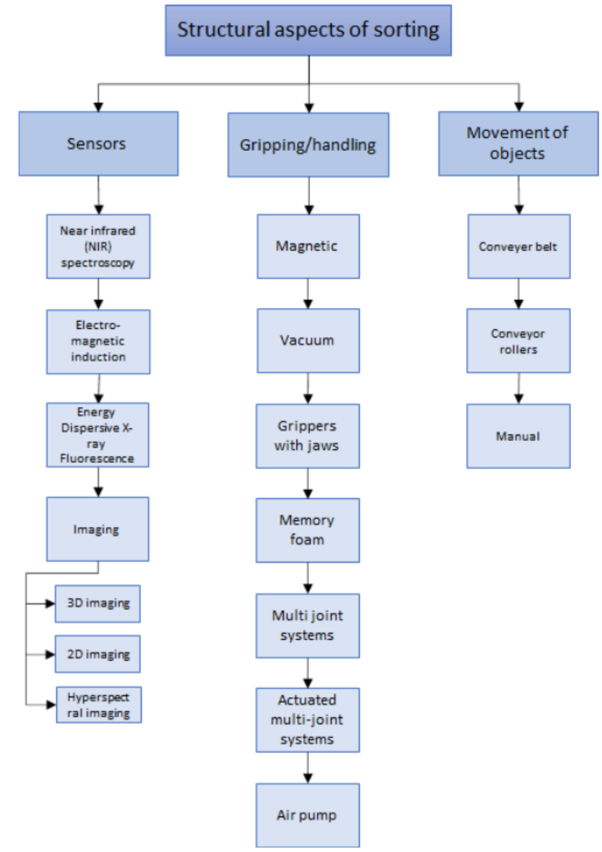

Figure 3 – Automation technology relevant for the sorting crates problem

PALLET SORTING

Sort Machine

Another relevant input was the successful automation of pallets sorting in the same type of industry, a robotic pallet sorting system called *Sort*, developed by Currence Robotics (2021). This system is now coming out of beta and is ready for production. According to the white paper from the company, *Sort* is a modular and scalable system, making it suitable for both small warehouse hubs and regional district centres, as it can handle a variety of pallets, Euro-, plastic-, eco-, half sized- and quarter sized pallets. It can process about 180 pallets per hour, working 24 hours a day. The future goal is 400-500 pallets per hour. (*Currence robotics*, 2021).

The machine is built up from five main parts, the infeed conveyor system, infeed tower with vision equipment, all the output towers, robot with gripper, and outfeed conveyors. The machine can be controlled from the main cabinet, located next to the machine (Figure 4). This is a large machine that requires substantial space, as well as additional space in the front for the access of the forklifts. This system is designed as a modular system, so at any given point there can be added more towers for different types of pallets. By adding towers and types of pallets to sort, the sorting time will decrease, as there is still only one robot to do the sorting (Figure 4).

Figure 4 – *Sort* pallet sorting system (Currence Robotics, 2021)

One of these five main parts is the outfeed towers, one for each type of pallet to be sorted. It is these output towers that make the system modular, the ability to add more towers as needed, and in this way handle new types of pallets. What is called the robot, grabs, lifts, and moves the pallets to the correct outfeed tower. This is based on the assessment made by 3D vision sensors. This robot moves between the output towers on a horizontal travers crane mounted on top of the towers. Figure 5 presents the automation technology from *Sort* also divided in the choose taxonomy.

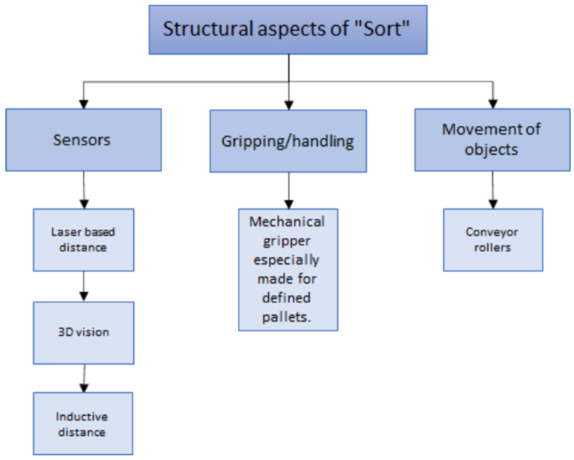

Figure 5 – *Sort* automation technology in terms of sensors, gripping and movement of objects.

