Effective Capacity Solutions for Resource Denmark's Sorting Plant

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Synopsis

The theme of this master thesis in Operations and Supply Chain Management is to effectively implement solutions to create the expected capacity in the Outbound Department of Resource Denmark.

The initial analysis of the project analyses whether the departmental capacity can reach the expected capacity set by the automated sorting system. Based on this analysis, it is evident that the Inbound Department reaches the expected capacity, while the Outbound Department does not and will therefore be the bottleneck of the sorting capacity of the plant.

Based on this identification of insufficient capacity, four alternative methods are identified. In collaboration with Resource Denmark, these four alternatives are ranked with relevant criteria using the AHP and TOPSIS methods, where the *UWUK* alternative is presented as the best option. With the use of the current three workers in the Outbound Department, the *UWUK* -machine ensures the sorting plant sets the capacity constraint, and not the Outbound Department

By signing this document, the author confirms responsibility for all contents of this paper.

This project is written by a fourth-semester student from Aalborg University. The author is grateful for the guidance, assistance, and counselling from the supervisor Kjeld Nielsen. Additionally, the author wishes to express gratitude to the Plant Director, Operation Manager, and Traceability Manager at Resource Denmark.
Lastly, a big thanks to the author's family and friends, who have motivated and helped finish the project successfully, despite the recent sad and unforeseen passing of the author's father.

The reference method used for this project is the Harvard method.
An example of the Harvard method (Source, Year).

The currency used in this project is DKK.
This project has used period (.) as decimals and commas (,) as thousand's separator. *This is an example of one thousand: 1,000.00.*

Aalborg university, 31. May 2024

Resumé

Dette projekt tager udgangspunkt i en analyse af mangel på kapacitet i den udgående afdeling af Resource Denmark. Denne problemstilling blev etableret i samarbejde med samarbejdsvirksomheden. Projektet formulerer en initierende problemformulering, der fokuserer på en analyser den aktuelle kapacitet af både den indgående og udgående afdeling. Dette er afgørende for at identificere problemets omfang. Denne analyse tager udgangspunkt i empirisk data for at basere kapacitetsanalysen ud fra reelle cyklustider. Det konkluderes, at de indgående afdelingens medarbejder var i stand til at håndtere og indsætte, det forventede antal tons i anlægget, mens den udgående afdelings medarbejder ikke havde tilstrækkeligt kapacitet til at håndtere det forventede antal baller, som kommer ud af anlægget.
Baseret på denne konklusion blev en problemformulering udarbejdet med fokus på at implementere en løsning til denne afdeling så der er kapacitet nok til at kunne håndtere de forventede antal baller.

Problemanalysen identificerede indledningsvist hvilke af processerne i den udgående afdeling der skulle ændres, baseret på de potentielle risikoområder, som hver proces indeholder. Ud fra denne analyse viste det sig, at proces 20, som er den eneste proces i denne afdeling, der har kapacitet nok til at håndtere alle ballerne i denne afdeling, indeholder flest potentielle risikoområder. Baseret på denne analyse blev tre potentielle kunder interviewet for at kunne afgøre, hvilke data der er nødvendige for dem, ved modtagelsen af en balle, eftersom dette er hovedformålet i proces 20. På baggrund af kundernes datakrav, blev fire alternative metoder identificeret igennem intern og ekstern kilder. I samarbejde med virksomheden blev kriterierne for sammenligningsfaktorerne mellem de alternative metoder fastlagt.
Vægten af disse sammenligningsfaktorer blev afgjort ved hjælp af AHP-metoden: Pris (7%), Antal risikoområder (38%), Ekstra træning (3%), Mulighed for at omfordele kapacitet (34%), Sorteringsforsinkelse (12%), og Medarbejdertilfredshed (6%).

Ved brug af TOPSIS-metoden blev disse alternativer rangeret, hvor *UWUK* -alternativet fremstod som den bedste mulighed, efterfulgt af Udstyr-opgraderinger. For disse to alternativer blev en kapacitets- og finansiel analyse gennemført, hvor *UWUK* -alternativet viste sig at være den bedste mulighed for Ressource Denmarks udgående afdeling. Ved at allokere to

medarbejdere til proces 30 & 40 og én medarbejder til proces 50, vil afdelingen kunne håndtere alle baller, som kommer ud fra sorteringsanlægget. Med en investering på omtrent 3 millioner DKK vil virksomheden nå break-even-punktet efter at have håndteret og solgt cirka 8.000 baller.

Den overstående kapacitetsanalyse blev valideret ved brug af en simulation, der påviste, at med implementeringen af dette alternativ og dets respektive cyklustid vil denne afdeling kunne håndtere det forventede antal baller, som kommer ud af anlægget.

Abbreviations

Abbreviation	Full word
AHP	Analytic Hierarchy Process
Approx.	Approximately
BC	Business Central
BEP	Break Even Point
CR	Consistency Ratio
DKK	Danish Krone
ERP	Enterprise Resource Planning
FMEA	Failure Mode and Effect Analysis
HDPE	High-Density Polyethylene
IBD	Inbound Department
LDPE	Low-Density Polyethylene
MCDM	Multi-Criteria Decision Making
NPV	Net Present Value
Nr	Number
OBD	Outbound Department
P10	Process 10
P20	Process 20
P30	Process 30
P40	Process 40
P50	Process 50
PET	Polyethylene Terephthalate
PFC	Process Flow Chart
PFMEA	Process Failure Mode and Effect Analysis
PP	Polypropylene
PS	Polystyrene
PVC	Polyvinyl Chloride
RFID	Radio-Frequency Identification
RPN	Risk Priority Number
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
UWUK	Unotech Weighing Unotech Marking
VOC	Voice of Customer

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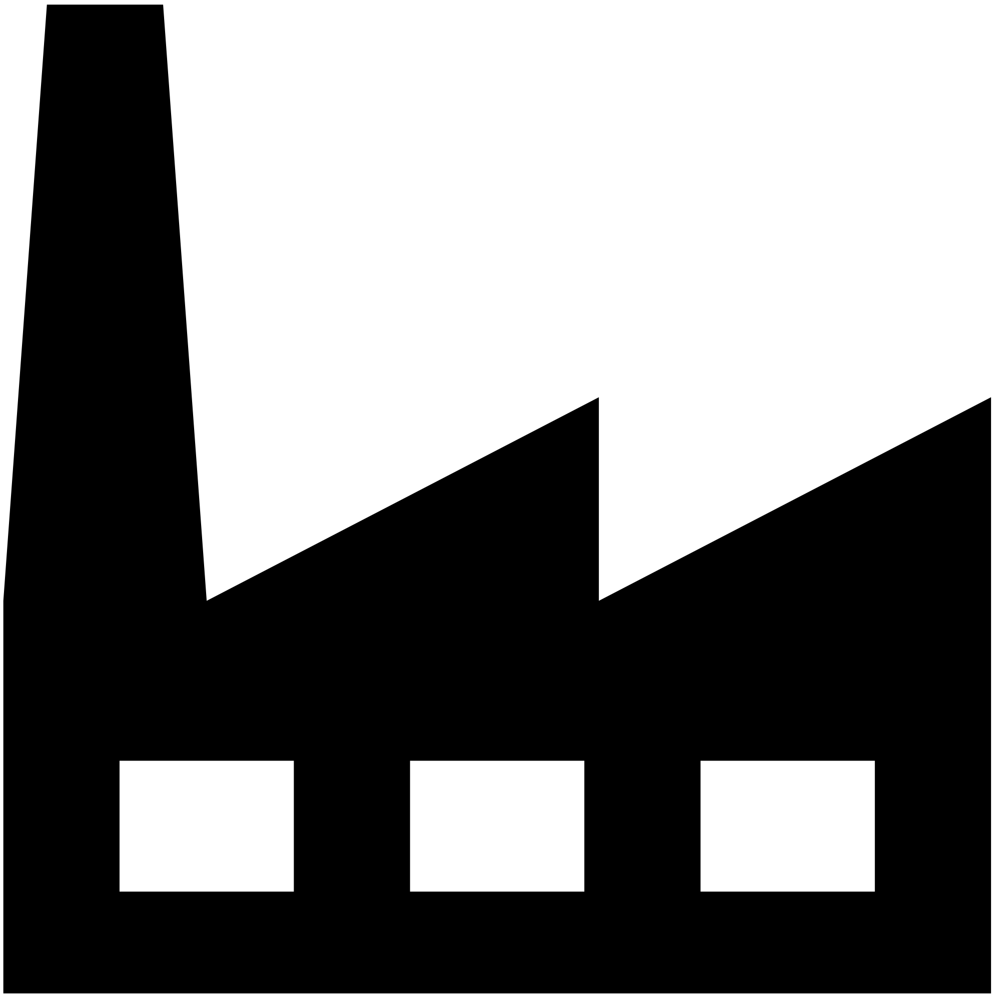


Chapter 1: Company Introduction

1.1 Introduction to Chapter 1

This chatper will introduce Resource Denmark along with its role in the recycling industry, their vision for the future, and describe the issues identified in collaboration with the company.

1.2 Plastic consumption in Europe

The production and management of plastic in Europe present a significant environmental challenge. In 1950, 1.5 million tons of plastic were produced worldwide, increasing to approx. 400 million tons globally by 2021 (Plastic Europe, 2022) (European Parliament, 2018). Europe accounts for about 14% of this total in 2021. Despite the high production rate, only 10% of Europe's plastic is recycled, with the remainder being fossil-based (Plastic Europe, 2022). This discrepancy underscores the need for improved recycling efforts in today's modern landscape. Resource Denmark aims to address this issue by increasing the use of post-consumer recycled plastic and reducing reliance on fossil-based plastics (director, 2024).

1.3 Resource Denmark

Resource Denmark, owned by Erazero and Quantafuel, is the first large-scale sorting plant in Denmark (Resource Denmark, 2024) (director, 2024). Located in Esbjerg, the plant sorts household plastic waste to increase the use of post-consumer plastic for new products. The plant uses an advanced automated sorting system, which is programmed to sort High-density polyethylene (HDPE), Low-density polyethylene (LDPE), Polypropylene (PP), Polyethylene terephthalate (PET), Polystyrene (PS), and Tetra (Resource Denmark, 2024) (Eggersmann, 2024). The plant commenced operations in January 2024 with the first mixed plastic bale inserted into the sorting plant.

In Figure 1, the value chain for the company is described.

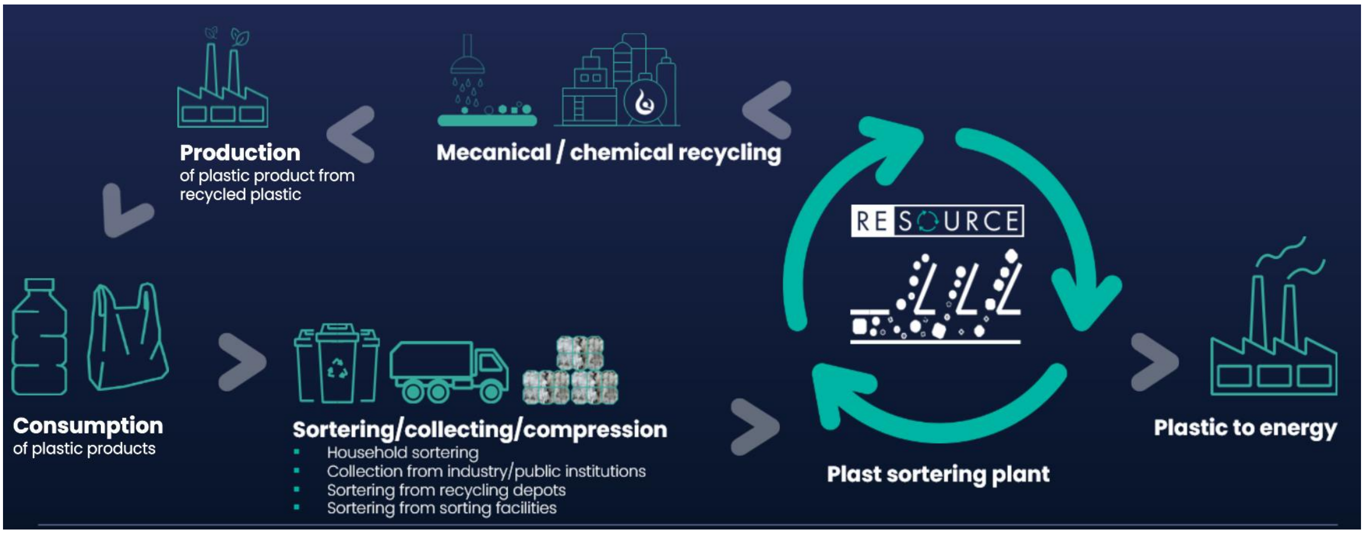


Figure 1: Value chain of Resource Denmark (director, 2024)

The value chain starts with households sorting all their plastic waste into one bin, which is collected by private companies, who are hired by the municipality. These private companies compress the garbage within the bin into bales and transport the compressed bales to plastic sorting companies. Resource Denmark, being a plastic sorting company, receives the compressed bales and sorts the plastic waste into the above-mentioned plastic types. The sorted plastic types and Tetra get compressed into bales and are sold to customers, who have either a mechanical or a chemical recycling plant. Both the mechanical and chemical recycling plants transform the sorted plastic into new plastic granulate, which is then sold to plastic manufacturers, who can use the consumed plastic and turn it into new plastic products (Chemistryviews, 2024) (director, 2024). These new products are then sold to households and can re-enter the whole recycling process if the quality of the plastic is suitable for recycling (Resource Denmark, 2024).

1.4 Sorting capacity

The automated sorting system, supplied by Eggersmann, can process 27 tons/hour, translating to an annual sorting capacity of 160,000 tons at full operation without any constraints (Eggersmann, 2024).

The Plant Director of Resource Denmark has set the goal of the plant to operate with an 80% efficiency level, using an eight-hour workday per shift (director, 2024) (Medarbejder- og Kompetencestyrelsen, 2024). The plant plans to operate with various shift configurations: 1 shift, 2 shifts, 3 shifts, and 3 + weekend shifts.

Based on these configurations, the plant's sorting capacity is detailed in Table 1 (director, 2024) (Eggersmann, 2024). The calculation of Table 1 is available in *Appendix 1: Calculation of sorting plant's capacity.*

1 Shift setup

		Mon	Tue	Wed	Thu	Fri	Week	Month	Year
Day	hours	7,5	7,5	7,5	7,5	7	37,0	160	1924
Planned maint./meetings	hours	4	0,5	0,5	0,5	0,5	6,0	26	312
Sorting	hours	3,5	7,0	7,0	7,0	6,5	31,0	134	1612
Efficient sorting	hours	2,8	5,6	5,6	5,6	5,2	24,8	107	1290
Sorting capacity	**tons**	**76**	**151**	**151**	**151**	**140**	**670**	**2902**	**34819**

2 Shift setup

		Mon	Tue	Wed	Thu	Fri	Week	Month	Year
Day	hours	7,5	7,5	7,5	7,5	7	37,0	160	1924
Evening	hours	7	7	7	7	6	34,0	147	1768
Planned maint./meetings	hours	4	1	1	1	3	10,0	43	520
Sorting	hours	10,5	13,5	13,5	13,5	10,0	61,0	264	3172
Efficient sorting	hours	8,4	10,8	10,8	10,8	8,0	48,8	211	2538
Sorting capacity	**tons**	**227**	**292**	**292**	**292**	**216**	**1318**	**5710**	**68515**

3 Shift setup

		Mon	Tue	Wed	Thu	Fri	Week	Month	Year
Day	hours	7,5	7,5	7,5	7,5	7	37,0	160	1924
Evening	hours	7	7	7	7	6	34,0	147	1768
Night	hours	7	7	7	7	4	32	139	1664
Planned maint./meetings	hours	4	1,5	1,5	1,5	1,5	10	43	520
Sorting	hours	17,5	20,0	20,0	20,0	15,5	93,0	403	4836
Efficient sorting	hours	14,0	16,0	16,0	16,0	12,4	74,4	322	3869
Sorting capacity	**tons**	**378**	**432**	**432**	**432**	**335**	**2009**	**8705**	**104458**

3 Shift setup + weekendshift

		Mon	Tue	Wed	Thu	Fri	Sat	Sun	Week	Month	Year
Day	hours	7,5	7,5	7,5	7,5	7			37,0	160	1924
Evening	hours	7	7	7	7	6			34,0	147	1768
Night	hours	7	7	7	7	4			32	139	1664
Weekendshift	hours						12	12	12	52	624
Sorting	hours	17,5	20,0	20,0	20,0	15,5	10,0	10,0	93,0	403	4836
Efficient sorting	hours	14,0	16,0	16,0	16,0	12,4	8,0	8,0	83,7	363	4352
Sorting capacity	**tons**	**378**	**432**	**432**	**432**	**335**	**216**	**216**	**2441**	**10577**	**126922**

Table 1: Sorting plants capacity (tons) during 1, 2, 3, 3 + weekend shifts (director, 2024)

As displayed in Table 1, operating with 1 shift, the sorting plant is expected to sort approx. 35,000 tons of mixed plastic annually. The annual sorting capacity of the plant nearly doubles to 69,000 tons, as an additional shift is incorporated. Operating with 3 shifts, results in a sorting capacity of approx.105,000 tons per year, and lastly including weekend shifts increases the maximum sorting capacity of the plant to approx. 130,000 tons per year.

Since operations commenced in January 2024, the plant is currently undergoing the hot commissioning phase, testing the functionality of the sorting plant with mixed plastic bales

(Ideematec, 2024) (Manager O. , 2024). This phase includes machine downtime to calibrate and test the equipment, preventing the plant from reaching the sorting capacity calculated in Table 1.

The stakeholders at Resource Denmark have stated that the automated sorting system's capacity should be fully utilized in the plant's sorting process (Manager O. , 2024) (director, 2024).

1.5 Current state of Resource Denmark

Resource Denmark has currently employed 23 workers: 9 white-collar workers and 14 blue-collar workers (Resource Denmark, 2024). Due to the lack of time and latest knowledge within the operations and supply chain management field, Resource Denmark has agreed to collaborate with Aalborg University to analyse their current processes (Manager O. , 2024) (director, 2024).

Currently, all processes related to bale handling are performed manually. Since January 2024, the emphasis has been on initiating the sorting process and conducting the hot commissioning of the automated sorting plant (Manager O. , 2024). Currently only Finnish plastic waste is sorted by the plant, as this is the available plastic waste during the hot commissioning phase (Resource Denmark, 2024) (Manager T. , 2024).

The Operations Manager at Resource Denmark has expressed the long-term vision for the sorting plant's capacity to be the company's primary constraint (Manager O. , 2024). However, observations over the past two months concerns the OBD may instead be the bottleneck, potentially reducing the plant's capacity (Manager O. , 2024) (Resource Denmark, 2024). This concern necessitates the formulation of an initial problem analysis and determining which operation sets the plant's sorting capacity constraint.

Chapter 2: Methodology

2.1 Introduction to Chapter 2

This chapter aims to describe the methodological framework that will be applied to this project and encompassing a description of the research and data collection method.

2.2 Analytical framework

Based on the current stage presentation and expected problem area at Resource Denmark, described in section 1.5, it implies the problem lies within the potential lack of capacity in the OBD. Therefore, the company is interested in analysing the current processes to determine the validity of this assumption. As the problem area presented by the company is very broad and no previous analysis has been conducted concerning the departmental capacity, the scale of the issue is not identified.

Therefore, this project will follow the Double Diamond Process model, as the analytical framework (Design Council, 2005). This framework is a structured approach to problem-solving and innovation. The framework is illustrated in Figure 2.

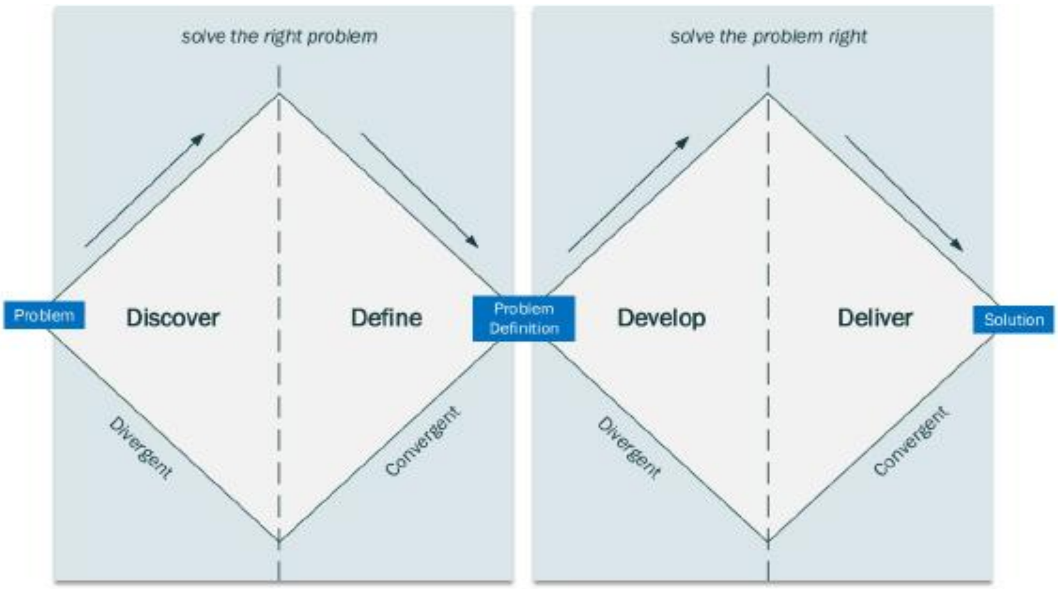


Figure 2: Double diamond method (Design Council, 2005)

The **Discover** phase is the first step of this project, where insights and exploration of the context of the problem are investigated using a broad range perspective, related to the problem area. In the **Define** phase, the insights obtained in the Discover phase are analysed and synthesized to define the core problem clearly. This phase involves framing the problem statement of the problem area and setting clear objectives for the outcome. The **Develop** phase is characterized by generating ideas or potential solutions by applying brainstorming or the development of concepts to solve the defined problem from the Define phase. The final step is **Deliver,** where the most optimal solution is finalized and tested to ensure the solution will solve the defined problem.

The double diamond method is particularly suitable for this project, as it provides a structured and comprehensive approach to problem solving. By thoroughly analyse and define the core and scale of the capacity issues, this method encourages creative generation of multiple alternatives and rigorous testing, ensuring the final recommendation is practically viable and align with Resource Denmark's operational priorities. Utilizing this framework aligns with the project's needs, enhancing the effectiveness of the analysis and robustness of the final recommendation (Design Council, 2005). In Table 2, the application of the framework for this project can be seen.

Phase	Analysis	Model	Data	Method	Reason
Discover	Chapter 3	Mass balance sheet, Capacity analysis	Primary data: Quantitative Qualitative	Empirical data collection Structured, semi-structured, unstructured interview, E-mail	Determine the capacity of Resource Denmark's departments
Define	Chapter 4	Mass balance sheet, capacity analysis	Primary data: Quantitative	Empirical data collection Structured, semi-structured, unstructured interview	Establishing the departments with insufficient capacity to cope with sorting capacity
Develop	Chapter 5	PFMEA, VOC, Brainstorming	Primary data: Quantitative Qualitative Secondary data: Quantitative Qualitative	Empirical data collection, Structured interview External data collection, Structured,	Determine what process will be modified and acquire requirements for the chosen process

				Semi-structured interview, E-mail	
Develop	Chapter 6	MCDM, AHP, TOPSIS,	Primary data: Quantitative Qualitative Secondary data: Quantitative Qualitative	Empirical data collection, Structured, semi-structured, unstructured interview	Mathematically determine which alternative is most Suitable to implement at Resource Denmark
Deliver	Chapter 7	Capacity analysis, Break-even, Simulation	Primary data: Quantitative Secondary data: Quantitative	Empirical data collection, semi-structured, unstructured interview	Validate the alternatives have can create the expected capacity and identify the investment cases

Table 2: Methodology for this project

For this project, comprehensive analyses are conducted to evaluate various aspects related to the operations at Resource Denmark. These analyses include detailed calculations and evaluations, which will referenced in appendices to provide additional information and a deeper understanding of the methodologies and findings. For complete transparency and thorough comprehension, it is recommended to consult the appendices where supplementary data and specific calculations are provided.

2.3 Data handling

Data collected for this project is categorised into primary and secondary data, with both qualitative and quantitative methods, as described in the following sections.

2.3.1 Primary data

The primary data for this project is gathered through observations and data collection made during the project writing period and the author's internship at Resource Denmark.

The primary data is collected through morning meetings, the designing phase of the inbound department, in-depth inventory calculations, and scenario analysis. The interviews conducted during the internship were mainly unstructured, while during the project-writing phase, more structured interviews were conducted. With the use of the primary data collected, this project's recommendation and calculations are deemed more reliable and valid for Resource Denmark.

2.3.2 Secondary data

The secondary data collected for this project consists of both qualitative and quantitative forms. In cases where the secondary data provided inadequate information, primary data were collected.

With the use of secondary data, the methodology applied for this project is verified. Reviewing previous cases and articles using relevant methodologies to conduct similar projects, ensures more validity to this project's final recommendation. For this purpose, the literature reviews are essential, as these reviews guide the project's path to a final recommendation.

2.4 Literature review structure

Literature review is a crucial component in all research endeavours (Jane Webster, 2002). They frequently generate ideas for new studies by identifying research issues, highlighting gaps in the knowledge, and underscoring the importance of addressing them. Serving as a foundational framework, they facilitate a deeper understanding of a field and elucidate the subject under investigation (Jane Webster, 2002). Additionally, by guiding data collection and analysis, literature review contributes to theory development and testing. When conducting meticulously, the literature review can significantly enhance the success of the research project (Jane Webster, 2002).