Movement of pallets

Stacks of unsorted pallets are transported to the sorting area by trucks. These stacks are picked up by forklifts and moved in to the *Sort* buffer area, pallet infeed. The infeed buffer is made of roller conveyors. These conveyors are slightly lifted at one end, giving it a slight slope towards the machine, making the pallets travel to the machine due to gravity. A mechanical stopper holds back the next stack of pallets, so the robot gripper can work with the front stack. In the same way, the output conveyors are sloped from the machine, making the pallets slide to the end of the roller conveyor. Here the mechanical stopper prevents the stack from sliding forward, until the stack has reached its predefined max height of 17 pallets. At the end of these output conveyors, forklift pick up the stack of pallets, moves it to the storage area where it is wrapped in plastic for stabilisation before it is placed on storage.

Sensors

The first sensor to detect new pallets are the laser based top limit sensor at the infeed tower. This is to prevent the stack of pallets from being higher than the machine can handle. The most important sensors are the six 3D vision cameras. They are all placed in the infeed tower and are used to examen and evaluate all the pallets, one by one. The pallets are then picked up by the robot and placed in the correct outfeed tower. In each of these output towers there are inductive limit sensors to detect the stack hight. When the stack contains 17 pallets, it is released and will slide down the outfeed conveyor. The number of stacks on the output conveyor is monitored by a laser-based outfeed sensor. There are absolute encoders in all motors on the robot and the towers, this to know the exact position of the robot.

Gripping

When unsorted pallets are fed the system through the infeed buffer, the 3D vision sensors do the quality assurance and sort identification before the robot with gripper grips and lifts the pallet. The 3D vision sensors do a second inspection from underneath, before the robot transports the pallet to the correct tower, sorted by type or due to damage. The gripper can handle seven different types of pallets.

SIMULATING SORTING OF CRATES – FROM MANUAL TO FULLY AUTOMATED

Overall Assumptions and Methodology

This work builds on a stepwise procedure for simulation. All change cases will contain different degrees of automation, the first as it is now, (fully manual) until the last one being (close to) fully automated. Our premise is based on the fact that the limit of the manual case currently lies on 300 crates per hour with two operators. This is already not enough, especially since there are some large seasonal variations. To meet future requirements from main stakeholders, it is a requirement that an automated solution must be able to sort 1200 crates per hour.

The first technology to consider was automatic visual quality assessment as this is the sub-process that takes the most time. In addition to the use of time, the quality of this process is also important. Later automatically sorting the crates according to the quality control is introduced. The crates are then ready to be transported to the designated area. The next case includes all the machinery for full automation for the sorting process. This may seem like a big step in relation to previous case, but to transport pallets with crates over relatively short distances of 5 -6 meters, and at the same time act as a buffer for the automatic sorting process, a roller conveyor will be a robust, simple, and good solution. As a buffer, there will be room for 5- 6 pallets of crates on a roller conveyor used today. If a larger buffer is needed, the roller conveyor can simply be expanded. The pallets with crates have enough weight that gravity roller conveyors can be used. The pallets that are waiting are held back with stop blocks integrated in the roller conveyors, which are controlled by sensors. Different sensors are used for different tasks. To detect the stacking height, both laser and inductive sensors are available. Several 3D vision cameras, all of which are located in the infeed tower, are used to verify both type and quality.

KPIs

The key performance indicators (KPIs) are decided upon stakeholders' analyses, based on conversations and interviews (Misund, 2021). The manual process is based on the time it takes to sort 51 crates, which is the average of IFCO- 4314 and 6420 on a pallet with several types of unsorted crates. This is then multiplied up to find the number of crates sorted per. hour. For the forklifts, which are included in all cases, the purchase price is divided by the estimated useful life, plus service and operating costs for the same period. The operators driving the forklifts is also to varying degrees included in all cases and here salaries, personal protective equipment, work clothes, sick leave, injuries are included in the various KPIs.

Opex [NOK]

Operating costs is the day-to-day expenses necessary for the process. This includes maintenance of equipment, and salary for the operators. The maintenance costs are divided into working time cost and material cost. In the processes described, there are two operators working, and, salaries, sick leave, personal protective equipment, and work clothes for the operators are included.

Capex [NOK]

Capital cost are major purchases designed to be used over a long term, included the installation. This is different for the different processes, especially the manual one in relation to those where automation is implemented to different degrees. For the manual case, the forklifts are responsible for the capital cost, as these are the only machines in use. For the three subsequent automated cases, the increased implementation of automated solutions (new equipment) will increase the capital cost for the processes. The installation costs will also increase with the amount of install equipment through the various cases, these costs are divided into working time cost and material cost.