Consequently, today's researchers are required to devise innovative approaches for conducting literature reviews – a challenge that can be difficult for researchers without experience (Sebastian K. Boell, 2014). This challenge is pronounced during the literature searching phase, where researchers must make critical decisions, such as selecting the appropriate database and sources, and defining search terms (Yair Levy, 2006). To ensure the inclusion of relevant and quality literature, a bibliometric analysis is applied (Naveen Donthu, 2021). Using the number of citations and reads for each reviewed literature, ensures reliability and influence. The bibliometric analysis for all reviewed literature can be found in *Appendix 2: Bibliometric analysis of all reviewed literature.*

Chapter 3 – Discover: Initial Problem Statement & Analysis

3.1 Introduction to Chapter 3

This chapter will formulate an initial problem statement, in collaboration with Resource Denmark, and identify where the sorting process's bottleneck is actually present.

3.2 Initial problem statement

Resource Denmark strives to operate the sorting plant with an 80% efficiency and wants to ensure the OBD does not function as a bottleneck and reducing the sorting plant's capacity.

Currently, there is no dedicated analysis showcasing whether the IBD or OBD has the capacity to cope with the sorting plant's capacity, established in Table 1. Therefore, the initial problem statement will be structured around a thorough examination of both department's capacities and evaluate the scale of this issue.

Based on this, the initial problem statement is constructed as the following:

With the current processes in the IBD and OBD, will Resource Denmark be able to cope with the plant's sorting capacity during the 1, 2, 3, and 3+ weekend shifts?

To answer this initial problem statement, the following sub-questions are constructed:

1) How many plastic bales do both departments need to handle, to cope with the plant's sorting capacity during 1, 2, 3, 3 + weekend shifts?
2) What are the cycle times of all processes within both departments?

3.2.1 Delimitations

Delimitations for this project are clearly defined by the timeframe within which data and information are collected, specifically from the 3rd of September 2023 to the 3rd of March 2024. Any data or information available beyond this point will not be included in this analysis or the findings of the project.

This project will focus on creating effective processes which aim to achieve the goal of creating sufficient capacity to cope with the plant's sorting capacity. Effective processes are described as process that can deliver a consistent output while minimizing the risk of producing faulty output (Nigel Slack, 2016) (Stevenson, Operations Management, 2015). This project will therefore not aim to analyse or improve the efficiency of the worker, as the data is collected during the hot commissioning phase. During this phase Resource Denmark often halted the sorting plant, to test and calibrate sensors and machinery (Resource Denmark, 2024). Therefore, analysing the current efficiency and improving this area, would not represent an accurate result.

3.3 Literature review for initial problem analysis

To conduct the initial problem analysis, it is important to understand the problem and the environment surrounding it. For this analysis, various methods are investigated concerning process analysis. An in-depth literature review can be seen in *Appendix 3: Full literature review for the initial problem analysis.*

The case study from the book "*Operations Management*" by Nigel Slack, Alistair Brandon-Jones, and Robert Johnson presents a detailed analysis of a machine's operational efficiency over a seven-day period (Nigel Slack, 2016). This example meticulously calculates the machine's overall equipment effectiveness by analysing the machine’s capacity and incorporating factors such as loading time, availability-, speed-, and quality losses due to defective parts. In the book “*Operations Management”* by William J. Stevenson an equation is presented to calculate the output rate based on the operator’s time per day and cycle time (Stevenson, Operations Management, 2015). For the case of Resource Denmark, the methodology from both literatures will be modified and applied when analysing the respective department’s capacities. Instead of deducting loading time, speed losses, etc, other factors such as break time, meetings, and maintenance must be deducted from the workers, to demonstrate the efficient sorting time at Resource Denmark. Using the equation William J. Stevenson’s to calculate the output rate, the actual capacities of the workers can be determined for both departments.

To conduct the capacity analysis for each respective worker, it is crucial to collect empirical data related to the process and cycle time. These data will determine the actual capacity of each worker, as the cycle time showcases the number of bales, they can handle daily, which will be measured with the expected capacity, set by the sorting plant (Stevenson, Operations Management, 2015).

In the paper *“Productivity Improvement through Work Sampling”,* Dr James L., Jenkins and Daryl L. Orth use the work sampling method to collect data (Dr. James L. Jenkinds, 2004). This paper applies the work sampling method with a defined sample size to evaluate the amount of productive and non-productive time spent on work. Based on this method, the results showcased that 17% of the time was spent waiting for materials. This paper suggests improving the communication between departments and hereafter colleting new empirical data using the work sampling method to determine the effect of the recommendation. The work sample method is an easy, inexpensive, and quick method to analyse and record process cycle times at random time intervals. Additionally, it is stated that the workers are more apt to cooperate when applying the work sampling method as the workers are not under constant observation. With the use of work sampling, an empirical study can be conducted for the process cycle times in the IBD and OBD of Resource Denmark.

Based on this reviewed literature, the initial problem analysis can now be conducted focusing on calculating the departmental capacity using valid and reliable methodology.

3.4 Initial problem analysis

Using the reviewed literature the departmental capacity can now be determine and compared to the expected capacity to cope with the plant's sorting capacity, shown in Table 1.

3.4.1 Capacity analysis of the IBD

To conduct the evaluation, the expected number of bales this department's workers must handle, and the actual number of bales the workers of the department can handle, must be identified.

3.4.1.1 Number of bales in the IBD

The workers in the IBD are responsible for feeding mixed plastic bales into the sorting plant (Resource Denmark, 2024). In Table 1, the number of tons that the sorting plant expects to sort per shift is showcased. Therefore, the number of bales the IBD must insert into the plant can be calculated by converting the tons from Table 1 into number of bales. The conversion from tons to bales can be seen in Table 3 using an average mixed bale weight of 557 kg in the IBD (Resource Denmark, 2024) (Wastecare, 2024). The calculation for Table 3, is showcased in *Appendix 4: Calculation of number of bales in the IBD.*

Nr of bales in the IBD	Shift 1	Shift 2	Shift 3	Shift 3 + weekend
Number of bales	62,512	123,008	187,536	227,866

Table 3: Expected capacity of workers in the IBD (Resource Denmark, 2024)

Table 3 illustrates the expected capacity the workers must have to cope with the sorting capacity of the plant. Operating with 1 shift, the workers in the IBD must insert approx. 63,000 bales annually into the sorting plant. This increases with each additional shift, resulting in approx. 230,000 bales annually operating with 3+ weekend shifts.

With the expected capacity of the workers in the IBD established, the number of bales the workers in the IBD actually can handle must be determined.

3.4.1.2 Actual capacity of the IBD

To evaluate the IBD worker's actual capacity, an empirical study using the work sampling method is conducted to determine the average cycle times of the processes present in the IBD (Dr. James L. Jenkinds, 2004) (Resource Denmark, 2024). These are illustrated in a Process Flow Chart (PFC) in Figure 3 (American Society for Quality, 2024).

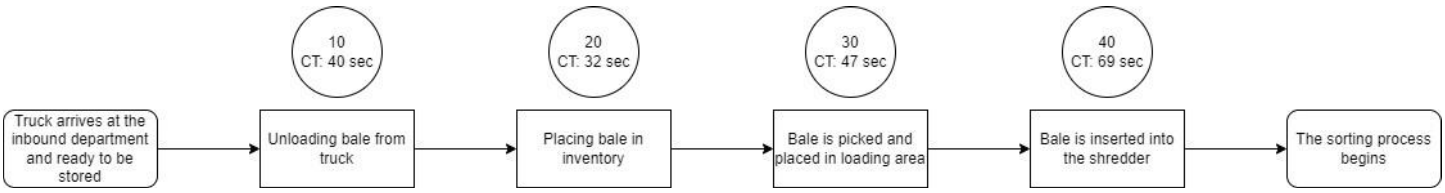


Figure 3: PFC of the IBD (Resource Denmark, 2024) (Dr. James L. Jenkinds, 2004)

Within the IBD, three workers are deployed. The first worker is responsible for process 10 and 20. The second worker is responsible for process 30 and also the cleaning of the department. The last worker is situated inside a crane and operates process 40. The cycle time of worker one is 72 sec, while the cycle time of worker two is 48 sec, and lastly the cycle time of worker three is 69 sec (Resource Denmark, 2024).

Using these cycle times and Resource Denmark's work hour description of eight hours per shift, the actual capacity of the workers can be calculated (Resource Denmark, 2024) (Medarbejder- og Kompetencestyrelsen, 2024). This is calculated using Equation 1 (Stevenson, Operations Management, 2015).

$$Output\ rate\ (bales) = \frac{Efficent\ sorting(sec)}{Workers\ process\ cycle\ time(sec)} \quad (1)$$

The "*Efficient sorting*" factor in Equation 1 represents the total amount of time available per worker to perform their respective task, deducting maintenance, cleaning, lunch breaks, and assuming an 80% work efficiency rate (director, 2024) (EMQ , 2024) (LeanProduction , 2024)

(ManagerPlus, 2024). By dividing this remaining time with the workers cycle time, it is possible to determine the respective worker's output rate of bales.

In Table 4, the capacity analysis for the worker operating process 10 & 20 is illustrated.

1. Shift								
Process 10 + 20	**Unit**	**Mon**	**Tue**	**Wed**	**Thu**	**Fri**	**Week**	**Year**
Day	Sec	27.000	27.000	27.000	27.000	25.200	133.200	6.926.400
Planned maint./meetings	Sec	14.400	1.800	1.800	1.800	1.800	21.600	1.123.200
Sorting	Sec	12.600	25.200	25.200	25.200	23.400	111.600	5.803.200
Efficient sorting (80%)	Sec	10.080	20.160	20.160	20.160	18.720	89.280	4.642.560
Cycle time	Sec	72	72	72	72	72	72	
Sorting capacity	**Bales**	**140**	**280**	**280**	**280**	**260**	**1.240**	**64.480**

Table 4: Capacity analysis for Worker 1 in the IBD operating with 1 shift (Resource Denmark, 2024) (Stevenson, Operations Management, 2015)

Based on Table 4, this worker can process approx. 64,000 bales annually operating with 1 shift. This analysis will be conducted for the two remaining workers in the IBD with their respective cycle times and shift types to determine all three worker's actual capacity in the IBD.

In Table 5, the expected capacity, from Table 3, and the actual capacity of all three workers can be seen. The full analysis has been referenced in *Appendix 5: Calculation of capacity in the IBD* along with the cycle time loggings.

Current vs expected capacity	Shift 1	Shift 2	Shift 3	Shift 3 + weekend
Process 10 + 20				
Worker capacity (bales)	64.480	126.880	193.440	235.040
Expected capacity (bales)	62.512	123.008	187.536	227.866
Difference	**1.968**	**3.872**	**5.904**	**7.174**
Process 30				
Worker capacity (bales)	98.778	170.073	296.334	360.061
Expected capacity (bales)	62.512	123.008	187.536	227.866
Difference	**36.266**	**47.066**	**108.798**	**132.195**
Process 40				
Worker capacity (bales)	67.283	132.397	201.850	245.259
Expected capacity (bales)	62.512	123.008	187.536	227.866
Difference	**4.771**	**9.389**	**14.314**	**17.393**

Table 5: Capacity analysis for all three workers in the IBD (Resource Denmark, 2024) (Stevenson, Operations Management, 2015)

Based on the expected and the worker's actual capacity in the IBD, it can be evaluated the workers hold sufficient capacity to cope with the plant sorting capacity, illustrated in Table 1. Therefore, the IBD will not operate as a bottleneck for the sorting process at Resource Denmark.

It can be seen the worker operating P30, has a high amount of excess capacity compared to the other two workers. This excess capacity is predicted as this worker also has the responsibility for maintaining and cleaning the IBD. The cycle time of cleaning and maintaining has not been included as a process, as there is no specific routine for cleaning yet (Resource Denmark, 2024).

Based on this evaluation, it is now possible to progress to the capacity calculation of the OBD.

3.4.2 Capacity analysis of the OBD

The same methodology of section 3.4.1 will be applied to determine whether the OBD will operate as a bottleneck for Resource Denmark.

3.4.2.1 Number of bales in the OBD

In contrast to the IBD, only sorted plastic bales will enter the OBD (Resource Denmark, 2024). To determine the number of bales that will enter the OBD, it is important to understand the relationship between the input bales and the anticipated output. To determine this relationship, a mass balance sheet will be applied (Yi, 2018) (Eggersmann, 2024). This sheet operates as a comprehensive framework projecting the quantities of bales the sorting plant will generate based on the input of mixed plastic bales from the IBD (Yi, 2018) (Resource Denmark, 2024).

Based on the inventory records of Resource Denmark, a data-derived mass balance sheet is calculated and showcased in Table 6 (Resource Denmark, 2024). The calculation for this can be seen in *Appendix 6: Number of bales entering the OBD.*

Gathered plastic W6,7,8,9	Total amount of bales	Total weight	Percentage of total weight
LDPE	421	284.529	23%
PP	415	186.835	15%
PET	266	161.020	13%
HDPE	229	129.401	11%
PS	38	18.645	2%
Tetra	0	0	10%
Total	1.369	780.430	74%

Table 6: Data-derived mass balance sheet (Resource Denmark, 2024) (Yi, 2018)

Examining the data from Resource Denmark's inventory records reveals that 64% of the total waste input into the sorting plant is effectively sorted into a plastic type. Notably, no Tetra is identified in the sorted output during this period. Questioning this, the Traceability manager from Resource Denmark clarifies that Tetra is absent from the Finnish plastic waste, as it I segregated along with other materials before reaching Resource Denmark (Manager T. , 2024). Despite the absence of Tetra in the current sorting data, this project will utilize the original 10% allocation for Tetra from Eggersmann's theoretical mass balance sheet (Eggersmann, 2024). This theoretical mass balance sheet is also illustrated in *Appendix 6: Number of bales entering the OBD.*

In Table 7, the expected number of bales the sorting plant will present to the OBD is showcased during each respective shift.

Nr of bales in the OBD	Shift 1	Shift 2	Shift 3	Shift 3 + weekend
Number of bales	46,048	90,610	138,143	167,851

Table 7: Expected capacity of workers in the OBD (Resource Denmark, 2024)

The plant's sorting projections indicate that with 1 shift, approx. 46,000 bales are expected to enter the OBD annually. With 3+ weekend shifts, this number increases to 168,000. These figures will operate as the expected capacity for the OBD, as these number of bales must be handled by the workers in the OBD, to cope with the automated plant's sorting capacity.

The expected capacity in the OBD is now determined, and now the actual capacity of the workers will be calculated.

3.4.2.2 Actual capacity in the OBD

As for section 3.4.1.2, a similar empirical study is conducted for the OBD (Dr. James L. Jenkinds, 2004). The insights garnered from this study are represented in a PFC, detailed in Figure 4, with a vertical rendition provided in *Appendix 7: Vertical view of the outbound*.

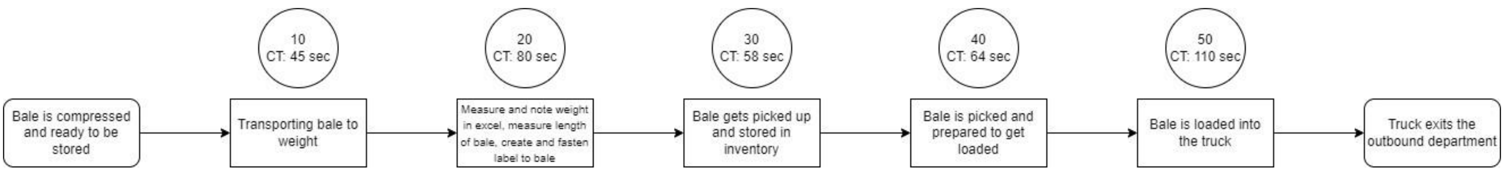


Figure 4: PFC of OBD (Resource Denmark, 2024) (Dr. James L. Jenkinds, 2004)

Within this department, there are four workers deployed. The first worker operates process 10 & 30 (P10 & P30) and has a cycle time of 103 sec while worker two operates process 20 (P20) and has a cycle time of 80 sec. Lastly, worker three operates process 40 & 50 (P40 &

P50) and has a cycle time of 174 sec (Resource Denmark, 2024). The last worker is solely responsible for cleaning and maintaining the department.

Using the same method as in section 3.4.1.2, each worker's actual capacity is determined (Stevenson, Operations Management, 2015) (Nigel Slack, 2016).

In Table 8, the expected capacity, from Table 7, and the actual capacity of the workers are illustrated. The full analysis of the workers in the OBD is explained in *Appendix 8: Calculation of capacity in the OBD*.

Current vs expected capacity	Shift 1	Shift 2	Shift 3	Shift 3 + weekend
Process 10 + 30				
Worker capacity (bales)	45.073	88.693	135.220	164.300
Expected capacity (bales)	46.048	90.610	138.143	167.851
Difference	**- 974**	**- 1.917**	**- 2.923**	**- 3.552**
Process 20				
Worker capacity (bales)	58.032	114.192	174.096	211.536
Expected capacity (bales)	46.048	90.610	138.143	167.851
Difference	**11.984**	**23.582**	**35.953**	**43.685**
Process 40 + 50				
Worker capacity (bales)	26.733	52.603	80.198	97.445
Expected capacity (bales)	46.048	90.610	138.143	167.851
Difference	**- 19.315**	**- 38.007**	**- 57.945**	**- 70.407**

Table 8: Capacity analysis for all three workers in the OBD IBD (Resource Denmark, 2024) (Stevenson, Operations Management, 2015)

According to on Table 8, two out of the three worker's actual capacity is lower than the expected capacity. This results in these two workers cannot cope with the established sorting capacity seen in Table 1 and will be the bottleneck of the sorting process.

The first worker, operating P10 & 30, lacks the capacity to handle approx. 1,000 bales when operating with 1 shift. This deficit is consistent across the other three shifts, signalling a critical need for additional capacity to cope with the plant's sorting capacity.

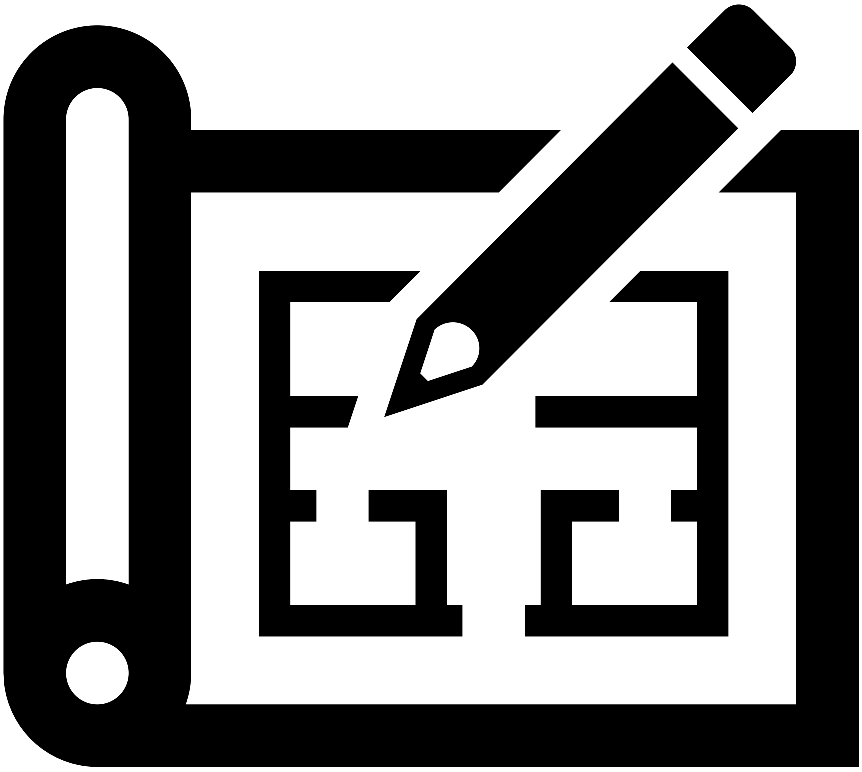
Contrastingly, the second worker, operating P20, possesses the expected capacity during all shifts, and using the excess capacity can process approx. 12,000 additional bales during the 1 shift operation annually. This excess capacity can potentially be reallocated to other processes if required.

The last worker lacks the greatest amount of capacity to cope with the plant sorting capacity. Operating with 1 shift, would result in the inability to handle approx. 19,000 bales annually, which increases to 70,000 bales annually operating with 3 + weekend shifts.

Based on the expected and actual capacity of the workers in both departments, it can be concluded that two out of three workers in the OBD lack the capacity to meet the plant's expected sorting capacity. While the OBD workers lack capacity, the IBD workers actually contain the expected capacity and can therefore cope with the expected number of bales, which must be inserted into the plant.

3.5 Sub-conclusion

Based on the sorting plant's capacity of 27 t/h, the three workers per shift in the IBD have the expected capacity to insert the required number of bales into the sorting plant during all four types of shifts. For the OBD, the expected capacity of the workers is determined by a data-driven mass balance sheet. This sheet showcases that 74% of the inserted mix plastic bale from the IBD workers, will be sorted into a plastic type that enters the OBD. During 1 shift operation, the OBD is expected to handle approx. 46,000 bales. Only one out of the three workers have capacity to cope with the expected sorting capacity. Based on this, the two workers in the OBD will operate as the sorting plant's bottleneck, as they cannot cope with the sorting capacity showcased in Table 1.



Chapter 4 – Define: Problem Statement

4.1 Introduction to Chapter 4

This chapter will formulate a problem statement for this project, based on the conclusions drawn from the initial problem analysis. The methodology for analysing the problem will also be reviewed.

4.2 Problem statement

From the conclusion drawn from the initial problem statement, it is evident that Resource Denmark's OBD lacks the expected capacity to cope with the sorting plant capacity. Consequently, the OBD, instead of the sorting plant, becomes the bottleneck, which does not align with the expected sorting plant's constraint factor set by Resource Denmark.

As a result of this, there is a need for a thorough analysis of the current processes in the OBD. This analysis should encompass all aspects of the department's process, not just those that currently lack the expected capacity.

The problem statement of this project is formulated as the following:

How can the processes within the Outbound Department be modified to achieve the expected capacity and align with the plant's sorting capacity?

To answer this problem statement, the following sub-questions are constructed:

1) Which process in the OBD is most optimal to modify?
2) What attributes are required for the chosen process?
3) What alternative methods can be used to conduct the chosen process?
4) Among the alternatives, which option fits with Resource Denmark's priorities?
5) How can the alternative method cope with the expected number of bales in the OBD?

4.3 Literature review for problem analysis

Using the same methodology as in section 2.3.1, the following literature has been reviewed for this project. As for the initial analysis's literature review, a full review of relevant literature can be seen in *Appendix 9: Full literature reviews for problem analysis.*

D. H. Stamatis has authored the book "*Failure Mode and Effect Analysis FMEA from Theory to Execution",* which gives a thorough description and the application of Failure Mode and Effect Analysis (FMEA) (Stamatis D. , 2003). An FMEA is a method to define, identify, and mitigate known or potential risk areas within a department. Using a Risk Priority Number (RPN) it is possible to prioritize the identified potential risk areas and conduct corrective actions to prevent the risk from happening. The FMEA analysis can be divided into two branches: Process FMEA (PFMEA) and Design FMEA (Stamatis D. , 2003). For this project, the PFMEA is applicable, as this branch focuses on the process of assembling or producing a product. This branch of the FMEA analyses the processes and examines the process steps to determine the RPN values. In the article "*Application of failure mode and effects analysis (FMEA) to improve medication safety in the dispensing process – a study at a teaching hospital, Sri Lanka",* by J. A. L. Anjalee, V. Rutter, and N. R. Samaranayake, the authors utilize FMEA analysis to identify system failures in high-risk processes and ranks the prioritization of possible failure modes using RPN values (J. A. L. Anjalee, 2021). For Resource Denmark, this PFMEA can be applied for each process handling a bale in the OBD. This project will only focus on the initial part of a standard PFMEA analysis, as the second part, involves implementing corrective actions and recalculating a new RPN value. The PFMEA analysis will serve the purpose of identifying which process will be replaced by alternative methods of conducting the respective process, with the main goal of reaching the expected capacity for all workers within the OBD.

In the paper "*Customer involvement in product development*" authored by Lisa Melander, the Voice of Customer (VOC) methodology is described along with how companies can leverage this method in product development (Melander, 2019). The author concludes the analysis of VOC application in product development, that this method is a strategic and structured method to include customers during the development phase. This methodology can be applied to identify which requirements the customers have for packing and preparing a bale. As Resource Denmark does not have experienced workers within this field, conducting an empirical study can ensure the process of handling a bale and preparing it for the customers, can be executed effectively. By using the customer, it is possible to determine if any requirements are needed when handling a bale, which will be used to identify alternative methods of conducting the chosen process.