Reliability [Stops over time]
In this context, a reliable process is a process with few stops and if a stop occurs, the process restarts again quickly. This indicator gives an average number of stops in the process per unit of time. A lower number equals a more reliable system. This average number is based on interviews of the main stakeholders, experiences made by the operators (Misund, 2021).

Robustness [%, Probability of consequence]
System robustness is here understood as the ability to remain functioning under a range of disturbances. (Mens *et al.*, 2011). To measure robustness to the process, three levels of failure with increasing consequence have been defined. The probability of the different failures for each case is then established equal for all cases.

- **Failure 1** is a simple failure that can be quickly corrected without stopping the process or the process restarting in seconds. This can be a box or crate falling on the floor, and an operator uses one or two second picking it up and continues the process.
- **Failure 2** is a medium failure. This can be equipment that fails and needs to be fixed, either within a few minutes or within a few hours. Standardized equipment in stock is replaced within minutes, while many spare parts are currently in centralized remote warehouses in the county and can be delivered within a few hours.
- **Failure 3** is a large failure. This type of error stops the process for a long time, often several days. This can be caused by major errors that require service personnel and ordering and waiting days for parts. A larger or smaller fire in the plant will be able to stop the process for a long time and is considered a major fault.

Efficiency [crates per. hour]
The efficiency indicator tells us how many crates are sorted per hour. There is today a desire to sort approx. 300 crates per. hour, but all main stakeholders agree that an automated system must handle more than this in the future to be considered viable. We established that an automatic sorting process must handle 1200 crates per hour when designing our final automated case.

CASES

Case 1 – Manual Sorting (as it is today)

The manual process is sketched in Figure 6. Its elements are:

1. Truck with unsorted crates and pallets from grocery stores.
2. Pallets with crates unloaded front rucks.
3. Move pallets with forklift to sorting station.
4. Sorting station
5. Pallets with sorted crates by type and size.
6. Pallets with sorted crates wrapped in plastic.
7. Storage.
8. Pallets with sorted crates ready for shipping.
9. Trucks transporting sorted crates to grocery suppliers.

Trucks collect pallets and crates at grocery stores and bring these to the sorting facility. The different crates arrive mixed and stacked on Euro-pallets. Truck drivers collect the pallets and bring them to the sorting area. Here the different crates are separated and stacked on new euro-pallets. When the stacks have reached the desired height, they are wrapped in plastic film for safety, and put in stock. The process to be investigated is the sorting, and not the processes before and after. The product delivery from this process is both the sorted and quality-controlled stacks of crates, the storage, and the distribution of crates when needed (numbers 7, 8 and 9, Figure 6).

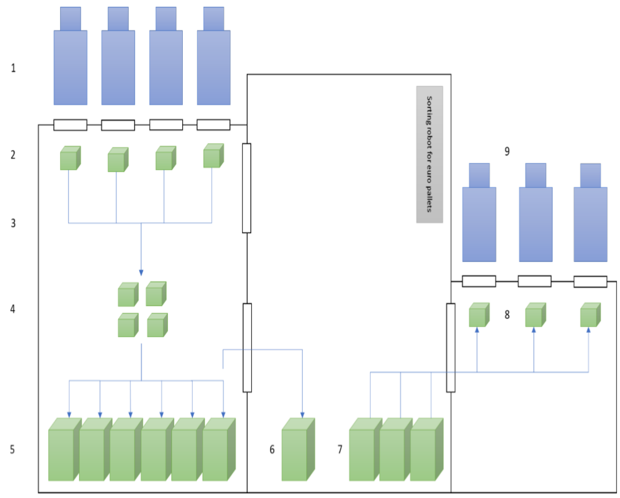

Figure 6 – Elements of the manual process of sorting crates

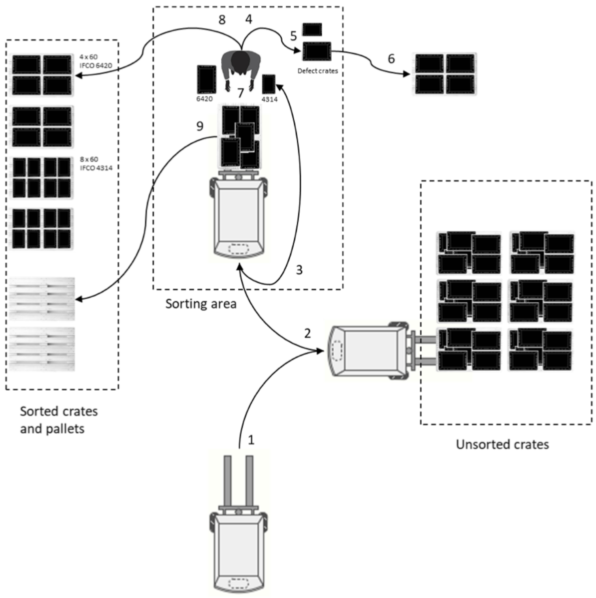

Figure 7 – Case 1 Manual Sorting

This process is nowadays mostly manual, with the help of forklifts to move pallets full of crates. The manual solution is working well if the volumes is moderate. When the volumes increase, which they do seasonally, the manual solution becomes a bottleneck. It simply takes too long to sort all the crates that arrive in a day, and overtime must be used to solve the challenge. The current elements of this process are therefore traditional, and consist of the forklift, the pallet with crates, and the crates themselves. This arrangement is observed in Figure 7.

The process is explained in the flowchart from Figure 8. Whit a forklift, one person picks up the pallet with unsorted crates (1) and drive as close to the pallets with sorted crates as is convenient (2). Here the person walks in front of the forklift and pallet (3) and starts to sort the crates by type and stack them on the floor in small and manageable stacks (7). All times while the person is collecting and sorting crates, the quality and functionality of the crates must be considered (4). Defect crates are sorted out (5) As the pallet with unsorted crates is empty, and there are several small stacks on the floor, the small stacks are then picked up by hand, and place on top of the already sorted crates (6 and 8). On each pallet there are 4 by 60 IFCO 6420 crates, and 8 by 60 IFCO 4314 crates (half size). The now empty pallet is then driven by forklift and placed on the designated place (9). The process then repeat itself, until all crates are sorted.

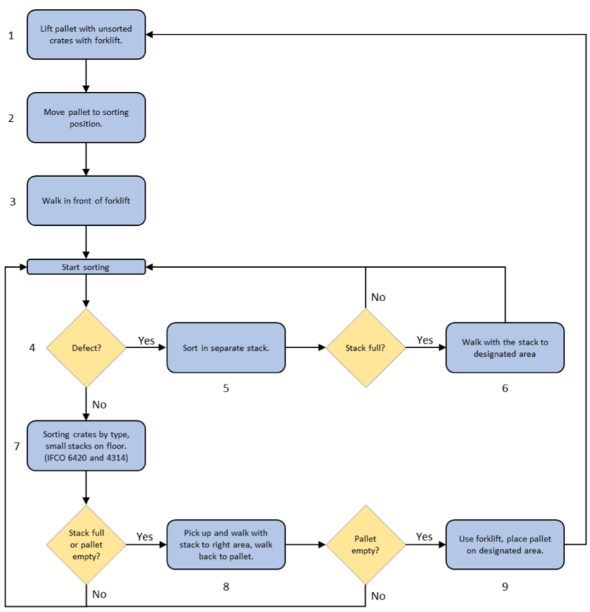

Figure 8 – Manual sorting process

Case 2 – Automatic Quality Control

The first step towards a fully automated process is to implement an automatic quality control of the crates. This is a consequence on the study that it takes an average of 255 sec to inspect 51 crates (Misund, 2021). This is the sub-process that takes the longest time to complete manually and both time use, and workload will hopefully benefit from automation. A sub-process has been added, marked with the number 4, which symbolizes the automatic quality control that is performed on all crates before sorting (Figure 9). The elements that are new in this case are the parts that the automatic quality control consists of. This is a large implementation as it contains most of the sensors, the gripper for the crates and the electronics that control it all. Namely, a laser based top limit sensor, several 3D-vision sensors to perform the quality control and a gripper handling the crates.