To evaluate alternative methods of conducting the chosen process, Jitesh J. Thakkar has authored the book "*Multi-Criteria Decision Making* "(MCDM) (Thakkar, 2021). This book introduces the concept of MCDM along with techniques that can be applied to rank alternatives. Thakkar explains how in recent decades a noticeable trend of successful integration of MCDM techniques has been, which are now commonly employed. Successful integration of two techniques can be seen in the case study "*Combining AHP and TOPSIS method for logistics hub selection"* by Apichat Sopadang and Ruth Banomyong (Apichat Sopadang, 2016). This case study aims to propose the optimal location of their new country-level logistic hub. Using the Analytical Hierarchy Process (AHP), the authors effectively assign weights to the selected criteria. With the use of four steps and calculation of the Consistency Ratio (CR), the authors successfully converted both quantitative and qualitative performances to determine a weight for each criterion, which resulted in an acceptable CR of 0.08. With the criteria and weights determined, the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method is applied to identify the country that most closely aligns with the ideal value for each criterion. Based on the combination of both MCDM methods, the TOPSIS concludes that Thailand is the optimal country to be considered as a logistics hub. Another study written by Ming-Chyuan Lin, Chen-Cheng Wang, Ming-Shi Chen, and C. Alec Chang demonstrates the appliance of AHP and TOPSIS in their paper "*Using AHP and TOPSIS approaches in customer-driven product design process*" (Ming-Chyuan Lin, 2007). This paper integrates the two MCDM techniques to create a customer-driven product design. The AHP method is applied to assist designers in identifying customer needs and preferences, while the TOPSIS method is employed to identify the most competitive design alternative for further detailed design. Combining these two techniques allows to efficiently generate a suitable design alternative for the personal digital assistant. For this project, the steps derived from MCDM will be applied, along with the framework from the case "*Combining AHP and TOPSIS method for logistics hub selection"*. This methodology allows applying quantitative and qualitative data to the determination of each criterion's weight, which is used in the TOPSIS analysis to rank the identified alternatives. By incorporating qualitative data from both white- and blue-collar workers, it becomes feasible to allocate objective and realistic weights to the selected criteria. Applying both the worker's point of view and historical experience would build a good fundamental for the AHP analysis and weight determination.

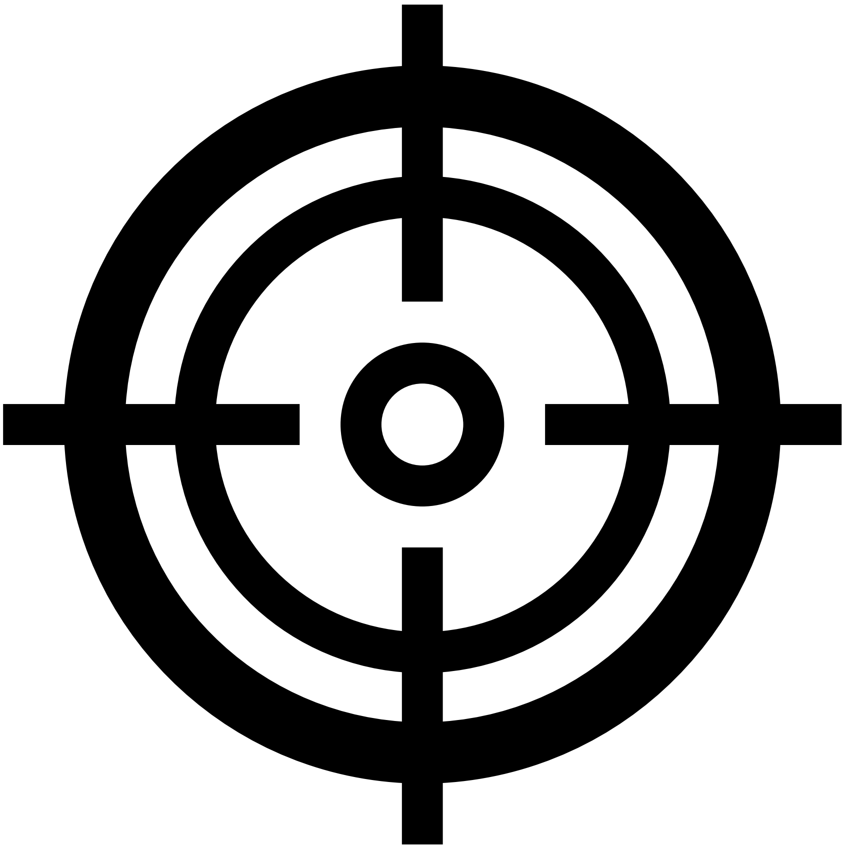
To choose which criteria will be relevant for this project, a case study on supplier selection for aerospace is reviewed. The authors Aksel Rasmussen, Haris Sabic, Subrata Saha, and Izabela Ewa Nielsen, have analysed the optimal criteria to measure performance by analysing 49 articles (Aksel Rasmussen, 2022). Using the research of relevant criteria based on the 49 articles, this project, in alignment with Resource Denmark, has chosen to prioritize the application of criteria that are relevant to the OBD, rather than selecting the most used criteria from this case study. This is because this project's alternative is not concerning supplier selection, but alternative methods to conduct a process. Even though this study is based on supplier selection, it is possible to draw some similarities to both cases, such as cost. Therefore, based on this study, the fitting criteria, in collaboration with Resource Denmark, will be chosen, where the AHP method will determine the weight of each criterion.

When proposing an investment project for management, it is crucial to incorporate an investment analysis. Nicholas H. Johnson and Barry D. Solomon have authored the article "*A Net-Present Value Analysis for a Wind Turbine Purchase at a Small US College*" where they evaluate the financial investment of implementing a single large-scale turbine for a university (Nicholas H. Johnson, 2010). The stakeholders of the university are interested in two time periods, to understand the expected investment profitability. The first alternative is a 20-year scenario and the second is a 30-year scenario. With the use of a Net Present Value (NPV) analysis, it is possible for the authors to determine if the project provide a positive NPV within both time frame. A positive NPV indicates the investment exceeds the anticipated cost of the implementation. To conduct an NPV analysis, the initial investment cost, ongoing operational cost, revenue, time period, and discount rate are required. Since Resource Denmark does not have all the data available, an NPV analysis cannot be performed.

In the article "*How much behaviour change is required for the investment in cycling infrastructure to be sustainable? A break-even analysis*" by Paolo Candio and Emma Frew, the authors investigate how many numbers of regular cyclists are required to break even the investment of 12.8 million dollars for new machinery (Paolo Candio, 2022). Using this analysis, the authors were able to present the stakeholders with a minimum number of regular cyclists to earn back the investment. The article concluded there was a need for 1,604 additional daily cyclists to earn back the initial investment of 12.8 million dollars. As the NPV analysis cannot be conducted for Resource Denmark, calculating the break-even of the identified alternatives would present a beneficial financial measurement for the stakeholders at Resource Denmark.

In the article "*SimPy: Simulating Real-World Processes with Python*", written by Jaya Zhané, the author describes the method to simulate real-world processes using the programming language Phyton (Realpython, 2024). Using this program, it is possible to set up a simulation environment, define processes, requirements, and run the simulation to verify or debunk an assumption. Using this programming language, it is possible to validate the capacity analysis for the scenarios. Through cross-validation, the capacity calculation ensures that the final recommendation is based on valid arguments and calculations.

Based on the reviewed literature, relevant methods and analyses have been identified and tailored to fit the specific problem analysis for this project. These insights will be used to proceed with the problem analysis, in the following chapters.



Chapter 5 – Develop: Process Selection and Requirement Identification

5.1 Introduction to Chapter 5

This chapter will analyse which process within the OBD will be selected for modification to reach the expected capacity to cope with the sorting plant. Based on the selected process, requirements for the process will be established according to customer preferences.

5.2 Selection of process in the OBD

Chapter three concluded that the two workers operating P10 & P30 and P40 & P50 lack the expected amount of capacity. Hence, modifications must be implemented in the OBD to reach the expected amount of capacity, outlined in Table 7, so the OBD will not be the bottleneck for the sorting process.

The upper-level management at Resource Denmark has stated that the highest priority is to create a safe work environment and conduct processes effectively (Resource Denmark, 2024). Given the high-risk materials and machinery managed by Resource Denmark, it is crucial to ensure proper handling for the safety of the workers (Wastecare, 2024). Additionally, as a newly established company, it is imperative to gain positive customer satisfaction (director, 2024) (Survicate, 2024). Failing to deliver materials with the required data to initial customers could impact the company's future performance (McKinsey & Company, 2016).

Given the emphasis on safety and process effectiveness, a Process Failure Modes and Effect Analysis (PFMEA) will be conducted to determine which process is optimal to modify based on process current risks and ineffectiveness (George Pantazopoulos, 2005) (Stamatis D. , 2003).

5.2.1 Identification of potential risk areas

A PMFEA provides an exhaustive framework for identifying and assessing potential risk areas within departmental processes (Stamatis D. , 2003). This detailed analysis is crucial for recognizing significant risks and process ineffectiveness. Through PFMEA, it is possible to identify which current process in the OBD presents the highest risk areas using the Risk Priority Number (RPN) (Stamatis D. , 2003).

The PFMEA assigns an RPN value to all identified risk areas based on three factors: Severity, Occurrence, and Detection. The factors will be evaluated using a scale from 1-10, which is illustrated in *Appendix 10: Detailed analysis of OBD's PFMEA* (Stamatis D. , 2003). The higher the RPN value the more urgent need for intervention to adjust or change the process (J. A. L. Anjalee, 2021).

The RPN values in the PFMEA analysis will be based on an empirical study comprising onsite observations, expert judgements, and unstructured interviews (Resource Denmark, 2024) (Stamatis D. , 2003).

In a standard PFMEA, all potential risk areas are listed along with the RPN values. Corrective actions can be brainstormed and based on the actions, a new RPN value is determined (J. A. L. Anjalee, 2021) (Ramkrishna Bharsakade, 2023) (Stamatis D. , 2003). However, the focus of this analysis is solely on identifying which current process contains the highest number of potential risk areas, therefore only the first part of the PFMEA will be conducted.

In Table 9, the PFMEA for the OBD is conducted.

Current process 20

Process	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Causes(s)/Mechanism(s) of Failures	Occur	Current Process Control	Detection	RPN
10	Clash with cleaning worker at balers	Injuries to the cleaning worker	10	Failure of forklift sensors and lack of awareness	2	Eye contact and walkie talkie	6	120
10	Clash with forklift nr. 2	Damage to forklift	9	Failure of forklift sensors and lack of awareness	2	Eye contact and walkie talkie	6	108
10	Bales get dropped on weight	Misinterpretation of bales positioning	1	Failure to identify bales and weight position cause of limited vision	3	Eye contact and walkie talkie	7	21
20	Wrongfull notation of weight	Inaccurate data of inventory	4	Stressfull situations when operating with high pace human errors can occur	4	None	9	144
20	Wrong identification of plastic type	Customer does not recieve right plastic type	8	Stressfull situations when operating with high pace human errors can occur	3	None	7	168
20	Sticks the wrong label on bale	Customer does not recieve right plastic type	8	Stressfull situations when operating with high pace human errors can occur	3	None	7	168
20	Label falls of plastic bale	Unable to identify the weight and type of plastic without furthur inspection	5	The glue from the label is not strong enough	5	Worker finds a flat surfase to attatch the label	5	125
20	Excel sheet with data crashes	Loss of inventory records	8	Laptop experience overload and crashes	2	None	5	80
20	Ergonomic damage to worker	Ressource Denmark responsible for insurance	7	Not using the right equipment for standing and sitting	2	None	2	28
30	Clamps on to both bale and weight	Weight gets damaged	1	Unable to identify the positioning of bale and weight accuratly	3	Eye contact and walkie talkie	7	21
30	Clash with forklift nr. 2	Damage to forklift	9	Failure of forklift sensors and lack of awareness	2	Eye contact and walkie talkie	6	108
40	Clash with forklift nr. 2	Damage to forklift	9	Failure of forklift sensors and lack of awarenes	2	Eye contact and walkie talki	6	108
50	Failure of placing the bales in the right position	Damage to truck and workers	10	Losing overveiw of previous placement of bales inside the truck	2	None	6	120
50	Pressuring the bales to hard inside the truck and the bales fall out on the other side	Damage to truck and workers	10	Losing overveiw of previous placement of bales	2	None	5	100
50	Clash with forklift nr. 2	Damage to forklift	9	Failure of forklift sensors and lack of awarenes	2	Eye contact and walkie talki	6	108

Table 9: PFMEA analysis of processes in the OBD (J. A. L. Anjalee, 2021) (Stamatis D. H., 2003)

The PFMEA analysis identifies 15 potential risk areas in the OBD (Resource Denmark, 2024). A full analysis of the PFMEA is illustrated in *Appendix 10: Detailed analysis of OBD's PFMEA.* The number of potential risk areas and RPN values for each process in the OBD are the following:

- Process 10: 3 risk areas – RPN: 249
- Process 20: 6 risk areas – RPN: 729
- Process 40: 2 risk areas – RPN: 108
- Process 50: 3 risk areas – RPN: 328

Based on the PFMEA analysis, P20 includes both the highest number of potential risk areas and RPN value.

The risk with the highest RPN value of 168 is "*Wrong identification of plastic-type*" and "*Sticks the wrong label on bale"* in P20. Both scenarios have a severity value of eight because providing a plastic bale with incorrect data could cause significant disruption for the customer. Plastic recycling processes vary depending on the type of plastic (director, 2024) (Chemistryviews, 2024). The likelihood of these scenarios occurring is low, as the worker operating P20 gains more experience in identifying plastic types and can quickly determine which label corresponds to which bale (Resource Denmark, 2024). Lastly, the detection is low, as it would require a random visual inspection to detect this risk.

The second highest RPN value of 144, is also in P20. This risk area is "*Wrongful notation of weight".* The severity of this risk is minor, as a single wrongful notation of a bale weight will only cause a minor disruption for the customer. The occurrence is low, as the risk only is expected to occur during stressful situations. Lastly, the detection is low, as there is no process control to determine if the noted bale weight is correct.

Despite P20's current capacity reaching the expected capacity, as shown in Table 8, the high amount of manual work and lack of control systems, significantly increase the likelihood of the potential risk becoming actual risks. The analysis reveals this process consists of the three highest RPN values and five out of the six risk areas stem from manual activities.

In light of these findings, P20 emerges as the primary candidate for modification, aiming to achieve the expected capacity for all workers in the OBD.

5.3 P20 requirements

Before searching for alternative methods of conducting P20, it is important to comprehend the significance of this process and establish requirements. This will be done by analysing the activities of P20. Based on empirical study the activities of P20 are showcased in Figure 5.

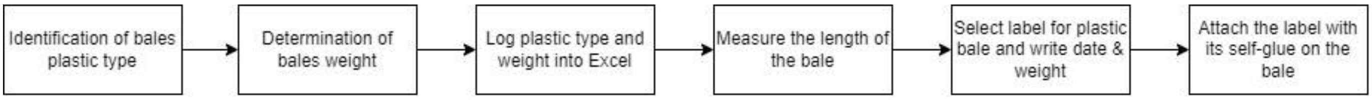


Figure 5: Activities of process 20 (Resource Denmark, 2024)

Figure 5 illustrates, P20 comprises six activities. These activities mainly focus on logging the respective bale's data into Excel and visualising it on the bale. Resource Denmark uses Excel as their inventory system and has preprinted A4 labels for each plastic type (Resource Denmark, 2024). A layout of the current OBD and the preprinted labels are illustrated in *Appendix 11: Layout of OBD and Plastic type label.*

The data that is logged into Excel are the date, weight, length, and plastic type of the respective bale. The data displayed on the bale includes the date, weight, and plastic type. The activity of measuring the length of the bale is temporary, as the current length of the bales is produced inconsistently (Manager T. , 2024). Based on PFC and P20's activities, it can be determined the value of this process, is to log and visualize the respective bales data.

When analysing new methods of conducting P20, it is important to understand which data are relevant for the customers, as logging unimportant data is waste of capacity. The relevant data will serve as a requirement when exploring alternative methods of conducting P20. These requirements will be determined by utilizing the Voice of Customers (VOC).

5.3.1 Voice of Customer (VOC)

VOC is a business strategy term referring to the process of conducting an empirical study, involving the customers (Melander, 2019). With the VOC, the requirements for alternative methods of conducting P20 will be determined by focusing on including value-adding activities. By setting requirements, it will be possible to scope the search for alternative methods.

Three potential customers of Resource Denmark, who have extensive experience in the recycling industry, have been interviewed with the focus on what data are necessary for them when receiving a sorted plastic bale (RC Plast, 2024) (Genplast, 2024) (StenaRecycling, 2024). The full interviews with the three potential customers can be found in *Appendix 12: Interview with potential customers*.

In Figure 6, three boxes are present. Box 1 illustrates data requirements mentioned by all three customers, Box 2 lists requirements mentioned by two out of the three customers, and Box 3 shows requirements mentioned by only one out of the three customers.

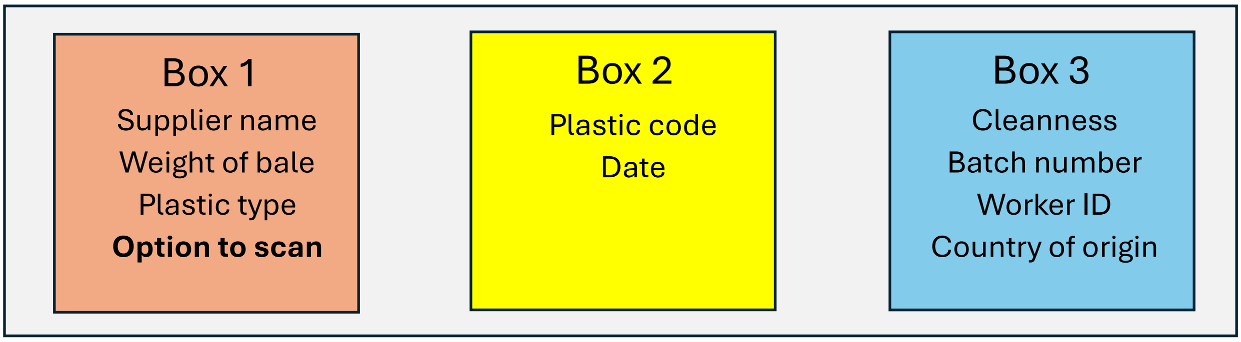


Figure 6: Customer requirements of bale information (RC Plast, 2024) (Genplast, 2024) (StenaRecycling, 2024)

Based on these interviews and the P20's current activities, it is evident that Resource Denmark currently logs and visualises three data points out of the mentioned nine based on Figure 5 & 6. The *"Option to scan*" is not a data point, but rather an alternative method of visualizing the data by digitalizing it. The plastic code is a universal indicator of plastic types and can be seen in *Appendix 13: Universal codes for plastic type.*

The data points listed in Box 1 & 2, will be set as requirements for the new P20, as they are requested by minimum two out of the three customers. Box 3 points will not be set as a requirement, but rather "nice to have" options, as they are only mentioned by one customer (Melander, 2019).

The next chapter of the project will focus on identifying alternative methods of conducting P20 with the requirements set by the potential customers in this chapter.

5.4 Sub-conclusion

Based on the PFMEA, P20 in the OBD is identified as the most optimal candidate for modification. This process currently consists of the highest RPN values in the OBD, highlighting the significant operational and safety risks that necessitate immediate attention to enhance operational safety and process effectiveness. Using empirical data collected through three potential customers, it is determined, when searching for alternative methods of conducting P20, supplier name, weight of the bale, plastic-type, date of the bale, and the universal plastic code must be present on the bale or give the customer an opportunity to scan an object and get access to these data. These requirements will guide the process of identifying alternative methods of conducting P20 while having the ability to showcase these data.

Chapter 6 – Develop: Multi-Criteria Decision Making

6.1 Introduction to Chapter 6

This chapter will identify alternative methods of conducting P20, based on the requirements set in the previous chapter and evaluate the alternatives using relevant criteria aligned with Resource Denmark's priorities.

6.2 Multi-Criteria Decision Making

To achieve the expected capacity, the OBD must implement modifications to the current P20. This modification must have the capability to reallocate sufficient capacity from the current P20 worker to the remaining two workers while providing the required data to the customers established in section 5.3. Thus, it is imperative to analyse different methods of conducting P20, aiming to attain the expected capacity, create a safe working environment, and execute processes effectively (Resource Denmark, 2024).

To conduct such an analysis the Multi-Criteria Decision Making (MCDM) method will be utilized (Thakkar, 2021). This method is ideal when a "one scenario will fit all" solution is not feasible (Thakkar, 2021). This problem appears due to the inclusion of different stakeholders' perspectives and diverse criteria they bring, all of which must be when finding the optimal solution.

The process of MCDM is governed by the following three steps (Apichat Sopadang, 2016) (Thakkar, 2021):

1) **Identifying the relevant alternatives and criteria**

The first step of the MCDM is identifying alternative methods of conducting the current P20 and determining which criteria these alternatives shall be compared by.

2) **Assigning a numerical value to each criterion indicating their respective importance.**

In the second step, the numerical value must be determined for each chosen criterion, which resembles the weight of the criterion. These weights must resemble the long-term vision and priorities of Resource Denmark. Both subjective and objective weights can be applied for each criterion (Thakkar, 2021).

3) **Use a mathematical procedure to analyse the numerical values to determine the ranking of the alternatives.**

The last step includes the final ranking of all identified alternatives, by mathematically calculating the most optimal alternative based on the set criteria and their respective weights.

Now that the MCDM method has been outlined, it is now possible to initiate the first step.

6.2.1 Alternative methods of conducting P20

This section will describe and analyse each identified method of conducting P20, based on the requirement of data visualised on the bale, set in section 5.3.

6.2.1.1 Brainstorming session

To identify alternative methods of conducting process 20, a brainstorming session is held with the Traceability manager at Resource Denmark (Manager T. , 2024).

Based on the requirement, the session concluded with the identification of two alternatives, illustrated in Figure 7.

Alternative 1:
Unotech Weighing Unotech Marking (UWUK)

Alternative 2:
Equipment upgrades

Figure 7: Alternative 1 and 2 (Manager T. , 2024) (Resource Denmark, 2024)

In sections 6.2.1.2 and 6.2.1.3, the following points will be summarized for each alternative:

- Description of the alternative
- PFC of the alternative, if implemented in the OBD
- Key differences between the alternative and current P20
- Price and expected sorting delay by implementing the alternative

6.2.1.2 Unotech Weighing Unotech Marking

In sections 6.2.1.2.1, 6.2.1.2.2, 6.2.1.2.3, and 6.2.1.2.4, the above-mentioned points will be summarized for the Unotech Weighting Unotech Marking (*UWUK).*

6.2.1.2.1 Description of Unotech Weighing Unotech Marking

The *UWUK* is an automated machine developed by Unotech. Unotech also provided the current baler, which is installed in the OBD (Unotech LM Group, 2024).

The *UWUK* is a fully automated weighing and labelling machine, which can be integrated with the Unotech bailer (Unotech LM Group, 2024). By integrating the two machines, it is possible to transfer data of the newly sorted bale from the bailer to the *UWUK* (Unotech LM Group, 2024).

The *UWUK* -machine can weigh and create a label for every sorted bale that enters the OBD. The label can automatically display the following: plastic type, weight, operator, date, specific bale number, energy consumption, plastic code, length, and generate a bar code (Unotech LM Group, 2024). In *Appendix 14: UWUK -machine information*, a visual representation of the *UWUK,* and a product catalogue is presented.

6.2.1.2.2 Process Flow Chart of *UWUK*

Based on the information gathered on the *UWUK,* Figure 8 illustrates the activities of the machine if it were to be implemented in Resource Denmark's OBD.

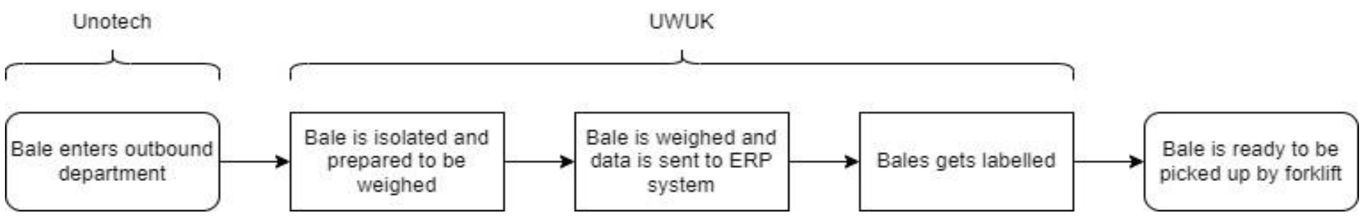


Figure 8: PFC of UWUK (Unotech LM Group, 2024)

If the *UWUK* -machine were to be implemented, P20 would consist of three activities instead of the current six. The process will be fully automated, and bales will enter the OBD having a label that can showcase required data: plastic type, weight, date, plastic code, name, and a barcode for the customer to scan. These data will automatically be registered into Resource Denmark's Enterprise Resource System (ERP) (Unotech LM Group, 2024).

6.2.1.2.3 Key differences in implementing the *UWUK* -machine

By implementing the *UWUK* -machine, P20 will become automated. This would eliminate the need for a dedicated worker to manually identify, log, and visualise the data of the bale. As five out of the six potential risk areas from Table 9 stem from human errors, implementing this solution would eliminate these potential risks. Automating processes reduces error margins by adhering to operation standards, unlike manual methods, which are more prone to errors (Adriana F. Melo, 2022) (ISACA, 2021).

Consequently, eliminating the need for a dedicated P20 worker through automation allows reallocating the current worker's capacity to other processes.

6.2.1.2.4 Price and expected sorting delay

The *UWUK* -machine carries a sales and implementation cost of 1,902,000 DKK (Unotech LM Group, 2024). Implementing this machinery is anticipated to delay the sorting by one week without the need of requiring any additional training for the workers (Unotech LM Group, 2024).

With the key points of this alternative summarized, it is now possible to move on to the second alternative.

6.2.1.3 Equipment upgrades

Opposite to the *UWUK* alternative, implementing *Equipment changes* only adjusts the current P20, rather than changing it. In sections 6.2.1.3.1, 6.2.1.3.2, 6.2.1.3.3, 6.2.1.3.4, and 6.2.1.3.5, the key points will be summarized.

6.2.1.3.1 Description of forklift with weight scales

Resource Denmark is currently using Toyota Triago 80 forklifts in the OBD equipped with clamps to pick up and transport bales (Manager O. , 2024) (Toyota Material Handling, 2024). Currently, on the market, there are clamps with integrated weight scales (Lifttruck, 2024). By using clamps with weight scales, it is possible to weigh each bale when transporting it. This feature can adjust the current process and save transportation time and electricity, by determining the weight by lifting the bale and not transporting it to a weight scale.

It is required to calibrate the weight scale often as this is critical to getting an accurate weight (Manager T. , 2024) (Forklift accessories, 2014). As the scale is a built-in feature for the Toyota forklift, the process of calibrating the scales takes approx. 30 minutes (Forklift accessories, 2014). As noting the weight wrongfully has the second highest RPN value and is an important measurement in terms of regulations set by The Danish Fire Department, it is important to incorporate this calibration each week (Manager O. , 2024) (Sydvestjysk Brandvæsen, 2023).

6.2.1.3.2 Description of Radio Frequency Indicator tags

Moving on to the second upgrade of this alternative, Radio Frequency Indicator (RFID) tags are an alternative option to showcase and log data.

RFID tag is a small device used to track and identify objects using radio waves (Camcode, 2024). This tag can contain data and can be attached or embedded into products, animals, and people (Camcode, 2024) (Quantafuel, 2024). Passive RFID tags are deemed suitable for Resource Denmark's case (Quantafuel, 2024) (Resource Denmark, 2024). These types of tags do not require any power source and draw power from a transmitter when scanned (Techtarget, 2024).

The RFID tag can be strapped to each bale, and with the use of an RFID reader, it is possible to gain data from the respective bale. (Techtarget, 2024) The data logged in the tag can be fully customized, based on Resource Denmark's preferences (Quantafuel, 2024).

6.2.1.2.2 Process Flow Chart of *Equipment upgrades*

As both *Equipment upgrades* are described, a PFC based on a combination of these presents a new list of activities for P20, illustrated in Figure 9.

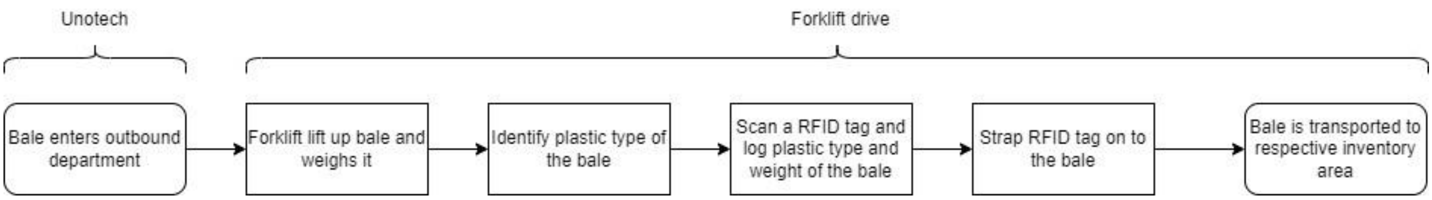


Figure 9: PFC with Equipment upgrades (Quantafuel, 2024)

With these adjustments, there is a total of four processes, compared to the current six. Based on the PFC, these four processes can be executed by the forklift driver. Using the upgraded clamps, the driver can determine the weight of the bale, log the data into a RFID tag, and attach it to the bale, before placing the bale in inventory.

There is still a requirement to manually identify and log the data. By logging the data into an RFID tag, the data of the bale is automatically registered into an Excel sheet, which operates as the inventory record (Quantafuel, 2024) (Resource Denmark, 2024).

6.2.1.2.3 Key differences in implementing the *Equipment upgrades*

The difference between the current method and this alternative lies in how the activities are executed. The activities mostly remain unchanged involving, manual weighing, logging, and visualising the data. However, the new clamps, eliminate the need for a dedicated P20 worker, as the forklift driver can execute all of activities in Figure 9.
With the RFID implementation, the worker is not required to manually log the bale's data into Excel, as the RFID app is internally linked to the Excel sheet (Quantafuel, 2024). This would mitigate some of the potential risk areas associated with manual entry of data.

As this alternative can be performed by the forklift driver, there is no need for a dedicated P20 worker at the weighing station. In contrast to the current procedures, the cycle of the forklift driver's processes will increase because of the addition of the activities of logging data into the RFID tag and attaching it to the bale.

6.2.1.3.4 Price and expected sorting delay

The prices of the *Equipment upgrades* are presented in the following bullet points:

- The clamps with weighing scales have a sales price of 19,250 DKK, not including the installation price (Lifttruck, 2024).
- 1.5 million RFID tags will be sufficient for the next 10 years and have a selling price of 104,000 DKK (Alibaba, 2024) (Quantafuel, 2024).
- An RFID tag reader has a selling price of 20,000 DKK (Link-labs, 2024).

Based on these selling prices the anticipated initial investment required to implement this alternative is approx. 140,000 DKK and does not require any additional training (Resource Denmark, 2024).

These upgrades would not delay the sorting process, as the software and hardware can be implemented concurrently with the execution of the current processes (Quantafuel, 2024) (Resource Denmark, 2024).

As these alternatives were concluded from the internal brainstorming session at Resource Denmark, additional analysis will be conducted focusing on other alternatives in the following sections. This ensures the analysis of alternatives incorporates both subjective and objective recommendations. The following two alternatives are recommended by external sources who are familiar with Resource Denmark's current stage, future vision, and industry context (Manager P. , 2024).

Using the input from external sources, the following two alternatives will be analysed:

Alternative 3: Business Central by Vektus

Alternative 4: Overhead crane

Figure 10: Alternative 3 & 4 (Manager P. , 2024)

These two new alternatives will be analysed using the same parameters mentioned in section 6.2.1.1.

6.2.1.4 Business Central by Vektus

During the empirical study to set the requirements for the new P20, a potential customer of Resource Denmark recommended investing in the ERP solution Business Central (BC) by Vektus (Manager P. , 2024).

6.2.1.4.1 Description of Business Central

BC is a software developed by Microsoft that operates as an ERP system and can be used for various purposes such as finance, inventory management, production, etc (Microsoft, 2024).

For the OBD, the relevant feature of this software is the inventory management system and its capabilities. This system can store and generate labels with the registered data (Manager P. , 2024) (Microsoft, 2024). While Resource Denmark currently holds a license for Dynamics 365, they have not yet developed this ERP, as it has not been a priority (director, 2024).

Based on the current P20 activities, the Sales Manager from Vektus stated that a *BC* solution with the integration of Tasklet would be the most optimal method of conducting P20 (manager, 2024). Tasklet is a mobile warehousing system that can register data by scanning and directly sending data to the *BC* system (Taskletfactory, 2024) (manager, 2024). This hardware enables the precise logging of data on the bales exiting the OBD. The full interview can be seen in *Appendix 15: Interview with the Sales Manager of Vektus*.

6.2.1.4.2 Process Flow Chart of Business Central

Based on the implementation of *BC* and Tasklet, the list of activities is illustrated in Figure 11. A vertical view of the PFC can be found in *Appendix 16: Vertical view of BC PFC*.

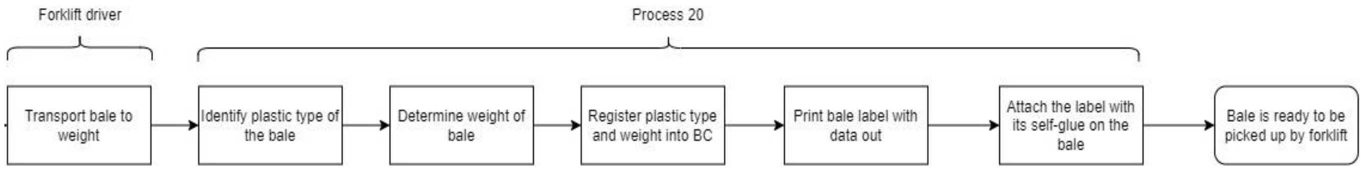


Figure 11: PFC of implementation of BC (manager, 2024) (Microsoft, 2024) (Taskletfactory, 2024)

Figure 11 illustrates, that by implementing this alternative, the P20 will consist of five activities. Comparing these activities to the current P20, they do not differ, except for the measuring the length, which is stated as a temporary activity (Manager T. , 2024).

6.2.1.2.3 Key differences in implementing Business Central

By implementing this alternative, the P20 worker does not need to create the physical labels and manually write the date and weight of the respective bale. With the use of BC, the system has an integrated print option, after having inserted the relevant data of the bale.

Besides this difference, this alternative is similar to the current P20, as a dedicated worker to conduct the activities of P20 is still required and the P10 worker must transport the bale from the bailer to the weight. Based on the requirement of a dedicated worker to conduct P20, the worker cannot reallocate more than the current excess capacity he/she has, showcased in Table 8.

6.2.1.3.4 Price and expected sorting delay

To have access to the inventory management system and its capabilities, the entire ERP system must be set up for Resource Denmark (manager, 2024). This includes configuring customer groups, vendors, prices, inventory, etc., before accessing the system's features. Based on this configuration, an investment of 1,000,000 DKK would be required to establish the *BC* system (manager, 2024).

To ensure all workers can operate these systems, a training period of three days is required and can be done internally by a superuser (manager, 2024).

6.2.1.5 Instalment of Overhead crane

Moving on to the last alternative is installing an *Overhead crane* in the OBD. This alternative is not primarily focused on changing or adjusting P20 but provides a significant opportunity for capacity reallocation.

6.2.1.5.1 Description of *Overhead crane*

An *Overhead crane* is an industrial lifting equipment used to move heavy loads in both vertical and horizontal directions within a restricted area (Mazzella companies, 2024). This machinery is often utilized in manufacturing plants or warehouses, where it is necessary to transport heavy loads safely. *Overhead crane*s are typically designed to meet the customer's specific needs and can vary greatly in terms of capacity, span, lift height, building statics, etc (Mazzella companies, 2024).

The instalment of an *Overhead crane* is not directly related to P20 activities, but rather a change of equipment for the department. Its purpose in the OBD is to transport bales from the baler to the P20 working station and lastly into the inventory areas. These are the processes do not have the expected capacity, as illustrated in Table 8.

6.2.1.5.2 Process Flow Chart of *Overhead crane*

In Figure 12 the activities of P20 are illustrated if this machinery were to be implemented in the OBD. A vertical view of the PFC can be seen in *Appendix 17: Vertical view of Overhead crane PFC.*

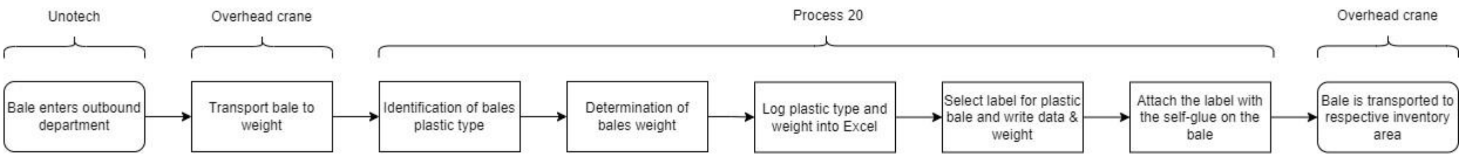


Figure 12: PFC of Overhead crane (Mazzella, 2024)

According to Figure 12, the P20 activities remain unchanged, but the transportation to and from weight differs. This is based on the *Overhead crane*'s purpose is not changing the P20's activities, but rather changing P10 & 30.

6.2.1.5.3 Key differences in implementing an *Overhead crane*

The key difference is not related to P20, but rather to P10 & P30. By installing an *Overhead crane*, it will be possible to eliminate the need to have a forklift driver to operate P10 & P30.

By removing the forklift from this OBD area, possible risk areas can also be removed, and possibly lower the RPN value in the OBD.

Although this could potentially mitigate some risk areas, P20's current risk areas, where the highest RPN values are present, will persist.

6.2.1.5.4 Price and expected sorting delay

The sales price of an *Overhead crane* is estimated to be 7,000,000 DKK (Mazzella companies, 2024). Unlike the previous alternatives, the installation price of this machinery would significantly increase the initial investment, as civil work must be conducted to successfully implement this alternative. Civil work requires analysis of building drawings, specifications, and on-site observations to determine the design of the crane (Abcoengineers, 2024). For this project, the civil work cost estimations have not been included due to limitation of resources, hence only the sales price of a standard crane is included.

Installing such machinery would require delaying the sorting process, as the crane needs to be installed overhead. Therefore, the ground underneath must be secured for safety, which would require no walking or driving activity for 31 days (Mazzella companies, 2024).

This alternative also mandates additional external training for the workers, as it is a requirement by the working institution to possess a crane certificate (Arbejdstilsynet , 2024).

As the alternative for the MCDM analysis has been identified, the second part of the first step of the MCDM methodology will now be conducted.

6.2.2 Determination of criteria

To determine which criteria will be used in the MCDM method, the priorities of creating a safe working environment and conducting processes effectively will be incorporated as well as analysing previous case studies (Resource Denmark, 2024) (Aksel Rasmussen, 2022).

With the use of internal sources at Resource Denmark, the following criteria have been discussed and chosen as relevant (Resource Denmark, 2024) (Aksel Rasmussen, 2022). A full analysis of each criterion can be seen In *Appendix 18: Criteria for MCDM.*

1) **Cost**

   It is imperative to generate a profit to run a successful company. To implement changes that require an investment, a business must account for the associated implementation cost (Zhang, 2024).

2) **Number of risk areas**

   In the OBD, workers handle plastic bales weighing up to 557 kg (Resource Denmark, 2024) (Wastecare, 2024). The bales can therefore be classified as heavy materials, which could easily harm the worker if handled improperly, and must be handled with care.

3) **Employee training**

   It is important to establish whether additional training is required due to potential modifications. This requirement varies depending on the respective modification (Stephan Knackstedt, 2023).

4) **Opportunity to reallocate capacity**

   As two out of three workers lack the expected capacity to cope with the sorting plant's capacity, it is important to implement a solution, that provides the opportunity to reallocate the expected capacity to these workers. (Manager O. , 2024).

5) **Sorting delay**

   Changes and adjustments can vary significantly in their implementation time, it is crucial to estimate and schedule this period. Failing to estimate it accurately, could lead to cost overrun and a reduction in the plant's capacity (Fakhar Hassan Shah, 2023).

6) **Employee satisfaction**

   The final criterion is focused on employee satisfaction with the activities of the newly implemented process. Resource Denmark aims to cultivate a positive working environment where the workers are motivated (director, 2024).

With the criteria established through primary and secondary data, it is now possible to proceed to step two of the MCDM method (Manager O. , 2024) (Resource Denmark, 2024) (Aksel Rasmussen, 2022).

6.2.3 Weight of each criterion

The second step of the MCDM methodology involves assigning weights to each criterion (Thakkar, 2021) (Apichat Sopadang, 2016). The weights will be determined by Resource Denmark's subjective preferences, based on inputs from relevant stakeholders. The Analytical Hierarchy Process (AHP) will be utilized to establish these subjective weights (Apichat Sopadang, 2016) (Saaty, 1980).

The AHP offers a significant advantage, given the diversity of stakeholders present at Resource Denmark (Ramaiyan Velmurugan, 2011). Leveraging insights from on-site observations and previous projects, primary data is collected from white- and blue-collar workers (Ramaiyan Velmurugan, 2011). This will ensure that the weighing of criteria is grounded in practical realities and aligned with the actual priorities of all stakeholders. This method also includes an evaluation of the calculated weights using the Consistency Ratio (CR) (Apichat Sopadang, 2016). Evaluating the applied methodology verifies the weight determinations are consistent and maintain a logical consistency throughout the decision-making process (Thakkar, 2021).

The initial step of conducting the AHP requires a systematic pairwise comparison of each criterion against every other criterion (Saaty, 1980) (Apichat Sopadang, 2016). This process utilizes qualitative data gathered from the stakeholders at Resource Denmark.

The scoring for these comparisons follows a standardized scale used in AHP. The scoring scale can be seen in Table 10 (Saaty, 1980). In *Appendix 19: AHP method explanation*, the steps of AHP and the respective scale are described.

Importance	Importance description
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values
1/3, 1/5, 1/7, 1/9	Value for inverse comparison

Table 10: Standardized scores for the AHP (Saaty, 1980)

Leveraging the scale, it is now possible to convert the qualitative data collected into quantifiable data, by comparing all the i-row with all j-columns. The pairwise comparison matrix is constructed in Table 11.

Pair-wise comparison	Price	Nr. of risk area	Employee training	Capacity reallocation	Sorting delay	Employee satisfaction
Price	1	1/5	3	1/5	1/3	1
Reduction of risk	5	1	7	1	7	7
Employee training	1/3	1/7	1	1/7	1/5	1/3
Capacity reallocation	5	1	7	1	5	5
Sorting delay	3	1/7	3	1/5	1	3
Working routine	1	1/7	3	1/7	1/3	1
Sum	**15,3**	**2,62**	**24**	**2,68**	**13,86**	**17,33**

Table 11: Pair-wise comparison matrix (Apichat Sopadang, 2016) (Saaty, 1980)

Based on the evaluation of each criterion, it is evident, that nr. of risk area is much more important than the required additional employee training, sorting delay, and employee satisfaction following the alternative. This represents Resource Denmark's vision of creating a safe and effective work environment. Additionally, it is apparent that the ability to reallocate capacity also is much more important than the expected employee training. This is based on the current processes in the OBD, not having the expected capacity required by the sorting plant. A thorough analysis of all criteria comparisons is available in *Appendix 20: Comprehensive analysis of the pairwise comparison*.

The next step is to determine the weight of each of these criteria (Saaty, 1980). This is done by normalizing the pair-wise comparison matrix. Normalizing the matrix is a crucial step in the AHP, as it converts the raw comparisons into a format that can be analysed to derive priority scales for each criterion (Saaty, 1980). To normalize the values from Table 11, Equation 3 is used (Saaty, 1980):

$$b_{ij} = \frac{a_{ij}}{S_j} \tag{3}$$

- b_{ij} is the normalized value of the i-th row and j-th colum.
- a_{ij} is the value in the i-th row and j-th column of the pair-wise comparison Table.
- S_j is the sum of the values in the j-th column.

In Table 12, the equation has been applied to all cells present in the pair-wise comparison matrix table.

Normalized pair-wise comparison	Price	Nr. of risk area	Employee training	Capacity reallocation	Sorting delay	Employee satisfaction
Price	0.065	0.076	0.125	0.074	0.024	0.057
Reduction of risk	0.326	0.380	0.291	0.372	0.504	0.403
Employee training	0.021	0.054	0.041	0.053	0.014	0.019
Capacity reallocation	0.326	0.380	0.291	0.372	0.360	0.288
Sorting delay	0.195	0.054	0.125	0.074	0.072	0.173
Working routine	0.065	0.054	0.125	0.053	0.024	0.057
Sum	1	1	1	1	1	1

Table 12: Normalized pair-wise comparison (Apichat Sopadang, 2016) (Saaty, 1980)

To showcase the normalized values are valid, the j-colums sums are identified along with the correct value of 1 (Saaty, 1980). Based on the normalized values, it is now possible to calculate the priority vector of the matrix. The priority vector of each criterion represents the weight (Saaty, 1980). The vector is calculated using Equation 4 (Saaty, 1980).

$$\omega_i = \frac{1}{n}\sum_{j=1}^{n} b_{ij} \tag{4}$$

- ω_i is the computed weight of the i-th criterion.
- N is the number of columns in Table 12.
- b_{ij} is the normalized value of Table 12.

Applying this equation to the normalized values, presents the following weights.

Weight of criteria	Price	Nr. of risk area	Employee training	Capacity realloca-tion	Sorting delay	Employee satisfaction
Weight value	7%	38%	3%	34%	12%	6%

Table 13: Weight of each criterion (Saaty, 1980)

With the application of the AHP method, the weights of each criterion have been determined, revealing insightful information about the respective importance of each criterion.

- Price of investment:
  The price of investment holds a moderate weight of 7%. This weight resembles Resource Denmark's choice of cost savings should not compromise reaching the expected capacity and ensuring safe and effective processes.
- Number of risk areas:
  The reduction of potential risk areas is the most crucial factor, with a weight of 38%. This aligns with the company's priority of creating a safe working environment and effective processes for the workers.
- Required employee training:
  This criterion has the lowest weight of 3%, which resembles the company's interest in developing their workers and seeing additional training as an opportunity instead of an obstacle.
- Ability to reallocation of capacity:
  The opportunity to reallocate capacity from P20 emerges as the second most important criterion. This emphasizes the priority of ensuring the OBD will not be the bottleneck of the sorting process and should reach the expected capacity level.

- Expected sorting delay:
  The sorting delay ranks third in importance, with a weight of 12%. Since Resource Denmark currently is running the hot commissioning phase, halting the operation would lower the chance of identifying faulty machinery.
- Employee satisfaction:
  This criterion is ranked second lowest in importance. Even though Resource Denmark has stated creating processes that motivate the staff is important, it can be seen that compared to the other mentioned criteria, this criterion decreases in importance.

To evaluate the consistency of the ratings in Table 11, which is the pillar of the weights, the CR will be calculated. A CR below 0.1 suggests that the qualitative data has been converted consistently when conducting the pairwise comparison (Apichat Sopadang, 2016) (Saaty, 1980). For the comparison, the CR value is 0.04. Based on this, the weights are deemed applicable and can be applied for the next step of the MCDM. The calculation for the CR value is presented in *Appendix 21: Calculation of CR value*.

Using these criteria weights it is now possible to proceed to the third and final step of the MCDM method.

6.2.4 The Technique for Order of Preference by Similarity to Ideal Solution

The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method will be applied as the mathematical procedure to determine the ranking of the alternatives (Apichat Sopadang, 2016) (Ming-Chyuan Lin, 2007) (Thakkar, 2021). This choice is based on the method's ability to effectively manage and balance multiple conflicting criteria, and provide a comprehensive evaluation, based on the geometric distance of each alternative to the ideal value for each criterion (Apichat Sopadang, 2016) (Ming-Chyuan Lin, 2007) (Thakkar, 2021) (Serafim Opricovic, 2004).

Having determined the weights of each criterion using AHP, TOPSIS allows a practical ranking mechanism that can handle large datasets effectively and is suited for quantitative data (Apichat Sopadang, 2016) (Ming-Chyuan Lin, 2007) (Thakkar, 2021). The integration of both AHP and TOPSIS leverages the AHP structured weight determination and the TOPSIS's effective ranking process, which ultimately provides a clear and intuitive decision-making framework

(Apichat Sopadang, 2016). The steps of this method are explained in-depth in *Appendix 22: TOPSIS method*.

Using both the selected criteria from section 6.2.2 and the calculated weights for each criterion, from section 6.2.3, it is possible to conduct the TOPSIS analysis. With the data and information gathered in section 6.2.1, Table 14 presents all findings for each alternative.

Raw data of alternative	Price (DDK)	Nr. of risk areas	Employee training (days)	Capacity reallocation	Sorting delay (days)	Employee satisfaction
UWUK	2.902.198	3	1	Yes (1)	5	5
Equipment upgrades	143,250	6	1	Yes (1)	0	2
BC	1,000,000	6	3	No (0)	0	3
Overhead crane	7,000,000	9	10	Yes (1)	31	5

Table 14: Raw data of alternative

Each value within the cells of Table 14 is described in detail in *Appendix 23: Comparison values of each alternative.* To determine the number of risk areas, a PFMEA analysis is conducted, where the *UWUK* alternative presents the lowest number of potential risk areas, while the *BC* & *Equipment upgrades* share the second lowest number of potential risk areas, with the *Overhead crane* presenting the highest number of potential risk areas (J. A. L. Anjalee, 2021).

The “Capacity reallocation” values are converted to binary values for a quantitative measurement. Specifically, “Yes” is assigned the value 1, while “No” is assigned the value 0, ensuring all criteria can be included in the decision matrix and normalized on a comparable scale (Gareth James, 2017).

The first step of the TOPSIS analysis is to create the normalized matrix based on Table 14. This is calculated using Equation 5 (Apichat Sopadang, 2016):

$$\bar{X}_{ij} = \frac{X_{ij}}{\sqrt{\sum_{j=1}^{n} {X_{ij}}^2}} \tag{5}$$

- $\bar{X}_{ij}$ is the normalized value for the i-th alternative under the j-th criterion.
- X_{ij} is the original value for the i-th alternative under the j-th criterion.

In Table 15, Equation 5 has been applied to all cells of Table 14.

Normalized matrix	Price (DKK)	Nr. of risk areas	Employe e traning	Capacity reallocation	Expected sorting delay (days)	Employee satisfaction
UWUK machine	0,38	0,24	0,09	0,58	0,16	0,63
Equipment upgrades	0,02	0,47	0,09	0,58	0,00	0,25
BC	0,13	0,47	0,28	0,00	0,00	0,38
Overhead crane	0,92	0,71	0,95	0,58	0,99	0,63

Table 15: Normalized matrix for the alternatives (Apichat Sopadang, 2016)

Using the normalized matrix, the next step is to calculate the weighted normalised matrix. In this step, the weight, calculated in section 6.2.3, is applied to the normalised matrix value. The equation for this is the following (Apichat Sopadang, 2016):

$$V_{ij} = \bar{X}_{ij} * W_j \qquad (6)$$

- V_{ij} is the weighted normalized value from the i-th alternative under the jth criterion.
- $\bar{X}_{ij}$ is the normalised value for the i-th alternative under the j-th criterion.
- W_j is the weight assigned to the j-th criterion.