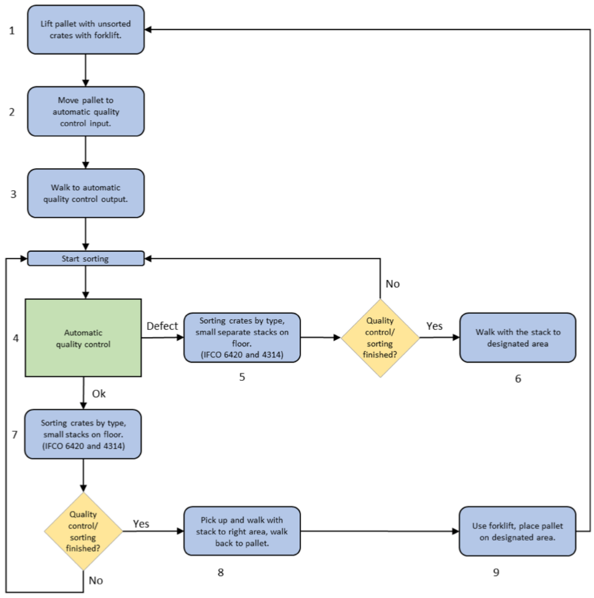

Figure 9 - Process with automatic quality control

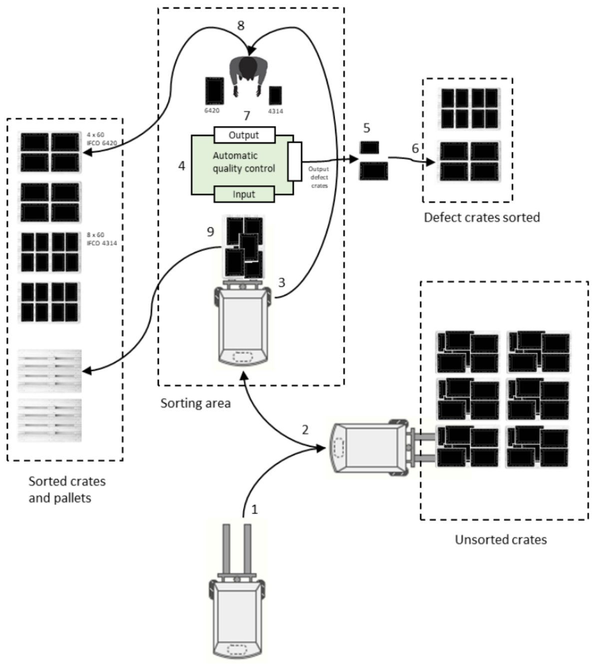

Figure 10 – Case 2 Automatic Quality Control

The first thing that meets the pallet crates are the laser based top limit sensor at the infeed. This sensor prevents the stack of crates from being higher than the machine can handle. The quality assurance is done by the 3D vision sensors first from the top before the gripper lifts the pallet and the 3D vision sensors do a second inspection from underneath. The defect crates are then sorted out in a separate stack (Figure 10).

Case 3 – Automatic Sorting of Size and Quality

The next step towards fully automated solution is automatic sorting by size and quality. There are two sizes of the crates, the IFCO 6420 and the half size 4314. It will be the same gripper used in the automatic quality control, which is used to sort crates. There are also the same 3D vision cameras that are used as sensors to determine size. The additional feature is that The gripper must be given greater freedom of movement to be able to place the different craters in different places. This is solved by placing the gripper on an overhead crane that has a horizontal movement. To be able to pick crates at different heights from the pallets, the gripper already can move vertically. To distinguish the different sizes, the software that performs the quality control must be expanded to separate the crates by size. Otherwise, the same sensors are in use (Figure 11).

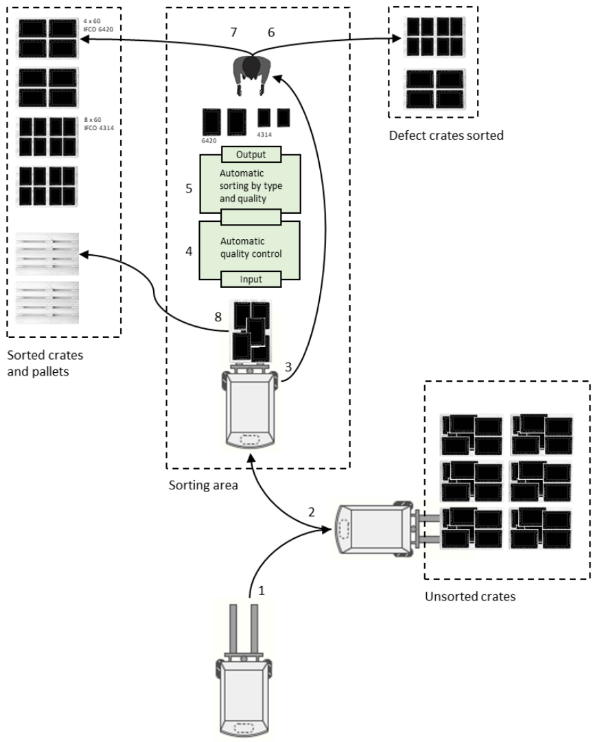

Figure 11 - Case 3 Automatic Sorting of Size and Quality

The crates are now stacked and presented to the operators according to size and quality. A predefined number of crates come stacked out of the machine ready to be carried to the specified place. The product from the automatic processes is now four different stacks, two stacks with approved crates one for each size, and two stacks with unapproved crates, one for each size.