Using this equation, the weights are applied to each of the normalised values. The result of these calculations can be seen in Table 16.

Weighted normalized matrix	Price (DKK)	Nr. of risk areas	Employee traning	Capacity reallocation	Expected sorting delay (days)	Employee satisfaction
UWUK machine	0,03	0,09	0,00	0,19	0,02	0,04
Equipment upgrades	0,00	0,18	0,00	0,19	0,00	0,02
BC	0,01	0,18	0,01	0,00	0,00	0,02
Overhead crane	0,06	0,27	0,03	0,19	0,11	0,04

Table 16: Weighted normalized matrix for alternatives (Apichat Sopadang, 2016)

Table 16 shows each alternative's value of the respective criterion using the weights calculated in section 6.2.3. The next step is to determine each criterion's ideal and worst value. This is done using the weighted normalised matrix values in Table 16 (Apichat Sopadang, 2016).

It is important to remember, the highest value is not always the ideal value for each criterion. Rather, the ideal value for "Nr. Of risk areas" is the lowest amount, as this is the preferred option with the lowest number of risks. In Table 17, the ideal and worst values have been determined for each criterion, based on the weighted normalized matrix in Table 16.

Best/worst value	Price (DKK)	Nr. of risk areas	Employee traning	Capacity reallocation	Expected sorting delay (days)	Employee satisfaction
V+	0,00	0,09	0,00	0,19	0,00	0,04
V-	0,06	0,27	0,03	0,00	0,11	0,02

Table 17: Ideal value and worst value for each criterion (Apichat Sopadang, 2016)

Based on the ideal and worst values for each criterion, it is now possible to determine the Euclidean distance for each alternative to these values. The Euclidean distance represents how close each alternative is to the best possible scenario (ideal value) and how far they are from the worst possible scenario (worst value) (Apichat Sopadang, 2016). This distance is based on the weighted normalized values for each alternative, calculated in Table 16.

The equation for calculating the Euclidean distance to the ideal value is by applying Equation 7 (Apichat Sopadang, 2016).

$$S_i^+ = \left[\sum_{j=1}^{m} \left(V_{ij} - V_j^+\right)^2\right]^{0,5} \tag{7}$$

- S_i^+ is the distance of the alternative i from the ideal solution.
- V_{ij} is the weighted normalized value from alternative i under criterion j.
- V_j^+ is the ideal value under the criterion j.

The equation for calculating the Euclidean distance to the worst value is by applying Equation 8 (Apichat Sopadang, 2016).

$$S_i^- = \left[\sum_{j=1}^{m} \left(V_{ij} - V_j^-\right)^2\right]^{0,5} \tag{8}$$

- S_i^- is the distance of alternative i from the negative solution.
- V_{ij} is the weighted normalized value from alternative i under criterion j.
- V_j^- is the negative value under criterion j.

By applying these two equations, Table 18 illustrates each alternative's Euclidean distances.

Weighted normalized matrix	Si+	Si-
UWUK machine	0,03	0,29
Equipment upgrades	0,09	0,25
BC	0,21	0,16
Overhead crane	0,22	0,20

Table 18: Euclidean distance of each alternative's to ideal and worst value (Apichat Sopadang, 2016)

Using these distances, it is possible to determine the performance score for each alternative, which is the last step of the TOPSIS analysis. The performance score establishes which alternative is closest to the ideal values in all criteria. This is calculated by applying Equation 9 (Apichat Sopadang, 2016):

$$P_i = \frac{S_i^-}{S_i^+ + S_i^-} \tag{9}$$

- P_i is the relative closeness of the alternative to the ideal solution.
- S_i^- is the Euclidean distance of the alternative from the negative solution.
- S_i^+ is the Euclidean distance of the alternative from the ideal solution.

The performance scores for each alternative are calculated in Table 19.

Weighted normalized matrix	Pi	Rank
UWUK machine	0,90	1
Equipment upgrades	0,73	2
BC	0,42	4
Overhead crane	0,47	3

Table 19: Performance scores for each alternative (Apichat Sopadang, 2016)

The *UWUK* -machine scores the highest performance value of 0.90. This score is based on the low number of risk areas and the ability to reallocate the current P20 worker's capacity. These two criteria, where the *UWUK* excels, are the criteria that consist of the highest weights. The disadvantages of this alternative are the initial investment required and the expected sorting delay. As these two criteria have a lower weight than number of risk areas and reallocation opportunity, this alternative scores the highest performance value.

The implementation of *Equipment upgrades* scores the second highest performance value of 0.73. This alternative also excels in the relevant criteria, while doubling the number of risk areas as the *UWUK* alternative. This alternative has a positive value in all criteria besides employee satisfaction. This is based on the empirical data collection, where multiple workers stated the requirement of exiting the forklift for each bale is not ideal (Resource Denmark, 2024). Based on the low investment cost, training requirement, sorting delay, and a moderate number of potential risk areas, this alternative gains a performance score of 0.73.

The second lowest performance value is acquired by the *Overhead crane* with a performance score of 0.46. The *Overhead crane* scores poorly in multiple criteria; high initial investment required, sorting delay, need for outsourced training, and the number of risks. The high number of risks is decisive for the low performance score of this alternative. As this option allows to reallocate capacity and employee satisfaction, it does not exceed the negative aspect of implementing the *Overhead crane*.

BC has the lowest score of 0.42. This adjustment does not provide any reallocation opportunity, besides the current excess capacity the P20 worker has. Therefore, it scores low in the second most influential criteria, while having a moderate value of six potential risk areas, in the most influential criteria. As this alternative does not perform well in either of the most weighted criteria, it earns the lowest score amongst the alternatives.

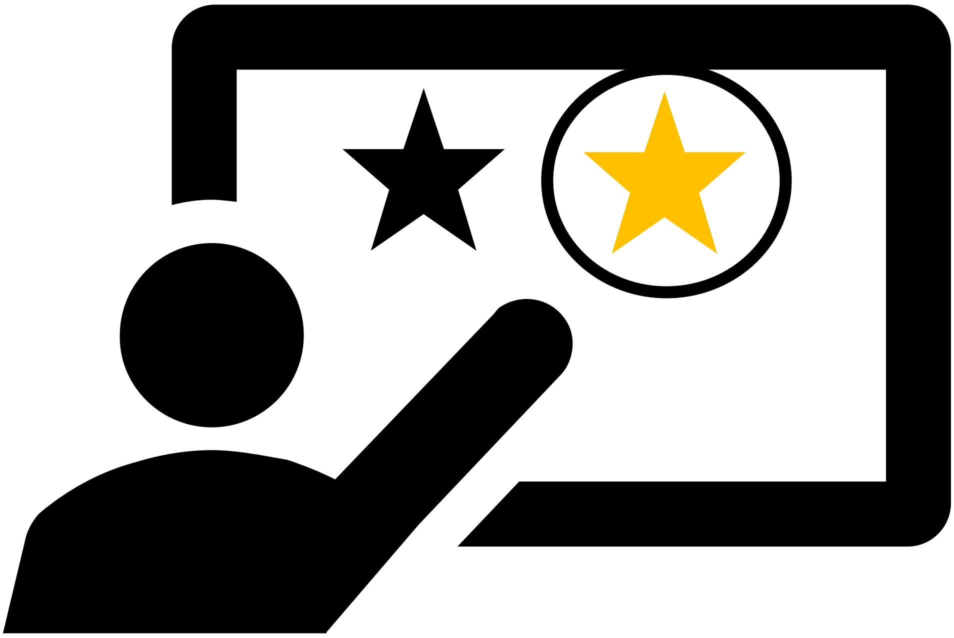
Before recommending a solution for Resource Denmark's OBD, a capacity analysis must be conducted to determine if the alternatives can reach the expected capacity, showcased in Table 7.

Following the capacity analysis, a financial analysis must also be performed, to showcase the investment case of the alternative. These additional in-depth analyses will only be conducted for the *UWUK* and *Equipment upgrades* alternative, as these acquired the highest performance scores.

6.3 Sub-conclusion

Utilizing the MCDM framework, this chapter has identified alternative methods of conducting P20, aligning with Resource Denmark's long-term vision and goals for the future. The identified alternative includes the *UWUK* -machine, *Equipment upgrades*, BC, and an *Overhead crane*. These alternatives are identified using both internal and external sources and have been evaluated based on the following criteria with their respective weights: Cost (7%), Capacity reallocation (34%), Number of risk areas (38%), Need of training (3%), Sorting delay (12%), and lastly Employee satisfaction (6%). These weights are determined using the AHP.

The TOPSIS method is applied to determine which alternative is closest to the ideal value of each criterion. The analysis ranks the *UWUK* -machine as the closest, followed by the *Equipment upgrades* alternative. Given the high placement of these alternatives, an in-depth capacity analysis is required to determine if both alternatives can reallocate sufficient capacity to reach the expected capacity required by the automated sorting plant.



Chapter 7 - Deliver: Final Recommendation

7.1 Introduction to Chapter 7

This chapter will propose the final recommendation for Resource Denmark's OBD. Before the recommendation, a capacity and break-even analysis will be conducted for both alternatives.

7.2 Capacity analysis for the two alternatives

As the main goal of this problem analysis is to implement processes in the OBD to reach the expected capacity shown in Table 7, a capacity analysis for both alternatives are imperative. To calculate these alternative's capacity, the same methodology from section 3.4.1.2, will be applied (Nigel Slack, 2016) (Stevenson, 2015).

7.2.1 *UWUK* capacity analysis

Starting with the capacity analysis for the *UWUK* -machine, this process is automated, eliminating the need for a dedicated worker to conduct the process activities. When calculating the capacity of such a machine, it is important to include all types of maintenance activities following the implementation of this machinery. As determined in section 6.2.1.3.1, weight scale calibration will take approx. 30 minutes (1800 sec) and must be performed once a week (Forklift accessories, 2014).

As this machine is not currently available at the OBD, collecting empirical data of its cycle time is not possible. According to internal sources, the cycle time to isolate, weigh, and label a bale is 70 sec (Unotech LM Group, 2024). Using this cycle time, it is now possible to calculate the capacity of the workers in OBD, if this alternative was to be implemented.

As P10 and P20 do not require a dedicated worker, the two worker's capacity can be reallocated. In *Appendix 24: All possible reallocation options for UWUK alternative*, all possible reallocation scenarios are evaluated. Based on the available scenarios, the optimal approach to achieve the expected capacity is to assign two workers to perform P30 & P40, and one worker to operate P50. In Table 20, the capacity analysis for the *UWUK* alternative is illustrated (Nigel Slack, 2016) (Stevenson, 2015).

Process	New CT (sec)
Process 10	0
Process 20	70
Process 30	103
Process 40	64
Process 50	110

Current vs expected capacity	Shift 1	Shift 2	Shift 3	Shift 3 + weekend
Process 20				
Worker capacity (bales)	65.253	129.435	197.897	240.686
Expected capacity (bales)	46.048	90.610	138.143	167.851
Difference	**19.205**	**38.825**	**59.754**	**72.834**
Process 30 + 40				
Worker capacity (bales)	60.653	106.929	160.842	215.654
Expected capacity (bales)	46.048	90.610	138.143	167.851
Difference	**14.605**	**16.319**	**22.699**	**47.803**
Process 50				
Worker capacity (bales)	42.205	83.049	126.615	153.844
Expected capacity (bales)	46.048	90.610	138.143	167.851
Difference	**- 3.843**	**- 7.561**	**- 11.528**	**- 14.007**

Table 20: Capacity analysis for UWUK (Unotech LM Group, 2024) (Stevenson, Operations Management, 2015)

As shown in Table 20, the two workers, operating P30 & P40, exceed the expected capacity, while the worker operating P50, does not reach the expected capacity. By utilizing the excess capacity from the two workers operating P30 & P40, it is feasible to reallocate their capacity to P50. In Table 21 the required excess capacity has been utilized and reallocated to P50.

Current vs expected capacity	Shift 1	Shift 2	Shift 3	Shift 3 + weekend
Process 20				
Worker capacity (bales)	65.253	129.435	197.897	240.686
Expected capacity (bales)	46.048	90.610	138.143	167.851
Difference	**19.205**	**38.825**	**59.754**	**72.834**
Process 30 + 40				
Worker capacity (bales)	60.653	106.929	160.842	215.654
Expected capacity (bales)	46.048	90.610	138.143	167.851
Difference	**10.762**	**8.758**	**11.171**	**33.796**
Process 50				
Worker capacity (bales)	46.048	90.610	138.143	167.851
Expected capacity (bales)	46.048	90.610	138.143	167.851
Difference	**0**	**- 0**	**0**	**0**

Table 21: Capacity analysis for UWUK utilizing excess capacity (Unotech LM Group, 2024) (Stevenson, Operations Management, 2015)

Even after reallocating the required capacity to P50, it is evident that the two workers from P30 & P40, still possess a significant amount of excess capacity.

From this analysis it can be concluded, by implementing the *UWUK* -machine into the OBD along with three dedicated workers, the expected capacity can be reached. With this implementation, the OBD will not act as the bottleneck for Resource Denmark sorting process. The full capacity calculation is shown in *Appendix 24: All possible reallocation options for UWUK alternative.*

7.2.2 *Equipment upgrades* capacity analysis

Moving on to the *Equipment upgrades* alternative, a sample of RFID tags has been purchased for testing, and during the testing, an empirical study has been conducted. The cycle time for creating an RFID tag and logging the data is estimated to be 42 sec while attaching the RFID tag to the bale is estimated to be an additional 23 sec (Resource Denmark, 2024). Thereby, the total cycle time of weighing, logging, and attaching the tag to the bale is 65 sec.

As previously, various scenarios have been explored, and it can be determined to reach the expected capacity for all workers, P20 & P30 will be operated by two workers, while P40 & P50 will also be operated by another two workers. It is not possible to deploy three workers in the OBD using the updated cycle times.

In Table 22, the capacity analysis for the *Equipment upgrades* using four workers is calculated (Nigel Slack, 2016) (Stevenson, Operations Management, 2015).

Process	New CT (sec)
Process 10	0
Process 20	65
Process 30	121
Process 40	64
Process 50	110

Current vs expected capacity	Shift 1	Shift 2	Shift 3	Shift 3 + weekend
Process 20 + 30				
Worker capacity (bales)	60.171	117.223	174.274	213.497
Expected capacity (bales)	46.048	90.610	138.143	167.851
Difference	**14.124**	**26.613**	**36.131**	**45.646**
Process 40 + 50				
Worker capacity (bales)	58.639	113.829	169.019	248.354
Expected capacity (bales)	46.048	90.610	138.143	167.851
Difference	**12.592**	**23.219**	**30.876**	**80.503**

Table 22: Capacity analysis for equipment improvements (Unotech LM Group, 2024) (Stevenson, Operations Management, 2015)

Based on Table 22, it can be established that operating with four workers in the OBD will ensure the workers consist of the expected capacity required by the sorting plant. The full capacity analysis for this scenario can be seen in *Appendix 25: All possible reallocation options for Equipment upgrades alternative.*

Based on this capacity analysis, it can be concluded implementing the *Equipment changes* and hiring an additional worker, would create the expected capacity for the OBD.

7.3 Financial analysis

With the use of the capacity analysis for both alternatives, the required number of workers is established, which also provides insight into a detailed initial investment requirement for both alternatives.

The detailed initial investment for each alternative is illustrated in Figure 13 and is based on the cost of machinery, equipment, and the required software and hardware to operate the alternatives effectively. The calculation of the initial investment for each alternative can be seen in *Appendix 26: Initial investment for both alternatives.*

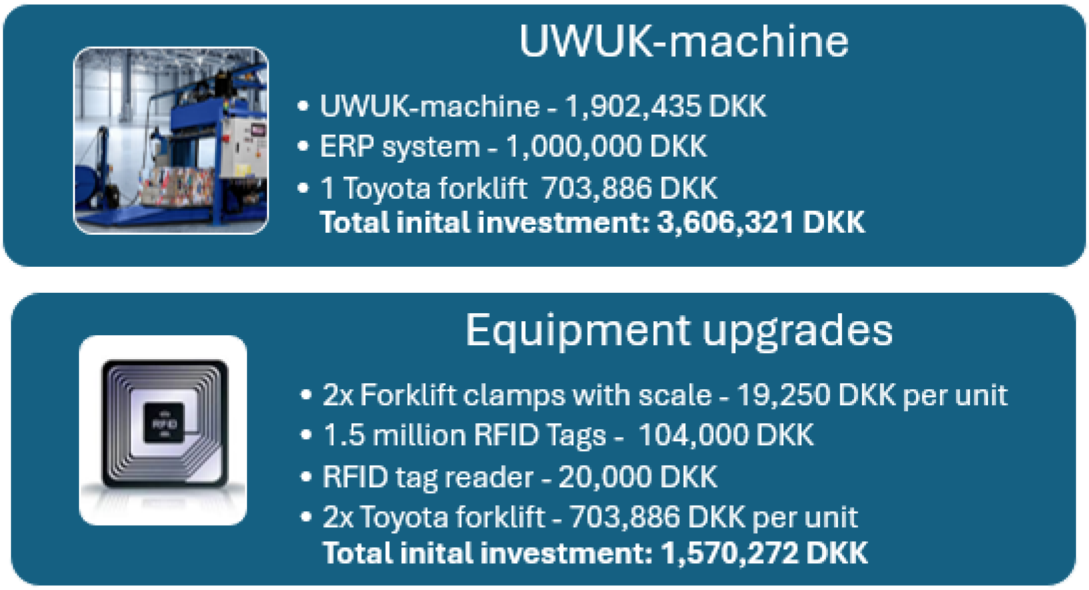


Figure 13: Required initial investment

For the *UWUK* alternative there is an initial investment requirement of approx. 3.5 million DKK, whereas for the *Equipment upgrades,* the investment requirement is approx. 1.5 million DKK.

Conducting a Net Present Value (NPV) analysis would be ideal, as it would demonstrate the profitability of each investment for the stakeholders while considering the time value of money (Nicholas H. Johnson, 2010) (Beaumont, 1998). As Resource Denmark is currently in the hot commissioning phase, the time table for when the plant is expected to sort the projected number of tons, as shown in Table 1, is uncertain (director, 2024) (Manager O. , 2024). This leads to the absence of a consist revenue stream. Due to this the absence of this key factor, it is not possible to conduct a NPV analysis at the current stage, as revenue is a crucial input for this analysis.

Based on the current stage of Resource Denmark and the available data a break-even analysis would be optimal to present to the stakeholders at Resource Denmark (Paolo Candio, 2022). This analysis will be based on secondary data, using the initial investment- and required labour-cost as outflows, and the sale of sorted plastic bales as inflow (Jobindex, 2024) (Schopwinkel, 2023). The operational cost has not been included, as secondary data only showcase the operational cost of Resource Denmark from 2022 (RSM, 2023). Applying this operational cost value, would present an unreliable break-even point (BEP) for each alternative. Based on the Plant Director at Resource Denmark, the current operational cost is unavailable for this project, so therefore this break-even analysis, will only include the initial investment cost and required labour cost for the OBD (director, 2024). These cost for each alternative is present in *Appendix 27: Break-even analysis* (Paolo Candio, 2022).

The break-even point (BEP) for both alternatives operating with 1 shift in the OBD, is illustrated In Table 23 (Paolo Candio, 2022).

Break even point	UWUK	Equipment upgrades
Nr of bales to reach BEI	7.983	4.929

Table 23: Break-even point for each alternative (Paolo Candio, 2022)

It can be seen the BEP for *Equipment upgrades* requires approx. 5,000 bales to be sorted and sold, to break even for the initial investment of approx. 1.5 million DKK. Due to the higher initial investment, the *UWUK* requires an additional approx. 3,000 bales to reach its respective BEP.

Based on Table 1, it can be determined, the required number of bales to reach the BEP for both alternatives can be reached within the span of a couple of months, if the expected sorting capacity is reached. Therefore, based on this analysis the small difference of 3,000 additional bales required to each the BEP for the *UWUK* alternative, which is more advantageous in terms of number of workers required and risk areas, does not significantly affect the final recommendation.

7.4 Final recommendation

Based on the PFMEA, TOPSIS, capacity, and break-even analysis, implementing the *UWUK* -machine in the OBD of Resource Denmark is the optimal solution.

This implementation of the *UWUK* -machine notably reduces the number of potential risk areas from six to three, reflecting a significant enhancement in safety and operation effectiveness. This determination arises from the shift in process from manual to automated.

With a strategic allocation of the current workforce in the OBD – two workers operating P30 & P40, and one worker operating P50 – the OBD is expected to reach the expected capacity during all shift operations. Although the worker operating P50 faces a capacity shortage, the excess capacity from the two workers at P30 & P40 can be reallocated to support P50. This will ensure that all the bales can be loaded into the arrived trucks.

Based on these worker allocation and implementation of the *UWUK* -machine, the OBD will not act as the bottleneck for the sorting process and will contain the expected capacity based on Table 1.

To validate this capacity analysis including the reallocation, a discrete event simulation is conducted (Realpython, 2024). This simulation uses the cycle time and number of workers described previously. The simulation model represents an eight-hour shift, incorporating lunch breaks, scheduled meetings, and maintenance, while assuming an operational efficiency of 80%. The results of this capacity simulation are presented in Figure 14. The detailed outcomes and input variables used in this simulation can be seen in *Appendix 28: Inputs and results of capacity simulation*.

	Process 20	Process 30+40	Process 50 (with help)
Shift 1	True	True	True
Shift 2	True	True	True
Shift 3	True	True	True
Shift 3 + Weekend	True	True	True

Figure 14: Simulation results of capacity analysis (Realpython, 2024)

Based on Figure 14, it can be confirmed implementing the *UWUK* -machine in the OBD can generate the expected capacity, as shown in Table 7. This simulation makes the use of reallocating capacity from the two workers operating P30 & P40, as described in section 7.2.1.

7.5 Sub-conclusion

Based on the capacity analysis of *UWUK* alternative, it is determined the expected capacity, required by the sorting plant can be reached allocating two workers to operate P30 & P40, while one worker operates P50. With the use of the excess capacity of the two workers and reallocate it to P50, the expected capacity can be reached. To implement this alternative, an initial investment of approx. 3.5 million DKK is required.

To achieve the expected capacity, by implementing the *Equipment upgrades*, two workers are required to operate P20 & P30, while another two workers are required to operate P40 & P50. It is not possible to achieve the expected capacity for this alternative by operating with the current three workers. The initial investment required for this alternative is approx. 1.5 million DKK.

For both alternatives, the BEP, based on initial investment- and labour-cost and sale of sorted plastic bale, is below 10,000 bales operating with 1 shift. Based on the expected 3,000 tons per week, from table 1 operating with 1 shift, the BEP for both alternative is expected to be reached within months, if the sorting plant's expected capacity is reached.

Based on the TOPSIS, capacity, and break-even analysis, it is concluded that the *UWUK* -machine is the recommended solution for Resource Denmark.

7.6 Conclusion

The investigation aimed to modify the processes within the OBD to reach the expected capacity, determined by the sorting plant's capacity, resulted in several critical insights and actionable recommendation.

Through a PFEMA analysis, P20 emerged as the optimal candidate for modifications due to its high operational and safety risks, based on the current processes in the ODB, proven by consisting of the three highest RPN values in the OBD and most potential risk areas.

Prior to identifying modifications to the current P20, the requirements of the process' activities were established by an analysis and prioritization of data through interviews with three potential customers. These requirements included the visualization or inclusion of a scanning option to display the supplier's name, bale weight, plastic type, and plastic code on each sorted bale.

From these requirements, the following alternatives for P20 were identified using both internal and external sources: 1) *UWUK* -machine, 2) *Equipment upgrades*, 3) *Business Central*, and 4) *Overhead crane*. These alternatives were evaluated based on criteria aligned with Resource Denmark's priorities. Using the AHP method and a diverse group of stakeholders at Resource Denmark, the chosen criteria were weighted as the following: Cost (7%), Opportunity to reallocate capacity (34%), Number of risk areas (38%), Need of training (3%), Sorting delay (12%), and Employee satisfaction (6%). Applying the TOPSIS analysis, using these criteria and their respective weights, resulted in ranking of the *UWUK* -machine as the optimal solution, followed by the *Equipment upgrade* alternative.

The capacity analysis for the *UWUK* alternative ensured the expected capacity could be reached with the three workers, if P30 & P40 are operated by two workers and P50 by one worker. For this alternative, P20 would become automated, so no dedicated worker is required to operate it. By reallocation excess capacity of the P30 & P40 workers to P50, the expected amount of capacity can be reached in the OBD.

For the capacity analysis of the *Equipment upgrades*, a requirement of hiring an additional worker is needed, as the expected capacity for the OBD cannot be reached operating with this implementation and the current three workers. Using two workers to operate P20 & P30 and the remaining two workers on P40 & P50, the expected capacity is proven to be reached.

Based on this capacity analysis for these two alternatives, a break-even analysis was conducted, showing both options would require selling under 10,000 sorted bales to reach their respective breakeven point of their required investment. This BEP is expected to be reached within a couple of months operating with 1 shift, if the expected sorting capacity is valid at Resource Denmark from Table 1.

Based on the TOPSIS, capacity, and break-even analysis, the *UWUK* -machine is recommended for the OBD. This solution addresses the immediate capacity needs with the current three workers and minimizes potential areas of risk from six to three. A simulation is conducted to confirm the effectiveness of implementing of the *UWUK* -machine and reallocating excess capacity from the two workers to P50, thereby validating the capacity analysis.

This comprehensive analysis ensures that implementing the *UWUK* machine will align with Resource Denmark's operational and strategic goal of the sorting plant setting the capacity constraint of the sorting process and not the OBD.

7.7 Reflection

This section will reflect on methodologies applied in the project and how different approaches could have affected the final recommendation for Resource Denmark's OBD.

7.7.1 Data collection

7.7.1.1 More accurate cycle times on P50 in the OBD

The data collection of the cycle times of P50 in the OBD, only included LDPE bales, as these were the plastic bales which were loaded into trucks during the data collection period. The worker operating P50 has stated that the cycle time for loading bales varies depending on the plastic type. Using only LDPE bale's cycle time lowers the reliability of the capacity analysis for this project and final recommendations. Therefore, it would have been advantageous to collect cycle times for different types of plastic bales. By using P50 cycle times for each plastic type, an accurate cycle time for this process could have been calculated. This approach to determine P50's cycle time would have provided a more reliable cycle time compared to the current cycle time based on solely LDPE bales.

7.7.1.2 Additional interviews with potential customers

To ascertain the customer requirements for P20, interviews with three potential customers were conducted, which is a relatively small sample size. Increasing the number of participants to a sufficient level could not only enhance the validity of the requirements of P20, but also potentially introduce additional requirements within Box 1 & 2. This could have affected the number of alternatives identified during the brainstorming session. Thereby, implementing additional or fewer alternatives could have altered the outcome of the TOPSIS analysis and final recommendation for Resource Denmark's OBD. Interviewing a larger pool of potential customers would have enhanced the validity of this project's final recommendation.

7.7.1.3 Machine downtime and worker efficiency

For this project, it is estimated that worker efficiency and machine breakdown will decrease the sorting capacity by 20%. This estimation is derived from primary and secondary sources, as no reliable empirical data can be collected at Resource Denmark currently, as the plant is conducting the hot commissioning. During the hot commissioning phase, the machinery is frequently halted for testing and calibration. Consequently, an accurate estimation for future machine breakdowns and worker efficiency is not possible at this stage, leading to the assumption of 20 % decrease in efficiency.

For a future study to present a valid and reliable capacity analysis, an empirical study of the machine break downs, and worker efficiency must be conducted, when the hot commissioning phase is completed. With the empirical driven machine break downs and worker efficiency, the current departmental capacity could be adjusted, providing a more valid and reliable result.

7.7.1.4 UWUK -machine maintenance

The *UWUK* -machine, as an automated solution for weighing and labelling, presents significant advantages, however, several challenges accompany an implementation of an automated solution.

Unplanned maintenance is a primary concern when operating with automated machines. These machines could regularly require specialized maintenance to prevent unexpected downtime. Unpanned downtime can significantly reduce the machines capacity and may require external experts due to the machine specialized nature (HighGear, 2024) (FieldCircle, 2024) (ManufacturingTomorrow, 2024). This reliance on external assistance could lead to sorting delays and additional costs.

As the machine is not present at Resource Denmark, no empirical data was collected concerning machine downtime, beside a 20% decrease in efficiency assumption. An empirical study could have been conducted in München, where the *UWUK* machine is present, to present a reliable capacity analysis of this implementation. Due to resources and time constraints, this study was no executed but is recommended as a future study to ensure accurate capacity planning. Operating with a reliable machine break down time could have influenced the final recommendation of this project, as no influential negative aspects of this alternative is currently present in this projects evaluation process.

7.7.2 MCDM

7.7.2.1 Criteria selection

The criteria selected for this project are based on Resource Denmark's priorities and a case study of 49 papers. These criteria portray a vital role for the final recommendation of this project, as the alternatives are measured against them. To validate these criteria, stakeholders at Resource Denmark were consulted. However, cross-validation by interviewing industry experts could have produced additional insights and validated the choice of criterion. Industry experts, with their greater experience in operating recycling plants, could assess the relevance of each chosen criteria. Their expertise could also introduce additional criteria for evaluating the alternatives. This process would validate and possible refine the current performance scores derives from the TOPSIS method, ensuring a comprehensive and accurate assessment of each identified alternative.

7.7.2.2 Additional alternatives

The TOPSIS analysis is based on four alternatives identified as potential modifications for the current P20, utilizing both internal and external sources.

It is highly likely that the current market contains more alternative methods for conducting P20, based on the requirements set by the potential customers. These unidentified alternatives have not been included in the TOPSIS analysis. Identifying additional alternatives, particularly automated solutions, could have influenced the outcome of the TOPSIS, given that the *UWUK* alternative was the only automated solution. To identity additional alternatives, more experts within the industry could have been interviews, based on their company's level of transparency.

Furthermore, interviews with label makers for products similar to plastic bales, could have been conducted, while also exploring customizable options, instead of only including standard solutions. Incorporating more alternatives, especially automated or semi-automated solutions, could also have led to a different result in the TOPSIS analysis.

7.7.2.3 Capacity analysis before TOPSIS

The ability to reallocate capacity for each alternative is based on their respective PFC, outlined in section 6.2.1. Empirical data, aside from the *Equipment upgrades*, was unavailable to substantiate to determine the capacity reallocation potential for each alternative. Consequently, the cycle time for the *UWUK* alternative is based on solely internal statement rather than empirical data. The collection of empirical data would have facilitated an accurate determination of cycle times for each alternative. Accurate cycle times could have enabled a capacity analysis prior to the TOPSIS, providing a quantitative measurement for each alternative, instead of the applied binary values in Table 14. Given the influential weight of this criterion, a capacity analysis demonstrating each alternative's ability to meet the expected capacity would have further validated the TOPSIS and provided a robust foundation for the exclusion of alternatives.

7.7.3 Financial analysis

7.7.3.1 Net Present Value analysis

As mentioned in section 7.3, and NPV analysis could not be conducted at the current stage of Resource Denmark. As the company is currently in the hot commissioning phase, the plant's current capacity does not align with the anticipated capacity showcased in table 1. It is not possible to assume a reliable revenue stream for Resource Denmark, as the current speed differs significantly from the expected sorting capacity. Based on the data from January 2024 to March 2024, the sorting capacity has shown an exponential increase, assuming this rate of increase in the sorting capacity, would not yield an accurate revenue forecast for the future, given the abnormally high percentage growth.

When the revenue becomes more stable, it will be beneficial to conduct an NPV analysis when comparing future alternatives. Using the NPV analysis, it is possible to evaluate the projected profitability and financial viability of each alternative considering the present value of expected future cash flows.

7.7.3.2 Sensitivity analysis on prices and their effect on the BEP

The selling price of sorted plastic is seen to change frequently based on the new technology available on the market (Resource Denmark, 2024) (Letsrecycle, 2024). For example, the price of mixed HDPE had the selling price of £405 per ton in 2021 that now has decreases to £310 in 2024 (Letsrecycle, 2024). With a frequent fluctuation in the selling price of sorted plastic, the current BEP of the *UWUK* implementation, shown in section 7.3 could be unreliable. To present Resource Denmark with a more comprehensive BEP, a sensitivity analysis could have been conducted for each plastic type's selling price. This analysis would have presented the Resource Denmark's stakeholders with a BEP of the investment based on the frequently fluctuating market for plastic. Conducting such an analysis would increase the reliability this project's financial calculations, as the current BEP could be inaccurate using the current markets selling price per ton.

Chapter 8: Appendix

8.1 Appendix 1: Calculation of sorting plant's capacity

This appendix showcases how the calculation for number of bales which the sorting plant can sort per day during each respective shift.

The sorting plant can sort 27 tons per hour, stated by Eggersmann, who is the supplier of the plant (Eggersmann, 2024). The normal shift type is 8 hours per day, with 30 minutes included break (Resource Denmark, 2024). Therefore, a working day is 7.5 hours, and for Friday the working day is short, so therefore 7 hours. This time is then deducted with the planned maintenance and meeting time during each day (Manager O. , 2024). This amount of time is set by the upper-level management of Resource Denmark. Based on this time an 80% efficiency is deducted from the remaining time, as this time represent efficient working time. The results of this showcase the efficient sorting time for the plant for each day of each shift.

Precondition:		
Sorting speed	27	tons/hour
Availability	90	%
Efficiency	90	%
Year	52	weeks

1 Shift setup

		Mon	Tue	Wed	Thu	Fri	Week	Month	Year
Day	hours	7,5	7,5	7,5	7,5	7	37,0	160	1924
Planned maint./meetings	hours	4	0,5	0,5	0,5	0,5	6,0	26	312
Sorting	hours	3,5	7,0	7,0	7,0	6,5	31,0	134	1612
Efficient sorting	hours	2,8	5,6	5,6	5,6	5,2	24,8	107	1290
Sorting capacity	**tons**	**76**	**151**	**151**	**151**	**140**	**670**	**2902**	**34819**

2 Shift setup

		Mon	Tue	Wed	Thu	Fri	Week	Month	Year
Day	hours	7,5	7,5	7,5	7,5	7	37,0	160	1924
Evening	hours	7	7	7	7	6	34,0	147	1768
Planned maint./meetings	hours	4	1	1	1	3	10,0	43	520
Sorting	hours	10,5	13,5	13,5	13,5	10,0	61,0	264	3172
Efficient sorting	hours	8,4	10,8	10,8	10,8	8,0	48,8	211	2538
Sorting capacity	**tons**	**227**	**292**	**292**	**292**	**216**	**1318**	**5710**	**68515**

3 Shift setup

		Mon	Tue	Wed	Thu	Fri	Week	Month	Year
Day	hours	7,5	7,5	7,5	7,5	7	37,0	160	1924
Evening	hours	7	7	7	7	6	34,0	147	1768
Night	hours	7	7	7	7	4	32	139	1664
Planned maint./meetings	hours	4	1,5	1,5	1,5	1,5	10	43	520
Sorting	hours	17,5	20,0	20,0	20,0	15,5	93,0	403	4836
Efficient sorting	hours	14,0	16,0	16,0	16,0	12,4	74,4	322	3869
Sorting capacity	**tons**	**378**	**432**	**432**	**432**	**335**	**2009**	**8705**	**104458**

3 Shift setup + weekendshift

		Mon	Tue	Wed	Thu	Fri	Sat	Sun	Week	Month	Year
Day	hours	7,5	7,5	7,5	7,5	7			37,0	160	1924
Evening	hours	7	7	7	7	6			34,0	147	1768
Night	hours	7	7	7	7	4			32	139	1664
Weekendshift	hours						12	12	12	52	624
Sorting	hours	17,5	20,0	20,0	20,0	15,5	10,0	10,0	93,0	403	4836
Efficient sorting	hours	14,0	16,0	16,0	16,0	12,4	8,0	8,0	75,3	326	3917
Sorting capacity	**tons**	**378**	**432**	**432**	**432**	**335**	**216**	**216**	**2441**	**10577**	**126922**

Table 25:Number of bales sorting plant can handle

Table 25 show what the automated sorting system is expected to handle in tons. This is the goal Resource Denmark, no other department should set the sorting speed.

8.2 Appendix 2: Bibliometric analysis of all reviewed literature

This appendix showcases the results of applying the bibliometric analysis on all literature applied for this project.

Source Name	Type	Authors	Year	Journal/Publisher	Citations	Reference
Supplier selection for aerospace & defense industry through	Article	Aksel Rasmussen, Haris Sabic, Subrata Saha, Izabela Ewa Nielsen	2022	Elsevier Ltd	15	68
Combining AHP and TOPSIS method for logistics	Article	Apichat Sopadang, Ruth Banomyong	2016	Inderscience Enterprises Ltd	7	37
Productivity improvement through work sampling	Article	Dr. James L. Jenkinds, D. L.	2004	AACE International	52	-
Application of Failure Mode Effect Analysis (FMEA) to Improve Medication Safety in the Dispensing Process – A Study at A Teaching Hospital, Sri Lanka	Case study	J. A. L. Anjalee, V. Rutter	2021	BMC Public Health	24	46
Analysing the past to prepare for the future: Writing a literature review	Article	Jane Webster, Richard T. Watson	2002	MIS Quarterly	8361	40
Using AHP and TOPSIS approaches in customer-driven product design process	Article	Ming-Chyuan Lin, Chen-Cheng Wang	2008	Computers in Industry	465	38
A Net-Present Value Analysis for a Wind Turbine Purchase at a Small US College	Case study	Nicholas H. Johnson, Barry Solomon	2010	Energies	16	25
How much behaviour change is required for the investment in cycling infrastructure to be sustainable? A break-even analysis	Case study	Paolo Candio, Emma Frew	2023	University of Trento	1	1177

Theory of Constraints – A Review of Its Philosophy and Its Applications	Article	Shams Rahman	1998	International Journal of Operations & Production Management	151	334
A Hermeneutic Approach for Conducting Literature Reviews and Literature Searches	Article	Sebastian K. Boell, Dubravka Cecez-Kecmanovic	2014	Communications of the Association for Information Systems	594	76
LCA for Manufacturing of Construction Materials using CO2 Mineral Carbonation Technology	Article	Sora Yi, Chang-sik Choi, Min-hye Seo, Sung-su Cho	2018	Journal of Korea Society of Waste Management	1	16
Project Net Present Value estimation under uncertainty	Article	Helena Gaspars-Wieloch	2017	CEJOR	35	-
The Effect of Product Introduction Delays on Operating Performance	Article	Kevin Hendricks, Vinod R. Singhal	2008	Management Science	123	33
Operations Management	Book	Nigel Slack, Alistair Brandon-Jones, Robert Johnston	2016	Pearson Education Limited	-	-
Investment decisions in Australian manufacturing	Article	N.B. Beaumont	1998	Technovation	16	689
Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS	Article	Serafim Opricovic, Gwo-Hshiung Tzeng	2004	European Journal of Operational Research	445	334
Using AHP and TOPSIS approaches in customer-driven product design process	Article	Ming-Chyuan Lin a, Chen-Cheng Wang a, Ming-Shi Chen a, C. Alec Chang b	2008	National Science Council	397	32
Customer involvement in product development	Article	Lisa Melander	2018	Ahead-of-print	24	59
Productivity improvements Work Sampling	Article	Dr. James L. Jenkinds, D. L.	2004	AACE International	53	-

Table 26: Bibliometric analysis of literature

8.3 Appendix 3: Full literature review for the initial problem analysis

This appendix will include literature review, which explores methodology that is not applied for this project based on the scope of this project.

Bhim Singh, Suresh K. Garg, and Surrender K. Sharma has written the paper *"Value stream mapping: literature review and implications for Indian industry"* which highlights its emergence as a preferred lean manufacturing technique (V. Ramesh, 2008). This paper conduct a thorough analysis across four categories: conceptual work, empirical/modelling work, case studies, and survey articles. A key component of the paper is a case study of a small Indian manufacturing industry, showcasing the application of VSM and its impact on reducing lead times, processing times, work-in-process inventory, and manpower requirements. As VSM is a method which can be used to showcase the gap between the current state and future state of Resource Denmark, the method focusses heavily on identifying waste and hereafter consults to take actions to eliminate these to improve key performance indicators such as lead time, transportation time, etc. As Resource Denmark is not running the sorting plant continuously yet, as the plant is still in the hot commissioning phase, they currently experience downtime on machinery and non-value adding activities from workers. The presence of inherent waste due to operational ramp-up indicates that while VSM offers valuable methodologies for long-term efficiency improvements, the primary focus for Resource Denmark is on analysing and streamlining processes rather than on waste elimination in the traditional sense.

Jaakko Nylund explores the methods of gathering data on a single workers processes and daily life in his paper *"Improving process Through Lean Management – A Case Study"* (Nylund, 2013). This study aims to enhance the departments flexibility and efficiency of Itella Logistics, focusing on their Customs and Forwarding department. The thesis applies various Lean principles and tools such as Value Stream Mapping, Competency Matrix, where "A Day in the Life OF" (DILO) analysis is conducted. This method records the action of a worker for two weeks and aims to records processes duration and identifying improvement areas by observing the daily activities of the worker. As this method is great for identifying each workers operating efficiency by measuring the value and non-value adding time, this is not the main goal of the analysis, as the current efficiency of the workers at Resource Denmark is expected to be low as there are still frequent machine downtime and recalibration of the machinery. Additionally due to the time limitations of the data and information collection, a multiple day's analysis of a single worker will not be the most useful method of collecting process data of a single worker.

8.4 Appendix 4: Calculation of number of bales in the IBD

This appendix will show the calculation of how the number of bales in the IBD is calculated.

To calculate the expected amount of bales the workers in the IBD must be able to handle, the results from Table 1 will be used. Table 1 showcase how many tons the sorting plant can handle, using an 80% worker efficiency, and a sorting capacity of 27 tons per hour.

To calculate the required number of bales in the IBD, the yearly number of tons must be converted into bales. To convert the yearly tons to yearly numbers of bales, Equation 10 will be applied.

$$Tons\ converted\ to\ bales\colon \frac{Required\ amount\ of\ tons}{1000\ kg} * bale\ weight \tag{10}$$

As the required number of tons which needs to be inserted to the plant is already known from Table 1, the bale weight must be determined.

Resource Denmark does not weight each single bale arriving in the inbound department. Rather than weighing each bale, they calculate the weight of load of the truck, and divides this total weight with the amount of bales the truck delivers. Doing this, an average weight of the load is registered inside database of Resource Denmark (Resource Denmark, 2024).

In Table 27, the average bale weight of each logged shipment can be seen and finding the average of all seven bales weight results in a bale weight of 557 kg in the inbound department.

Number of loads	Weight	Unit
Average bale weight 1	450	kg
Average bale weight 2	550	kg
Average bale weight 3	558	kg
Average bale weight 4	570	kg
Average bale weight 5	600	kg
Average bale weight 6	557	kg
Average bale weight 7	615	kg

Table 27: Average bale weight

Using the data from the IBD, the average bale weight is determined to be 557 kg per bale.

As both factors from Equation 1, is known, it is now possible to determine the number of bales which must be handled by the workers in the IBD.

Number of bales needs handling	
Shift type	**Bales**
Shift 1	62.512
Shift 2	123.008
Shift 3	187.536
Shift 3 + weekend	227.866

Table 28: Number of bales per shift

Table 28 showcases, operating with 1 shift, the employees in the IBD must be able to handle 62,500 bales per year, which consistently increases by each additional shift. With 3 + weekend shift, it can be seen the workers must be able to ha ndle 192,000 bales annually.

8.5 Appendix 5: Calculation of capacity in the IBD

This appendix will showcase the empirical study of cycle time loggings made on site in the inbound department at Resource Denmark and the capacity analysis for this department.

8.5.1 Cycle time loggings:

The date of the cycle time loggings for the inbound department is 27.02.2024 (Allaboutlean, 2024) (Researchgaps, 2024)

8.5.1.1 Process 10 cycle time loggings:

Worker	Process 10	From-to movement	Cycle time
	Forklift - manual process		
Worker 1	Off loading of bales form truck	Truck to ground	45
Worker 1	Off loading of bales form truck	Truck to ground	50
Worker 1	Off loading of bales form truck	Truck to ground	25
Worker 1	Off loading of bales form truck	Truck to ground	28
Worker 1	Off loading of bales form truck	Truck to ground	50
Worker 1	Off loading of bales form truck	Truck to ground	45
Worker 1	Off loading of bales form truck	Truck to ground	47
Worker 2	Off loading of bales form truck	Truck to ground	35
Worker 2	Off loading of bales form truck	Truck to ground	50
Worker 2	Off loading of bales form truck	Truck to ground	25
Worker 2	Off loading of bales form truck	Truck to ground	30
Worker 2	Off loading of bales form truck	Truck to ground	50
		Average cycle time (sec)	40

Table 29: Average cycle time of P10

8.5.1.2 Process 20 cycle time loggings:

	Process 20	From-to movemer	Cycle time	Comment
	Forklift - manual process			
Worker 2	Placing the offloaded bale in inventory	Unloading area to inventory	19	Close locaton
Worker 2	Placing the offloaded bale in inventory	Unloading area to inventory	45	Far location
Worker 2	Placing the offloaded bale in inventory	Unloading area to inventory	50	Far location
Worker 2	Placing the offloaded bale in inventory	Unloading area to inventory	30	
Worker 2	Placing the offloaded bale in inventory	Unloading area to inventory	23	
Worker 1	Placing the offloaded bale in inventory	Unloading area to inventory	15	Close location
Worker 1	Placing the offloaded bale in inventory	Unloading area to inventory	40	Far location
Worker 1	Placing the offloaded bale in inventory	Unloading area to inventory	36	
Worker 1	Placing the offloaded bale in inventory	Unloading area to inventory	34	
Worker 1	Placing the offloaded bale in inventory	Unloading area to inventory	28	Close location
		Average cycle time (sec)	32	

Table 30:Average cycle time of P20

8.5.1.3 Process 30 cycle time loggings:

	Process 30	From-to movement		Comment
	Forklift - manual process			
Worker 1	Picking a bale from inventory and placing it in loading area	Inventory area to loading area	48	
Worker 1	Picking a bale from inventory and placing it in loading area	Inventory area to loading area	60	Held still for some time
Worker 1	Picking a bale from inventory and placing it in loading area	Inventory area to loading area	35	Close inventory area
Worker 1	Picking a bale from inventory and placing it in loading area	Inventory area to loading area	45	
Worker 1	Picking a bale from inventory and placing it in loading area	Inventory area to loading area	47	
Worker 1	Picking a bale from inventory and placing it in loading area	Inventory area to loading area	53	
Worker 1	Picking a bale from inventory and placing it in loading area	Inventory area to loading area	55	
Worker 1	Picking a bale from inventory and placing it in loading area	Inventory area to loading area	55	Far inventory area
Worker 1	Picking a bale from inventory and placing it in loading area	Inventory area to loading area	45	
Worker 1	Picking a bale from inventory and placing it in loading area	Inventory area to loading area	39	
Worker 1	Picking a bale from inventory and placing it in loading area	Inventory area to loading area	35	
		Average	47	

Table 31: Average cycle time of P30

8.5.1.4 Process 40 cycle time loggings:

	Process 40	From-to movement	Cycle time	Comment
	Crane - manual process			
Worker 1	Lifting bale from loading area and into the shredder	Loading area to shredder	85	Grabbed bale and held still
Worker 1	Lifting bale from loading area and into the shredder	Loading area to shredder	65	
Worker 1	Lifting bale from loading area and into the shredder	Loading area to shredder	69	
Worker 1	Lifting bale from loading area and into the shredder	Loading area to shredder	67	
Worker 1	Lifting bale from loading area and into the shredder	Loading area to shredder	75	
Worker 1	Lifting bale from loading area and into the shredder	Loading area to shredder	79	Grabbed bale and held still
Worker 1	Lifting bale from loading area and into the shredder	Loading area to shredder	69	
Worker 1	Lifting bale from loading area and into the shredder	Loading area to shredder	72	
Worker 1	Lifting bale from loading area and into the shredder	Loading area to shredder	70	
Worker 1	Lifting bale from loading area and into the shredder	Loading area to shredder	71	
Worker1	Lifting bale from loading area and into the shredder	Loading area to shredder	67	
		Average cycle time (sec)	72	

Table 32: Average cycle time of P40

Based on these cycle time loggings the following PFC generated.

This is also the PFC used in the project.