Case 4 – Fully Automated

This is the third and final step towards fully automation of the sorting process. Although the process is now called fully automated, it yet requires manual work, as pallets with unsorted crates must be delivered to the infeed by forklift, in the same way the pallets with sorted crates must be picked up by forklift at the outfeed. The solution consists of 5 main elements. The first is the infeed conveyor which is fed with pallets with unsorted crates. These pallets are detected by a laser-based sensor that also detects the height of the unsorted crates, so they do not exceed the maximum height. The second main unit is the main sensors which consist of several 3D vision cameras which are used to identify the size and quality of the crates. The third main unit is the gripper which lifts the crate for examination from the underside. This gripper is mounted on the fourth main unit, an overhead crane that moves the gripper with crate to the right outfeed conveyor (Figure 12).

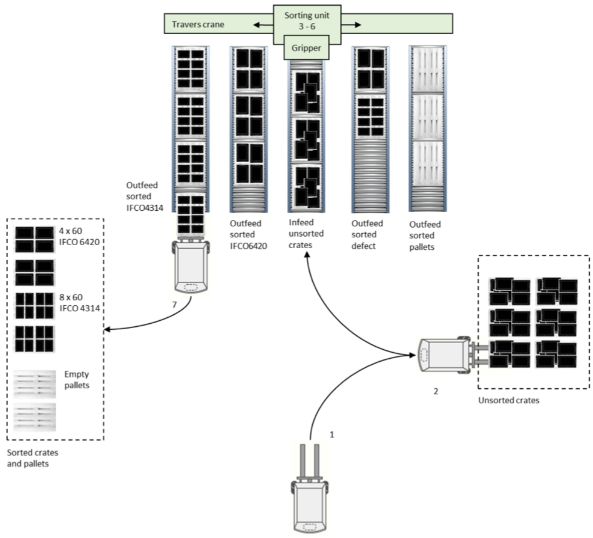

Figure 12 – Case 4 Fully Automated Sorting

The detailed process is presented in Figure 13. (1) The forklifts pick up pallets with unsorted crates, (2) which are lowered onto the infeed conveyor. Depending on the volume, the infeed conveyors can be adjusted in length to accommodate as many pallets as are necessary for the overall process. These conveyors are slightly lifted at one end, giving it a slight slope towards the machine, making the pallets travel to the machine due to gravity. A mechanical stopper holds back the next stack of pallets, so the robot gripper can work with the front stack. (3) When the pallet with crates arrives at the sorting unit, one by one the crate is identified, and quality checked from the top. Griper then picks up the selected crate, lifts it up, for quality control from the underside. 3D vision sensors are constantly being used to assess size and quality. (4)(5) Once size and quality are identified, the entire gripper moves along the overhead crane, placing the crate on a pallet on the correct outfeed roller conveyor. (6)(7) When the pallet on an outfeed conveyor is full, it is released, and it rolls forward so that it can be picked up by a forklift. The machine will work as long as there are unsorted crates on the infeed conveyor, and the sorted crates are picked up from the outfeed conveyor and this does not become full.

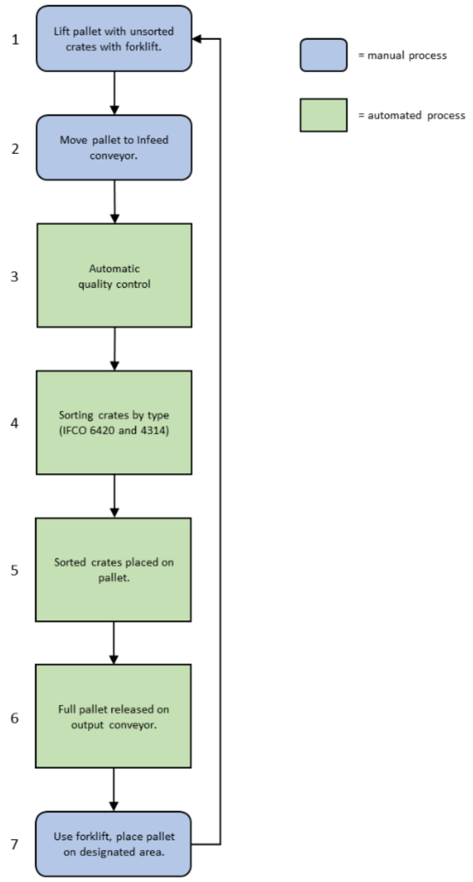

Figure 13 – Case 4 Overall process for the fully automated sorting

Evaluation

The starting point for this work has been a manual sorting process, where several different reusable plastic crates are sorted. Results are observed in Tables 1-4.