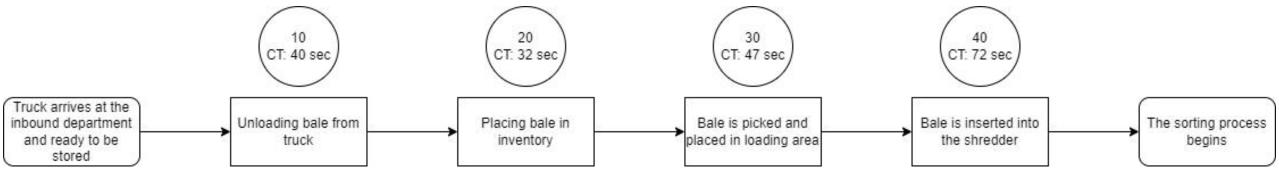


Figure 15: PFC of IBD

8.5.2 Inbound department capacity analysis:

8.5.1.1 Shift 1:

1. Shift

Process 10 + 20	Unit	Mon	Tue	Wed	Thu	Fri	Week	Year
Day	Sec	27.000	27.000	27.000	27.000	25.200	133.200	6.926.400
Planned maint./meetings	Sec	14.400	1.800	1.800	1.800	1.800	21.600	1.123.200
Sorting	Sec	12.600	25.200	25.200	25.200	23.400	111.600	5.803.200
Efficient sorting (80%)	Sec	10.080	20.160	20.160	20.160	18.720	89.280	4.642.560
Cycle time	Sec	72	72	72	72	72	72	
Sorting capacity	**Bales**	**140**	**280**	**280**	**280**	**260**	**1.240**	**64.480**

1. Shift

Process 30	Unit	Mon	Tue	Wed	Thu	Fri	Week	Year
Day	Sec	27.000	27.000	27.000	27.000	25.200	133.200	6.926.400
Planned maint./meetings	Sec	14.400	1.800	1.800	1.800	1.800	21.600	1.123.200
Sorting	Sec	12.600	25.200	25.200	25.200	23.400	111.600	5.803.200
Efficient sorting (80%)	Sec	10.080	20.160	20.160	20.160	18.720	89.280	4.642.560
Cycle time	Sec	47	47	47	47	47	47	
Sorting capacity	**Bales**	**214**	**429**	**429**	**429**	**398**	**1.900**	**98.778**
Sorting capacity	**Tons**	**119**	**239**	**239**	**239**	**222**	**1.058**	**55.009**

1. Shift

Process 40	Unit	Mon	Tue	Wed	Thu	Fri	Week	Year
Day	Sec	27.000	27.000	27.000	27.000	25.200	133.200	6.926.400
Planned maint./meetings	Sec	14.400	1.800	1.800	1.800	1.800	21.600	1.123.200
Sorting	Sec	12.600	25.200	25.200	25.200	23.400	111.600	5.803.200
Efficient sorting (80%)	Sec	10.080	20.160	20.160	20.160	18.720	89.280	4.642.560
Cycle time	Sec	69	69	69	69	69	69	
Sorting capacity	**Bales**	**146**	**292**	**292**	**292**	**271**	**1.294**	**67.283**
Sorting capacity	**Tons**	**81**	**163**	**163**	**163**	**151**	**721**	**37.470**

Table 33: IBD capacity 1 shift

8.5.1.2 Shift 2:

2. Shift

Process 10 + 20	Unit	Mon	Tue	Wed	Thu	Fri	Week	Year
Day	Sec	52.200	52.200	52.200	52.200	46.800	255.600	13.291.200
Planned maint./meetings	Sec	14.400	3.600	3.600	3.600	10.800	36.000	1.872.000
Sorting	Sec	37.800	48.600	48.600	48.600	36.000	219.600	11.419.200
Efficient sorting (80%)	Sec	30.240	38.880	38.880	38.880	28.800	175.680	9.135.360
Cycle time	Sec	72	72	72	72	72	72	
Sorting capacity	**Bales**	**420**	**540**	**540**	**540**	**400**	**2.440**	**126.880**

2. Shift

Process 30	Unit	Mon	Tue	Wed	Thu	Fri	Week	Year
Day	Sec	52.200	52.200	52.200	52.200	46.800	255.600	13.291.200
Planned maint./meetings	Sec	14.400	3.600	3.600	3.600	10.800	36.000	1.872.000
Sorting	Sec	37.800	48.600	48.600	48.600	36.000	219.600	11.419.200
Efficient sorting (80%)	Sec	30.240	38.880	38.880	38.880	28.800	153.720	7.993.440
Cycle time	Sec	47	47	47	47	47	47	
Sorting capacity	**Bales**	**643**	**827**	**827**	**827**	**613**	**3.271**	**170.073**
Sorting capacity	**Tons**	**358**	**461**	**461**	**461**	**341**	**2.082**	**108.243**

2. Shift

Process 40	Unit	Mon	Tue	Wed	Thu	Fri	Week	Year
Day	Sec	52.200	52.200	52.200	52.200	46.800	255.600	13.291.200
Planned maint./meetings	Sec	14.400	3.600	3.600	3.600	10.800	36.000	1.872.000
Sorting	Sec	37.800	48.600	48.600	48.600	36.000	219.600	11.419.200
Efficient sorting (80%)	Sec	30.240	38.880	38.880	38.880	28.800	175.680	9.135.360
Cycle time	Sec	69	69	69	69	69	69	
Sorting capacity	**Bales**	**438**	**563**	**563**	**563**	**417**	**2.546**	**132.397**
Sorting capacity	**Tons**	**244**	**314**	**314**	**314**	**232**	**1.418**	**73.730**

Table 34: IBD capacity 2 shift

8.5.1.3 Shift 3:

3. Shift

Process 10 + 20	Unit	Mon	Tue	Wed	Thu	Fri	Week	Year
Day	Sec	77.400	77.400	77.400	77.400	61.200	370.800	19.281.600
Planned maint./meetings	Sec	14.400	5.400	5.400	5.400	5.400	36.000	1.872.000
Sorting	Sec	63.000	72.000	72.000	72.000	55.800	334.800	17.409.600
Efficient sorting (80%)	Sec	50.400	57.600	57.600	57.600	44.640	267.840	13.927.680
Cycle time	Sec	72	72	72	72	72	72	
Sorting capacity	**Bales**	**700**	**800**	**800**	**800**	**620**	**3.720**	**193.440**

3. Shift

Process 30	Unit	Mon	Tue	Wed	Thu	Fri	Week	Year
Day	Sec	77.400	77.400	77.400	77.400	61.200	370.800	19.281.600
Planned maint./meetings	Sec	14.400	5.400	5.400	5.400	5.400	36.000	1.872.000
Sorting	Sec	63.000	72.000	72.000	72.000	55.800	334.800	17.409.600
Efficient sorting (80%)	Sec	50.400	57.600	57.600	57.600	44.640	267.840	13.927.680
Cycle time	Sec	47	47	47	47	47	47	
Sorting capacity	**Bales**	**1.072**	**1.226**	**1.226**	**1.226**	**950**	**5.699**	**296.334**
Sorting capacity	**Tons**	**597**	**682**	**682**	**682**	**529**	**3.174**	**165.026**

3. Shift

Process 40	Unit	Mon	Tue	Wed	Thu	Fri	Week	Year
Day	Sec	77.400	77.400	77.400	77.400	61.200	370.800	19.281.600
Planned maint./meetings	Sec	14.400	5.400	5.400	5.400	5.400	36.000	1.872.000
Sorting	Sec	63.000	72.000	72.000	72.000	55.800	334.800	17.409.600
Efficient sorting (80%)	Sec	50.400	57.600	57.600	57.600	44.640	267.840	13.927.680
Cycle time	Sec	69	69	69	69	69	69	
Sorting capacity	**Bales**	**730**	**835**	**835**	**835**	**647**	**3.882**	**201.850**
Sorting capacity	**Tons**	**407**	**465**	**465**	**465**	**360**	**2.162**	**112.409**

Table 35: IBD capacity 3 shift

8.5.1.4 Shift 3 + weekend:

3. Shift + weekend

Process 10 + 20	Unit	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Week	Year
Day	Sec	77.400	77.400	77.400	77.400	61.200	43.200	43.200	457.200	23.774.400
Planned maint./meetings	Sec	14.400	5.400	5.400	5.400	5.400	7.200	7.200	50.400	2.620.800
Sorting	Sec	63.000	72.000	72.000	72.000	55.800	36.000	36.000	406.800	21.153.600
Efficient sorting (80%)	Sec	50.400	57.600	57.600	57.600	44.640	28.800	28.800	325.440	16.922.880
Cycle time	Sec	72	72	72	72	72	72	72	72	
Sorting capacity	**Bales**	**700**	**800**	**800**	**800**	**620**	**400**	**400**	**4.520**	**235.040**

3. Shift + weekend

Process 30	Unit	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Week	Year
Day	Sec	77.400	77.400	77.400	77.400	61.200	43.200	43.200	457.200	23.774.400
Planned maint./meetings	Sec	14.400	5.400	5.400	5.400	5.400	7.200	7.200	50.400	2.620.800
Sorting	Sec	63.000	72.000	72.000	72.000	55.800	36.000	36.000	406.800	21.153.600
Efficient sorting (80%)	Sec	50.400	57.600	57.600	57.600	44.640	28.800	28.800	325.440	16.922.880
Cycle time	Sec	47	47	47	47	47	47	47	47	
Sorting capacity	**Bales**	**1.072**	**1.226**	**1.226**	**1.226**	**950**	**613**	**613**	**6.924**	**360.061**
Sorting capacity	**Tons**	**597**	**682**	**682**	**682**	**529**	**341**	**341**	**3.856**	**200.515**

3. Shift + weekend

Process 40	Unit	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Week	Year
Day	Sec	77.400	77.400	77.400	77.400	61.200	43.200	43.200	457.200	23.774.400
Planned maint./meetings	Sec	14.400	5.400	5.400	5.400	5.400	7.200	7.200	50.400	2.620.800
Sorting	Sec	63.000	72.000	72.000	72.000	55.800	36.000	36.000	406.800	21.153.600
Efficient sorting (80%)	Sec	50.400	57.600	57.600	57.600	44.640	28.800	28.800	325.440	16.922.880
Cycle time	Sec	69	69	69	69	69	69	69	69	
Sorting capacity	**Bales**	**730**	**835**	**835**	**835**	**647**	**417**	**417**	**4.717**	**245.259**

Table 36: IBD capacity 3+ weekend shift

8.6 Appendix 6: Number of bales entering the OBD

Prior to the operational launch in January, Eggersmann provided Resource Denmark with a theoretical mass balance sheet based on the input and outputs from their previous projects (Eggersmann, 2024). This theoretical mass balance sheet can be seen in Figure 16.

Material	Percentage	Total weight (Mg/a)
Dirt and stones	7%	2.205
Ferrous metals	1%	315
Non ferrous metals	1%	315
PS	5%	1.575
HDPE	8%	2.520
LDPE	35%	11.025
PP	16%	5.040
Tetrapack	10%	3.150
PET	10%	3.150
Other Plastics types	4%	1.260
PVC	3%	945
Total amount (ton)	100%	31.500

Figure 16: Theoretical Mass Balance Sheet

As garbage differs from country to country, and even municipalities to municipalities, it would be more ideal to construct a data driven mass balance sheet (director, 2024) (Manager T. , 2024). A data driven mass balance sheet would be more applicable for Resource Denmark.

However, as the plant is operational for nearly two months now, and receiving plastic waste from Finland, there is an opportunity to develop a mass balance sheet based on Resource Denmark's current data and sorting efficiencies.

To develop an accurate mass balance sheet reflecting on Resource Denmark's data, it is essential to gather the following data on the sorting plant performance:

1. The total volume of compressed garbage introduced into the sorting plant
2. The quantity of LDPE, PP, PET, HDPE, PS, and Tetra extracted from the sorting plant

For the empirical study of this project, data has been collected spanning from the 1st of February to the end of February, covering week 6 through 9 of the year 2024. Table 37 details the weekly input of compressed waste into the sorting plant.

Compressed bales inserted into the sorting plant					
Month	Febuary 2024				
Week	**Week 6**	**Week 7**	**Week 8**	**Week 9**	**Total**
Amount of bales	361	559	661	691	2.272
Total weight (kg)	191.700	302.000	327.100	186.114	1.006.914

Table 37: Total amount of compressed bales inserted into the plant (Resource Denmark, 2024)

In week six, marking the start of the month, Resource Denmark processed 361 mixed plastic bales, a key figure that nearly doubled to 691 bales just two weeks later. Furthermore, an average weight has been calculated for the bales each week, revealing an estimated average compressed bale weight of 533 kg. The details supporting these calculations are shown in Table 38+39.

The next essential piece of data required from Resource Denmark to construct an accurate mass balance sheet is the bale quantity of each type of plastic sorted. The output directly correlates to the number of mixed plastic bales, which are fed into the sorting plant. Table 38+39 displays the quantity of the five plastic types and Tetra sorted through week six through nine.

	Input	
	Baller	Vægt
	99	46.900
	100	54.000
	80	43.000
6	82	47.800
	361	**191.700**
Status	78	46.400
	60	35.200
	136	65.400
7	128	72.400
	157	82.600
Status	**559**	**302.000**
	71	34.900
8	167	86.900
	1,546	1,3639
	241	102.400
	182	102.900
Status		
	661	**327.100**
	153	87.100
9	196	99.014
	0	0

Table 38: Raw inventory data

							LDPE, PP film		PP		PET		HDPE, PP		HDPE		PS	
							Baller	Vægt	Baller	Vægt	Baller	Vægt	Baller	Vægt	Baller	Vægt	Baller	Vægt
Status	*Friday, 2 February 2024*	269	74.378				17	10.682	154	14.985	20	9.809	20	9.905	35	17.432	23	11.566
	Monday, 5 February 2024	34	17.317				9	5.757	11	4.681	4	2.100	5	2.382	5	2.397	0	0
	Monday, 5 February 2024	0	0															
	Tuesday, 6 February 2024	53	27.763	59%	99	46.900	16	10.797	14	5.857	6	3.112	8	3.819	7	3.208	2	970
	Tuesday, 6 February 2024	-103	-51.840										-55	-27.960	-48	-23.880		
	Wednesday, 7 February 2024	40	20.697	38%	100	54.000	11	7.220	13	5.453	4	2.058	10	5.020	1	445	1	501
	Wednesday, 7 February 2024	-97	-54.080				-43	-28.440	54	-25.640								
6	Thursday, 8 February 2024	54	27.159	63%	80	43.000	13	8.702	17	6.926	6	3.037	12	5.714	4	1.819	2	961
	Thursday, 8 February 2024	-8	-4.961				-6	-4.010							-2	-951		
	Friday, 9 February 2024	61	31.283	65%	82	47.800	17	11.447	24	10.021	7	3.521	10	4.917	2	899	1	478
	Friday, 9 February 2024	0	0															
	EXIT Warehouse	**303**	**87.716**				**34**	**22.155**	**179**	**22.283**	**47**	**23.637**	**10**	**3.797**	**4**	**1.369**	**29**	**14.476**
	Produceret / uge (%)	**100%**	**100%**				[illegible]	**35%**	**33%**	**27%**	**11%**	**11%**	**19%**	**18%**	**8%**	**7%**	**2%**	**2%**
	Produceret / uge (kg)	**242**	**124.219**	65%	**361**	**191.700**	**66**	[illegible]	**79**	**32.938**	**27**	**13.828**	**45**	**21.852**	**19**	**8.768**	**6**	**2.910**
Status	*Friday, 9 February 2024*	237	136.941				44	30.396	59	32.791	51	28.660	46	25.789	8	4.352	29	14.953
	Monday, 12 February 2024	55	29.408	63%	78	46.400	15	10.326	17	7.074	8	4.261	10	5.400	4	1.859	1	488
	Monday, 12 February 2024	-150	-84.340				-43	-28.840			-53	-27.540	-54	-27.960				
	Tuesday, 13 February 2024	48	23.495	67%	60	35.200	10	7.080	16	6.353	8	3.957	8	3.853	5	1.779	1	473
	Tuesday, 13 February 2024	-54	-22.320						-54	-22.320								
	Wednesday, 14 February 2024	87	47.483	73%	136	65.400	24	15.941	25	11.511	15	8.717	13	6.817	8	3.397	2	1.100
	Wednesday, 14 February 2024	-87	-39.594						-54	-22.580							-33	-17.014
7	Thursday, 15 February 2024	81	47.011	65%	128	72.400	22	14.824	20	10.105	15	9.064	14	8.362	8	3.896	2	760
	Thursday, 15 February 2024	-43	-29.160				-43	-29.160										
	Friday, 16 February 2024	100	60.121	73%	157	82.600	28	19.303	25	13.237	20	12.636	14	8.416	9	4.536	4	1.993
	Friday, 16 February 2024	-101	-55.580						-48	-24.320	-53	-31.260						
	EXIT Warehouse	**173**	**113.465**				**57**	**39.870**	**6**	**11.851**	**11**	**8.495**	**51**	**30.677**	**42**	**19.819**	**6**	**2.753**
	Produceret / uge (%)	**100%**	**100%**				**27%**	**33%**	**28%**	**23%**	**18%**	**19%**	**16%**	**16%**	**9%**	**7%**	**3%**	**2%**
	Produceret / uge (kg)	**371**	**207.518**	69%	**559**	**302.000**	**99**	**67.474**	**103**	**48.280**	**66**	**38.635**	**59**	**32.848**	**34**	**15.467**	**10**	**4.814**
Status	*Friday, 9 February 2024*	169	111.031				57	39.870	6	11.851	10	7.723	49	29.474	42	19.819	5	2.294
	Monday, 19 February 2024	0	0				0	0	0	0	0	0	0	0	0	0	0	0
	Monday, 19 February 2024	-43	-29.660				-43	-29.660										
	Tuesday, 20 February 2024	43	24.280	70%	71	34.900	12	8.109	10	4.696	10	5.901	7	3.535	4	2.039	0	0
	Tuesday, 20 February 2024	-55	-30.580										-55	-30.580				
	Wednesday, 21 February 2024	108	63.715	73%	167	86.900	32	21.409	27	13.709	21	13.848	14	7.808	11	5.494	3	1.447
	Wednesday, 21 February 2024	-91	-51.820		1,546	1,3639	-43	-29.300							-48	-22.520		
8	Thursday, 22 February 2024	132	74.081	72%	241	102.400	39	26.538	36	16.262	27	16.000	18	9.549	10	4.706	2	1.026
	Thursday, 22 February 2024	-54	-26.740						-54	-26.740								
	Friday, 23 February 2024	141	79.288	77%	182	102.900	41	27.867	36	15.816	26	16.175	20	10.945	12	5.528	6	2.957
	Friday, 23 February 2024	-53	-32.880								-53	-32.880						
	EXIT Warehouse	**297**	**180.715**				**95**	**64.833**	**61**	**35.594**	**41**	**26.767**	**53**	**30.731**	**31**	**15.066**	**16**	**7.724**
	Produceret / uge (%)	**100%**	**100%**				**29%**	**35%**	**26%**	**21%**	**20%**	**22%**	**14%**	**13%**	**9%**	**7%**	**3%**	**2%**
	Produceret / uge (kg)	**424**	**241.364**	74%	**661**	**327.100**	**124**	**83.923**	**109**	**50.483**	**84**	**51.924**	**59**	**31.837**	**37**	**17.767**	**11**	**5.430**
Status	*Friday, 23 February 2024*	247	146.960				50	34.122	62	36.178	39	25.461	49	28.411	30	14.580	17	8.207
	Monday, 26 February 2024	97	55.335	64%	153	87.100	24	16.106	24	11.001	20	12.626	15	8.350	12	6.286	2	966
	Monday, 26 February 2024	-196	-110.560				-43	-29.340	-54	-23.960	-44	-27.280	-55	-29.980				
	Tuesday, 27 February 2024	127	72.597		196	99.014	35	23.474	33	14.360	24	15.847	20	11.656	11	5.216	4	2.044
	Tuesday, 27 February 2024	-91	-52.060				-43	-29.120							-48	-22.940		
	Wednesday, 28 February 2024	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Wednesday, 28 February 2024	0	0															
9	Thursday, 29 February 2024	0	0				0	0	0	0	0	0	0	0	0	0	0	0
	Thursday, 29 February 2024	0	0															
	Friday, 1 March 2024	0	0				0	0	0	0	0	0	0	0	0	0	0	0
	Friday, 1 March 2024	0	0															
	EXIT Warehouse	**184**	**112.272**				**23**	**15.242**	**65**	**37.579**	**39**	**26.654**	**29**	**18.437**	**5**	**3.142**	**23**	**11.217**
	Produceret / uge (%)	**100%**	**100%**				**26%**	**31%**	**25%**	**20%**	**20%**	**22%**	**16%**	**16%**	**10%**	**9%**	**3%**	**2%**
	Produceret / uge (kg)	**224**	**127.932**	69%	**349**	**186.114**	**59**	**39.580**	**57**	**25.361**	**44**	**28.473**	**35**	**20.006**	**23**	**11.502**	**6**	**3.010**

All these positive weights are added together to showcase how much tons have been sorted to each of the plastic

Table 39: Resource Denmark inventory records

Gathered plastic W6,7,8,9	Total amount of bales	Total weight (kg)
LDPE	348	234.900
PP	348	157.062
PET	221	132.860
HDPE	198	112.292
PS	33	16.164
Tetra	0	0
Total	1.148	653.278

Table 40: Total amount of bales per plastic type

Using the key figure from Table 39, it is possible to calculate the plastic types size in relation to the total weight. This is calculated by using Equation 11.

$$Percentage\ of\ total\ weight\ (\%): \frac{Total\ weight\ of\ sorted\ plastic\ type}{Total\ amount\ of\ plastic\ inserted\ into\ the\ plant} * 100\% \quad (11)$$

The total amount of plastic inserted into the plant be seen in Table 37, while the total weight of the sorted plastic type can be seen in Table 40. Therefore, both factors in this calculation is known, and can be calculated without further investigation. The percentage of each plastic compared to the total weight can be seen in Table 41.

Gathered plastic W6,7,8,9	Total amount of bales	Total weight	Percentage of total weight
LDPE	421	284.529	23%
PP	415	186.835	15%
PET	266	161.020	13%
HDPE	229	129.401	11%
PS	38	18.645	2%
Tetra	0	0	10%
Total	1.369	780.430	74%

Table 41: Percentage of each plastic compared to the total amount inserted into the plant

Examining the data from weeks six to nine, reveals that 64% of the total weight input into the sorting plant is effectively sorted into the following type of plastic: 23% LDPE, 15% PP, 13% PET, 11% HDPE, and 2% PS. Notably no Tetra was identified in the sorted output during this period. Questioning this, the Traceability Manager from Resource Denmark clarifies that Tetra is absent from the Finnish plastic waste, as it is segregated along with other materials before reaching Resource Denmark (Manager T. , 2024). Consequently, 64% of the compressed plastic waste introduced into the sorting system is processed and prepared for sale to plastic manufacturer, according to the operational data. Despite the absence of Tetra in the current sorting data, this project will utilize the original 10% allocation for Tetra from Eggersmann's theoretical mass balance sheet, as detailed in Figure 2. With the percentages documented in Table 46, a data-based mass balance sheet for Resource Denmark's sorting plant has been constructed.

With the percentages documented in Table 41, a data-based mass balance sheet for Resource Denmark's sorting plant has been constructed. This refined mass balance sheet is presented in Table 42 with an example of inserting 100,000 tons mixed plastic waste

Input	**100.000**			
Material	**Percentage**	**Total weight (ton)**	**Average bale weight (kg)**	**Amount of bales**
PS	2%	1.605	451	3.557
HDPE	11%	11.152	567	19.664
LDPE	23%	23.329	675	34.561
PP	16%	15.598	451	34.561
Tetrapack	10%	10.000	557	17.957
PET	13%	13.195	601	21.948
Total amount (ton)	75%	74.879		132.248

Table 42: Example of inserting 100,000 tons plastic waste in the plant

Based on this example, Resource Denmark can anticipate the following outputs for the various plastic types. For LDPE an estimated 23,000 tons of LDPE can be expected from this volume, which equals to around 35,000 bales which needs to be handled. The number of bales is calculated using the respective average weight of the sorted plastic type.

With the use of this data driven mass balance sheet, it is possible to determine how many bales of each plastic type will enter the OBD depending on sorting capacity across the various shift operations.

8.6.1 Expected bales for each respective shift

As it is known how much material will be inserted into the sorting plant, showcased in Table 1, it is possible to insert the input data for each shift operation and the number of bales will be presented using the mass balance sheet. Table 43 showcases the total amount of bales the OBD workers must be able to handle during the respective shifts.

Shift 1				
Input	**34819**			
Material	**Percentage**	**Total weight (ton)**	**Average bale weight (kg)**	**Amount of bales**
PS	2%	559	451	1.238
HDPE	11%	3.883	567	6.847
LDPE	23%	8.123	675	12.034
PP	16%	5.431	451	12.034
Tetrapack	10%	3.482	557	6.252
PET	13%	4.594	601	7.642
Total amount (ton)	75%	26.072		46.048

Shift 2				
Input	**68515**			
Material	**Percentage**	**Total weight (ton)**	**Average bale weight (kg)**	**Amount of bales**
PS	2%	1.100	451	2.437
HDPE	11%	7.641	567	13.473
LDPE	23%	15.984	675	23.680
PP	16%	10.687	451	23.680
Tetrapack	10%	6.852	557	12.303
PET	13%	9.040	601	15.038
Total amount (ton)	75%	51.304		90.610

Shift 3				
Input	**104458**			
Material	**Percentage**	**Total weight (ton)**	**Average bale weight (kg)**	**Amount of bales**
PS	2%	1.677	451	3.715
HDPE	11%	11.649	567	20.541
LDPE	23%	24.369	675	36.102
PP	16%	16.294	451	36.102
Tetrapack	10%	10.446	557	18.757
PET	13%	13.783	601	22.927
Total amount (ton)	75%	78.217		138.143

Shift 3 + weekend				
Input	**126922**			
Material	**Percentage**	**Total weight (ton)**	**Average bale weight (kg)**	**Amount of bales**
PS	2%	2.037	451	4.514
HDPE	11%	14.154	567	24.958
LDPE	23%	29.609	675	43.865
PP	16%	19.798	451	43.865
Tetrapack	10%	12.692	557	22.791
PET	13%	16.747	601	27.857
Total amount (ton)	75%	95.038		167.851

Table 43: Total number of bales for each shift operation

The projections indicate that operating with a single shift result in a yearly output of 46,000 bales. With the addition of a second shift, the annual output doubles to approximately 90,500 bales. Furthermore, expanding to three shifts escalates the number of bales to 138,000 bales annually, and incorporating weekend shifts, further increases the total to approximately 168,000 bales annually. For the purpose of this project, the specific composition of the bales is less significant than understanding the total number of bales which will be processed and ready for the OBD for handling. This volume of output allows for an assessment of Resource Denmark's current operational capacity, considering their process and cycle times, to determine if they can accommodate the projected capacity demands associated with each shift.

8.7 Appendix 7: Vertical view of the outbound departments PFC

This appendix showcases the PFC of the OBD in a horizontal view.

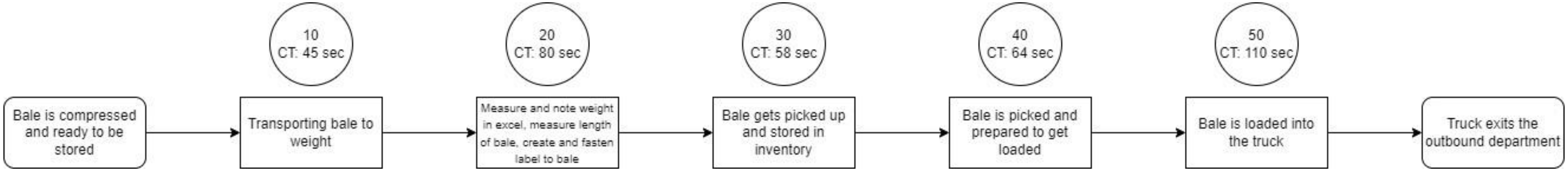


Figure 17: Horizontal view of OBD PFC

The text in process 10 is: Transporting the bale to the weight

The text in process 20 is: Measure and note weight in excel, measure length of bale, create and fasten label to bale

The text in process 30 is: Bale gets picked up and stored in inventory

The text in process 40 is: Bale is picked and prepared to get loaded

The text in process 50 is: Bale is loaded into truck

8.8 Appendix 8: Calculation of capacity in the OBD

This appendix showcases the calculation of the outbound workers capacity using the same methodology as shown in the inbound department of worker 1 operating process 10 in a 1 shift operation.