The unsorted crates arrive on pallets, and these pallets contain several different crates. During the observations, it was found that each pallet contained an average of 51 crates of 6420 and 4314. It is therefore based on the time it takes to sort 51 crates, which takes 612 seconds in the manual process, and which is gradually reduced to 153 seconds in the fully automated case 3, a reduction of 75% (Table 1). With reduced time consumption comes the ability to sort more crates per hour. From 300 in the manual case via 409 pieces and 712 pieces in change cases 1 and 2, to 1200 in change case 3. This is an increase of 400% from the manual case. Despite this increase in capacity, both operators from previous cases are retained in the cost calculations. This is because it will be impossible for one person to both feed the machine and empty it of sorted crates fast enough when it sorts 1200 crates per hour. In addition, there are the two forklifts, one for each operator. We observed an Opex raise costs of 77% due to an annual maintenance cost of the automated solution (Table 2, Case 4). For capex costs, the purchase price for the structural components is included. We observed an 803% increase in capital costs. Capex costs are spread over 10 years, as this is a conservative estimate of the lifespan to the machine. Despite this increase in costs, the price of each sorted crate decreases. This price comes from the sum of Capex and Opex, divided by the number of sorted crates in each case.

Reliability is only described as stops per unit of time. With a slightly unclear definition, and divided opinions about what is a stop in the manual process, but at the same time with the certainty that some stops are, it is difficult to say if one stop per day, 0.13 per hour is a valid assessment. As for Robustness, probability of failure 1 is defined as a simple failure that can be quickly corrected like a box or crate falling on the floor, and an operator uses one or two second picking it up. These are small errors that are directly related to how large a part of the process the operators are part of. With an increasing degree of automation, the probability of such errors will be reduced. Therefore, the probability of failure 1 is reduced between the cases. The definition of failure 2 has been a bit inconsistent throughout the simulation. It has both been defined as components that fail and need to be replaced, and slightly larger work accidents such as crashing the forklift into a pallet that results in many crates falling on the floor. In definition one, with defective components, the probability should increase for each case due to increasing number of components used in the automation solution. In definition two, slightly larger work accidents primarily caused by forklifts, the probability will be unchanged between the cases because forklifts are used to about the same extent. Therefore, the probability of failure 3 is the same for all cases. This is defined as a major accident that stops the process for a long time. This could be a power outage in the area or a minor fire. Our assumption is that an automated solution requires electricity, but it is not a question of enormous power consumption. There are relatively light parts to be lifted and moved, with associated small electric motors in the various moving parts. A sufficiently dimensioned power supply in the room will not affect the power supply in the area.

Table 1 – KPIs for all cases

	Task	Duration sec.					Change from	
		Manual process	Change case 1	Change case 2	Change case 3	Unit	manual case	Unit
	Time to sort 51 crates	612	449	258	153	sec.	-75	%
1	Opex (NOK per hour)	675	832	989	1198	NOK	77,5	%
2	Capex (NOK per hour)	26	92	157	209	NOK	803,8	%
3	Reliability (Stops per hour)	0,13	0,13	0,13	0,13	Stops per hour	0	%
4	Robustness (%)							
	Probability of failure 1	85	70	60	10	%	-88	%
	Probability of failure 2	20	20	20	20	%	0	%
	Probability of failure 3	1	1	1	1	%	0	%
5	Efficiency (crates per. hour)	300	409	712	1200	crates per. hour	400	%
6	Cost per sorted crate (Sum Capex + sum Opex/ sorted)	2,34	2,26	1,61	1,17	NOK per crate	-49,822	%

Table 2 -OPEX and CAPEX for Case 4

System performance indicators (KPIs)							
	Unit price	Operators	Days per year	Hours per day	Calculation	Sum	Unit
Opex							
Sallary	472 680,00	2	239	4	472680 / (239*4*2)	494	NOK per hour
Sick leave	247,00	2	20	4	(247*2*20*4)/239	165	NOK per hour
Maintenance forklift	8 000,00	2	239	8	(8000*2)/(239*8)	8	NOK per hour
Personal protective equipment	4 000,00	2	239	8	(4000*2)/(239*8)	4	NOK per hour
Work clothes	3 000,00	2	239	8	(3000*2)/(239*8)	3	NOK per hour
Yearly maintenance Automatic quality control	300 000,00		239	8	300 000/(239*8)	157	NOK per hour
Yearly maintenance sorting unit	300 000,00		239	8	300 000/(239*8)	157	NOK per hour
Yearly maintenance outfeed	400 000,00		239	8	300 000/(239*8)	209	NOK per hour
Sum						**1198**	**NOK per hour**
Capex							
Purchase price forklift	250 000	2	239	8	(250 000*2)/(239*8*10 years)	26	NOK per hour
Automatic quality control	1 250 000		239	8	(1000 000*2)/(239*8*10 years)	65	NOK per hour
Automatic sorting unit	1 250 000		239	8	(1000 000*2)/(239*8*10 years)	65	NOK per hour
Automatic sorting unit	1 000 000		239	8	(1000 000*2)/(239*8*10 years)	52	NOK per hour
Sum						**209**	**NOK per hour**

Table 3 – Efficiency per Case

Task	Efficiency (crates per. hour)				Unit
	Manual process	Change case 1	Change case 2	Change case 3	
Efficiency (crates per. hour)	300	409	712	1200	crates per. hour
Increase in number of crates sorted between cases.		36	74	69	%
Increase between manuel case and case 3				400	%
Cost per sorted crate (Sum Capex + sum Opex/ sorted)	2,34	2,26	1,61	1,17	NOK per crate
Decrease in cost between cases.		-3,30	-29	-27	%
Decrease between manuel case and case 3				-50	%

Table 4 – Cost per sorted crate

Task	NOK per sorted crate			
	Manual process (300)	Change case 1 (409)	Change case 2 (712)	Change case 3 (1200)
Cost per sorted crate at **300** crates available per hour	2,34	3,08	3,82	4,69
Cost per sorted crate at **400** crates available per hour		2,31	2,87	3,52
Cost per sorted crate at **500** crates available per hour		1,85	2,29	2,81
Cost per sorted crate at **600** crates available per hour			1,91	2,35
Cost per sorted crate at **700** crates available per hour			1,64	2,01
Cost per sorted crate at **800** crates available per hour			1,43	1,76
Cost per sorted crate at **900** crates available per hour				1,56
Cost per sorted crate at 1**000** crates available per hour				1,41
Cost per sorted crate at 1**100** crates available per hour				1,28
Cost per sorted crate at 1**200** crates available per hour				1,17

Tables 3 and 4 show the efficiency and cost per sorted crate for a varying number of available crates for each change case. Breakeven point for each solution is presented in Table 4, and the fully automated solution presented itself profitable at 600 crates per hour.

DISCUSSION AND FUTURE WORK

The stepwise approach was found relevant for the given simulation. Large parts of the works were spent on mapping the current sorting process (Figure 6 and 7) as well as studying the available technology. Including changes one process at time were useful for understanding the gaps between manual and automation, as well as understand the consequences of changes. This was clearly mapped in the simulation, as every new product/process affected the KPIs.

There are many simplification, however, s made in this simulation also in connection with the estimation of KPIs. If it turns out that the real cost picture is significantly higher in change case three, it is still likely that the process is profitable, given the cost per sorted crate at 1200 crates per hour is half of what it is at 600 crates per hour. The KPI Reliability (stops per hour) did not provide the feedback that was intended, as it proved difficult to calculate or in other ways make the values probable. Robustness [%, Probability of consequence] also proved to be a theoretically difficult exercise, it was somewhat better defined than Reliability, but still not good enough. This shows the importance of well-thought-out KPIs, and possibly a test case to see what results they give and how easy it is to arrive at probable values. A simplified test case was also proposed by the supervisor, but not completed.

The chosen method provided a good understanding of the process, which is critical to be able to evaluate how the implementation of automation will affect the process. It is now clear in retrospect that these should have been defined differently. This is especially true for Reliability, where in interviews about the manual process, there have been divided opinions and perceptions about what a stop is, and what is just a normal work pace with small talk and natural breaks. Given the validity of the results in this thesis, it seems a valid risk to already automate this process. If they can reuse parts and equipment from existing pallet sorting machine, the probability will increase that this will be an economically profitable project. The good results for the automated solution include those operators who are already performing this process manually. Together with the increased capacity, these are good arguments that one can keep today's employees while increasing sorting capacity.

Natural next steps is a 3D digital manufacturing simulation (REF). A detailed simulation of the automated process will further strengthen the value of the results, and if not, it can reveal possible errors or deficient assumptions. Building a test case of the process, a prototype, will also be a further option. By using existing parts from the pallet sorting robot, it is possible to see what can be reused. It will also be interesting to see if the available software can be reused, and to what extent it needs to be rewritten.

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