8.8.1 Shift 1:

1. Shift

Process 10 + 30	Unit	Mon	Tue	Wed	Thu	Fri	Week	Year
Day	Sec	27.000	27.000	27.000	27.000	25.200	133.200	6.926.400
Planned maint./meetings	Sec	14.400	1.800	1.800	1.800	1.800	21.600	1.123.200
Sorting	Sec	12.600	25.200	25.200	25.200	23.400	111.600	5.803.200
Efficient sorting (80%)	Sec	10.080	20.160	20.160	20.160	18.720	89.280	4.642.560
Cycle time	Sec	103	103	103	103	103	103	
Sorting capacity	**Bales**	**98**	**196**	**196**	**196**	**182**	**867**	**45.073**
Sorting capacity	**Tons**	**54**	**109**	**109**	**109**	**101**	**483**	**25.101**

1. Shift

Process 20	Unit	Mon	Tue	Wed	Thu	Fri	Week	Year
Day	Sec	27.000	27.000	27.000	27.000	25.200	133.200	6.926.400
Planned maint./meetings	Sec	14.400	1.800	1.800	1.800	1.800	21.600	1.123.200
Sorting	Sec	12.600	25.200	25.200	25.200	23.400	111.600	5.803.200
Efficient sorting (80%)	Sec	10.080	20.160	20.160	20.160	18.720	89.280	4.642.560
Cycle time	Sec	80	80	80	80	80	80	
Sorting capacity	**Bales**	**126**	**252**	**252**	**252**	**234**	**1.116**	**58.032**
Sorting capacity	**Tons**	**70**	**140**	**140**	**140**	**130**	**621**	**32.318**

1. Shift

Process 40 - 50	Unit	Mon	Tue	Wed	Thu	Fri	Week	Year
Day	Sec	27.000	27.000	27.000	27.000	25.200	133.200	6.926.400
Planned maint./meetings	Sec	14.400	1.800	1.800	1.800	1.800	21.600	1.123.200
Sorting	Sec	12.600	25.200	25.200	25.200	23.400	111.600	5.803.200
Efficient sorting (80%)	Sec	10.080	20.160	20.160	20.160	18.720	89.280	4.642.560
Cycle time	Sec	174	174	174	174	174	174	
Sorting capacity	**Bales**	**58**	**116**	**116**	**116**	**108**	**514**	**26.733**
Sorting capacity	**Tons**	**32**	**65**	**65**	**65**	**60**	**286**	**14.887**

Table 44: OBD workers capacity in shift 1

8.8.2 Shift 2:

2. Shift

Process 10 + 30	Unit	Mon	Tue	Wed	Thu	Fri	Week	Year
Day	Sec	52.200	52.200	52.200	52.200	46.800	255.600	13.291.200
Planned maint./meetings	Sec	14.400	3.600	3.600	3.600	10.800	36.000	1.872.000
Sorting	Sec	37.800	48.600	48.600	48.600	36.000	219.600	11.419.200
Efficient sorting (80%)	Sec	30.240	38.880	38.880	38.880	28.800	175.680	9.135.360
Cycle time	Sec	103	103	103	103	103	103	
Sorting capacity	**Bales**	**294**	**377**	**377**	**377**	**280**	**1.706**	**88.693**
Sorting capacity	**Tons**	**163**	**210**	**210**	**210**	**156**	**950**	**49.392**

2. Shift

Process 20	Unit	Mon	Tue	Wed	Thu	Fri	Week	Year
Day	Sec	52.200	52.200	52.200	52.200	46.800	255.600	13.291.200
Planned maint./meetings	Sec	14.400	3.600	3.600	3.600	10.800	36.000	1.872.000
Sorting	Sec	37.800	48.600	48.600	48.600	36.000	219.600	11.419.200
Efficient sorting (80%)	Sec	30.240	38.880	38.880	38.880	28.800	175.680	9.135.360
Cycle time	Sec	80	80	80	80	80	80	
Sorting capacity	**Bales**	**378**	**486**	**486**	**486**	**360**	**2.196**	**114.192**
Sorting capacity	**Tons**	**211**	**271**	**271**	**271**	**200**	**1.223**	**63.593**

2. Shift

Process 40 - 50	Unit	Mon	Tue	Wed	Thu	Fri	Week	Year
Day	Sec	52.200	52.200	52.200	52.200	46.800	255.600	13.291.200
Planned maint./meetings	Sec	14.400	3.600	3.600	3.600	10.800	36.000	1.872.000
Sorting	Sec	37.800	48.600	48.600	48.600	36.000	219.600	11.419.200
Efficient sorting (80%)	Sec	30.240	38.880	38.880	38.880	28.800	175.680	9.135.360
Cycle time	Sec	174	174	174	174	174	174	
Sorting capacity	**Bales**	**174**	**224**	**224**	**224**	**166**	**1.012**	**52.603**
Sorting capacity	**Tons**	**97**	**125**	**125**	**125**	**92**	**563**	**29.294**

Table 45: OBD workers capacity in shift 2

8.8.3 Shift 3:

3. Shift

Process 10 + 30	Unit	Mon	Tue	Wed	Thu	Fri	Week	Year
Day	Sec	77.400	77.400	77.400	77.400	61.200	370.800	19.281.600
Planned maint./meetings	Sec	14.400	5.400	5.400	5.400	5.400	36.000	1.872.000
Sorting	Sec	63.000	72.000	72.000	72.000	55.800	334.800	17.409.600
Efficient sorting (80%)	Sec	50.400	57.600	57.600	57.600	44.640	267.840	13.927.680
Cycle time	Sec	103	103	103	103	103	103	
Sorting capacity	**Bales**	**489**	**559**	**559**	**559**	**433**	**2.600**	**135.220**
Sorting capacity	**Tons**	**272**	**311**	**311**	**311**	**241**	**1.448**	**75.303**

3. Shift

Process 20	Unit	Mon	Tue	Wed	Thu	Fri	Week	Year
Day	Sec	77.400	77.400	77.400	77.400	61.200	370.800	19.281.600
Planned maint./meetings	Sec	14.400	5.400	5.400	5.400	5.400	36.000	1.872.000
Sorting	Sec	63.000	72.000	72.000	72.000	55.800	334.800	17.409.600
Efficient sorting (80%)	Sec	50.400	57.600	57.600	57.600	44.640	267.840	13.927.680
Cycle time	Sec	80	80	80	80	80	80	
Sorting capacity	**Bales**	**630**	**720**	**720**	**720**	**558**	**3.348**	**174.096**
Sorting capacity	**Tons**	**351**	**401**	**401**	**401**	**311**	**1.864**	**96.953**

3. Shift

Process 40 - 50	Unit	Mon	Tue	Wed	Thu	Fri	Week	Year
Day	Sec	77.400	77.400	77.400	77.400	61.200	370.800	19.281.600
Planned maint./meetings	Sec	14.400	5.400	5.400	5.400	5.400	36.000	1.872.000
Sorting	Sec	63.000	72.000	72.000	72.000	55.800	334.800	17.409.600
Efficient sorting (80%)	Sec	50.400	57.600	57.600	57.600	44.640	267.840	13.927.680
Cycle time	Sec	174	174	174	174	174	174	
Sorting capacity	**Bales**	**290**	**332**	**332**	**332**	**257**	**1.542**	**80.198**
Sorting capacity	**Tons**	**162**	**185**	**185**	**185**	**143**	**859**	**44.661**

Table 46: OBD workers capacity in shift 3

8.8.4 Shift 3 + weekend:

3. Shift + weekend										
Process 10 + 30	**Unit**	**Mon**	**Tue**	**Wed**	**Thu**	**Fri**	**Sat**	**Sun**	**Week**	**Year**
Day	Sec	77.400	77.400	77.400	77.400	61.200	43.200	43.200	457.200	23.774.400
Planned maint./meetings	Sec	14.400	5.400	5.400	5.400	5.400	7.200	7.200	50.400	2.620.800
Sorting	Sec	63.000	72.000	72.000	72.000	55.800	36.000	36.000	406.800	21.153.600
Efficient sorting (80%)	Sec	50.400	57.600	57.600	57.600	44.640	28.800	28.800	325.440	16.922.880
Cycle time	Sec	103	103	103	103	103	103	103	103	
Sorting capacity	**Bales**	**489**	**559**	**559**	**559**	**433**	**280**	**280**	**3.160**	**164.300**
Sorting capacity	**Tons**	**272**	**311**	**311**	**311**	**241**	**156**	**156**	**1.760**	**91.497**

3. Shift + weekend										
Process 20	**Unit**	**Mon**	**Tue**	**Wed**	**Thu**	**Fri**	**Sat**	**Sun**	**Week**	**Year**
Day	Sec	77.400	77.400	77.400	77.400	61.200	43.200	43.200	457.200	23.774.400
Planned maint./meetings	Sec	14.400	5.400	5.400	5.400	5.400	7.200	7.200	50.400	2.620.800
Sorting	Sec	63.000	72.000	72.000	72.000	55.800	36.000	36.000	406.800	21.153.600
Efficient sorting (80%)	Sec	50.400	57.600	57.600	57.600	44.640	28.800	28.800	325.440	16.922.880
Cycle time	Sec	80	80	80	80	80	80	80	80	
Sorting capacity	**Bales**	**630**	**720**	**720**	**720**	**558**	**360**	**360**	**4.068**	**211.536**
Sorting capacity	**Tons**	**351**	**401**	**401**	**401**	**311**	**200**	**200**	**2.265**	**117.803**

3. Shift + weekend										
Process 20	**Unit**	**Mon**	**Tue**	**Wed**	**Thu**	**Fri**	**Sat**	**Sun**	**Week**	**Year**
Day	Sec	77.400	77.400	77.400	77.400	61.200	43.200	43.200	457.200	23.774.400
Planned maint./meetings	Sec	14.400	5.400	5.400	5.400	5.400	7.200	7.200	50.400	2.620.800
Sorting	Sec	63.000	72.000	72.000	72.000	55.800	36.000	36.000	406.800	21.153.600
Efficient sorting (80%)	Sec	50.400	57.600	57.600	57.600	44.640	28.800	28.800	325.440	16.922.880
Cycle time	Sec	174	174	174	174	174	174	174	174	
Sorting capacity	**Bales**	**290**	**332**	**332**	**332**	**257**	**166**	**166**	**1.874**	**97.445**
Sorting capacity	**Tons**	**162**	**185**	**185**	**185**	**143**	**92**	**92**	**1.044**	**54.266**

Table 47: OBD workers capacity in shift 3 + weekends

8.8.5 Total:

Current vs expected capacity	**Shift 1**	**Shift 2**	**Shift 3**	**Shift 3 + weekend**
Process 10 + 30				
Worker capacity (bales)	45.073	88.693	135.220	164.300
Expected capacity (bales)	46.048	90.610	138.143	167.851
Difference	**- 974**	**- 1.917**	**- 2.923**	**- 3.552**
Process 20				
Worker capacity (bales)	58.032	114.192	174.096	211.536
Expected capacity (bales)	46.048	90.610	138.143	167.851
Difference	**11.984**	**23.582**	**35.953**	**43.685**
Process 40 + 50				
Worker capacity (bales)	26.733	52.603	80.198	97.445
Expected capacity (bales)	46.048	90.610	138.143	167.851
Difference	**- 19.315**	**- 38.007**	**- 57.945**	**- 70.407**

Table 48: Capacity analysis for all three workers in the OBD

8.9 Appendix 9: Full literature reviews for problem analysis

As for the initial analysis's literature review, this appendix will include the literature review for literature which is deemed not applicable for Resource Denmark.

In the paper "*Project Net Present Value estimation under uncertainty*" by Helena Gaspars-Wieloch, she describes the use of NPV, and the requirements needed. With the use of a NPV analysis it is possible to evaluate projects (Gaspars-Wieloch, 2019). This method computes all foreseen and discounted revenues and cost over the lifetime of a project. The traditional method treats future cash flows as a certain value, even though many NPV analysis is based on estimations for the cash flow based on assumptions. These assumptions are uncertain, which is justifiable as both the inflow and outflow related to the project is based on the future. To tackle this obstacle the author proses four solutions 1) Increase the discount rate 2) conduct a sensitivity analysis 3) compare the pessimistic and optimistic cash flow 4) estimate the expected cash flow by means of scenario planning and the probability of distribution. Analysing the first option of increasing the discount rate, it does not solve the fundamental issue of an unpredictable cash flow. The higher the discount rate merely reduces the present value of uncertain future cash flow, which does not improve the analysis reliability. Therefore, based on this method adjusting the risk, but not addressing the core issue of determining when Resource Denmark would sort the applied number of bales in this project. Without credible cash flow projections, this method is futile.
The second of conducting a sensitivity analysis, is a viable option. Using this method different scenarios of increase of sorting tons per month could be applied, which could vary 10%, 20%, 30%, 40%, based in historical data. This would eventually provide an almost accurate estimation of the cashflow, but will include conducing multiple sensitivity analysis, and multiple NPV values, which would be time consuming compared the current break-even analysis. If more time were present, this method could be applied, but to make it further accurate sensitivity analysis on prices would be essential, as this also seem it change.
The third option is to create a pessimistic and optimistic cash flow. Without any reliable growth in sorting capacity, it could result in a vague estimation on the best case and worst cast and the scenarios will become too wide rendering the analysis impracticality.

The last one being the scenario planning probability distribution. This involves assigning probabilities to difference cash flow outcomes. This one is impractical as there is no knowledge of when each scenario is present. The closest would be to ask experts or internal sources, but based on their responds it would not be beneficial to conduct a financial analysis where two factors are unknown and can vary in the future: cash inflows and price of plastic. Therefore, based on this article solutions and Resource Denmark's current state, the most accurate analysis is determined to be a break even analysis, even though the plastic price still has a uncertainty level.

In the paper "*A Short, Practical Guide to Implementing Strategy*" by Micheal K. Allio, he states the importance of implementation plan to ensure the success of strategic initiatives. Based on a non-clear implementation plan, many businesses have failed to execute strategics. The challenges for companies for failing to construct implementation plans are they neglect the execution phase. For this project an implementation plan would have been crucial as implementing changes would require planning. But this is not conducted for this project. The reason for this is because Resource Denmark are currently in the development phase, meaning changes happens frequently and cannot be planned. An example can be seen in the IBD, where a layout was created for the future, but after two weeks knowledge this layout was changed. Therefore, conducting and recommending an implementation plan for this project would not be valuable and highly possibly not valid.

8.10 Appendix 10: Detailed analysis of OBD's PFMEA

This will present a detailed recap of what FMEA and PFMEA is and explain each cell in the PFMEA conducting for the OBD.

Failure mode and Effect Analysis (FMEA) is a structured approach to identity and address potential risk areas in a system, design, or process. The main goal with the FMEA is to foresee potential risk areas mode and implement measurements to mitigate the impact, and thereby enhance reliability and safety. This methodology was developed in 1940 for military purpose, and since then FMMEA has been widely adopted across various industries, such as aerospace, manufacturing, and automotive (Stamatis D. H., 2003).

Within FMEA, there are two branches:

1. Design FMEA (DFMEA)
   DMFEA is applied to the design phase of a product. The main goal of this branch is to identify potential failure modes related to the product design before it occurs. Thie is a proactive approach and helps improving the product quality and reliability by focusing on design related issues that could lead to failure (Stamatis D. H., 2003).
2. Process FMEA (PFMEA)
   PFMEA focuses on identifying potential risk areas in the manufacturing and assembly process of a product. By analysing each step in the process, PFMEA can help identify possible potential risk areas which could affect the product quality and safety. This type of FMEA is used for improving the process reliability and effectiveness (Stamatis D. H., 2003).

For Resource Denmark's case the PFMEA has been employed to analyse each process within the OBD. The analysis purpose is to identify all possible risk areas involving all processes within the OBD. By identifying all the possible risk areas, it is possible to determine which possible must be changed and adjusted to create sufficient capacity in the OBD and create a safe working environment. In Table 49 the PFMEA has been conducted. These risk areas are identified based on experience and expert judgement (Resource Denmark, 2024)

Current process 20

Process	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Causes(s)/Mechanism(s) of Failures	Occur	Current Process Control	Detection	RPN
10	Clash with cleaning worker at balers	Injuries to the cleaning worker	10	Failure of forklift sensors and lack of awareness	2	Eye contact and walkie talkie	6	120
10	Clash with forklift nr. 2	Damage to forklift	9	Failure of forklift sensors and lack of awareness	2	Eye contact and walkie talkie	6	108
10	Bales get dropped on weight	Misinterpretation of bales positioning	1	Failure to identify bales and weight position cause of limited vision	3	Eye contact and walkie talkie	7	21
20	Wrongfull notation of weight	Inaccurate data of inventory	6	Stressfull situations when operating with high pace human errors can occur	4	None	10	240
20	Wrong identification of plastic type	Customer does not recieve right plastic type	8	Stressfull situations when operating with high pace human errors can occur	3	None	7	168
20	Sticks the wrong label on bale	Customer does not recieve right plastic type	8	Stressfull situations when operating with high pace human errors can occur	3	None	7	168
20	Label falls of plastic bale	Unable to identify the weight and type of plastic without furthur inspection	6	The glue from the label is not strong enough	5	Worker finds a flat surfase to attatch the label	5	150
20	Excel sheet with data crashes	Loss of inventory records	8	Laptop experience overload and crashes	2	None	5	80
20	Ergonomic damage to worker	Ressource Denmark responsible for insurance	7	Not using the right equipment for standing and sitting	2	None	2	28
30	Clamps on to both bale and weight	Weight gets damaged	1	Unable to identify the positioning of bale and weight accuratly	3	Eye contact and walkie talkie	7	21
30	Clash with forklift nr. 2	Damage to forklift	9	Failure of forklift sensors and lack of awareness	2	Eye contact and walkie talkie	6	108
40	Clash with forklift nr. 2	Damage to forklift	9	Failure of forklift sensors and lack of awarenes	2	Eye contact and walkie talki	6	108
50	Failure of placing the bales in the right position	Damage to truck and workers	6	Losing overveiw of previous placement of bales inside the truck	1	None	5	30
50	Pressuring the bales to hard inside the truck and the bales fall out on the other side	Damage to truck and workers	10	Losing overveiw of previous placement of bales	1	None	5	50
50	Clash with forklift nr. 2	Damage to forklift	9	Failure of forklift sensors and lack of awarenes	2	Eye contact and walkie talki	6	108

Table 49: PFMEA analysis of processes in the OBD

To scale each potential risk areas the following scale has been applied (Stamatis D. H., 2003).

Severity scale:

Severity

The Severity of each effect is selected based on both Process Effects as well as Design Effects. The severity ranking is typically between 1 through 10.

Typical Severity for Process Effects (when no Special Characteristics / design inputs are given) is as follows:

- 2-4: Minor Disruption with rework / adjustment in stations; slows down production (does not describe a lean operation)
- 5-6: Minor disruption with rework out of station; additional operations required (does not describe a lean operation)
- 7-8: Major disruption, rework and/or scrap is produced; may shutdown lines at customer or internally within the organization
- 9-10: Regulatory and safety of the station is a concern; machine / tool damage or unsafe work conditions

Occurrence scale:

Typical Occurrence rankings for known / similar technology are as follows:

- 1: Prevented through product / process design; error proofed
- 2: 1 in 1,000, 000
- 3: 1in 100,000
- 4: 1 in 10,000
- 5: 1 in 2,000
- 6: 1 in 500
- 7: 1 in 100
- 8: 1 in 50
- 9: 1 in 20
- 10: 1 in 10

Detection scale:

- 1: Error (Cause) has been fully prevented and cannot occur
- 2: Error Detection in-station, will not allow a nonconforming product to be made
- 3: Failure Detection in-station, will not allow nonconforming product to pass
- 4: Failure Detection out of station, will not leave plant / pass through to customer
- 5-6: Variables gage, attribute gages, control charts, etc., requires operator to complete the activity
- 7-8: Visual, tactile or audible inspection
- 9: Lot sample by inspection personnel
- 10: No Controls

Process 10:

There is a cleaning worker, who is always present in the outbound department. At the bailer there is a high demand of cleaning, as plastic waste tends to fall of the bale if not connected with the wire's strings of the bale. An example of this can be seen in the following visualisation:

Figure 18: Illustration of waste at the bailer

There is a chance of clashing with the cleaning worker at this place of the ODB. The severity is rated 10, which is the highest, as this could cause life changing damages to the worker if the forklift driver clashes with him/her in driving speed. The occurrence is 2 as they tend to show great communication and visual skills. The lack of detection is 6, as this worker do have a walkie talkie to warn the forklift driver. The RPN value is 120.

The second risk is the clash opportunity with the other forklift driver. The severity is lower but still high, as they are in a machine compared to the cleaning worker. Additionally, the occurrence and detection are the same, as the workers can communicate using walkie talkies and shows great communication skills.

The last risk for this process is dropping the bale on the weight and not placing it. The severity is 1, as the impact is not a non-collation with any human being but cases a minor disruption. The occurrence is 2, as the forklift driver can feel when the bale is on the weight and can release, although it is hard for the forklift driver to visually identify when it is placed on the weigh. The detection is 7 as there is communication with process 20 worker, if he/she identifies the bale is not placed on the weight and warns that it will be dropped.

Process 20:

The first risk of wrongful notation has a moderate severity, as this would provide the customers with a false weight of the bale. It is 6, as the single bale weight is not that relevant and only causes a minor disruption, along with potential rework if equipment can handle additional weight. But if all the bales inside a shipment consist of wrong weights it is a problem. The occurrence is 4, as this can happen in stressful situations, and there is no way of telling if the weight on the label is right. This is also showcased as the missing detection level high, as there are no control systems.

The second risk is the wrongfully identification of plastic type. This has an 8 value in severity, as it would give the customers the wrong plastic type. The occurrence is low, as the workers gain more and more experience in quicker identifying the plastic type. And there is a no dedicated control system, as if the forklift driver were to analyse the bale by chance and identify the plastic type is not the right plastic type mentioned on the label. This is rated 7, as this is not a dedicated control system for these risks beside random human interaction.

The third risk consist of wrongfully applying a label to a bale. The P20 worker operates with two weights so therefore 2 bales at the time and placing the wrong label on the long bale has a high severity as the customer do have false information about the bale. The occurrence of this issue it deemed to be low, as the worker can with the use of this eyes identify the plastic type before sticking the label to a bale. For this there is no control system before the bale is at the customer, thus the high score of 7.

The next risk is that label falls of the bale. The label is sticked on using self-glue, which tends to fall off quite often. The severity of this issue is 6, as the customer receives many bales and one bale without label is not that big of an issue. The occurrence is high, as this happened quite a lot, when picking bales form inventory, as there is friction when two bales are placed next to each other and makes the label fall off. The detection scores are high, but not the highest as the worker each time, analyses the bale to find a flat surface to stick the label on, but after this if a label is floating in the OBD, the label is not picked up.

The next risk it that the excel sheet with where all the data crashes and data is deleted. The severity of this is high, as inventory records can be lost, but does not danger any workers so 8 is fitting. The occurrence is low due to the laptop has great software and hardware and auto save feature. There is no control system for retrieving lost data, so therefore the detection score is 5 since operators can identify heating of the laptop of crashing of Excel.

The last risk in P20, is the ergonomical damages to the worker, as he is currently standing up, recently a chair was placed, but the table is not a table which can be lowered or made tall. The severity of this risk to the workers is 7, as the chair has been placed in the OBD but there is no height adjustable table for the worker. The occurrence is low, as the worker has awareness of what position is best for him/her. There is no detection system on the workers wellbeing beside his own and comments to his worker. The workers do small talk and if any issues arise it will be talked about during these small talks. So even though no dedicated control system is present there is still options to detect this by the own worker to though the other workers awareness.

Process 30

The first risk is that the forklift driver picks up the weight as well with the bale. This has a severity of 1, as this will slow down the sorting capacity, but as it can be handled internally by the maintenance team. The occurrence of this is 3, as the driver often feel what he clamps on to, and therefore it can happen but not often. The detection is 7, as there is no control systems and the driver do not have any vision knowing when he/she clamped to the bale and weight. But he/she can communicate with the P20 worker who has clear vision using walkie talkie.

The next risk is the clash with the forklift driver which is recapped in process 10.

Process 40

The only risk here is clash with the forklift driver which is described in process 10.

Process 50

The first risk is failure to place the bale in the right position inside the truck. The severity 6, as this can cause many problems and risk. The occurrence is low, as the loading worker is skilled with this process. There is no dedicated control system, but can be verified by the worker, and possible the worker transporting bales to inventory by change.

The next risk is pressuring the bales too much and it can fall out on the other side. The severity is high for this one, as it can damage the truck and fall upon a worker on the other side. The occurrence is low, as the workers are very aware of this possibility and therefore operate this very carefully, which is why it takes much longer time to load a truck than unloading. Once again there is no dedicated control system, beside the workers experience, and possible chance of the other forklift driver to identify and alert the worker operating process 50.

The last risk is coalition with the other forklift driver described in process 10

8.11 Appendix 11: Layout of OBD and Plastic type label

In this appendix a visualisation of the current OBD can be seen. This is illustrated in figure 19

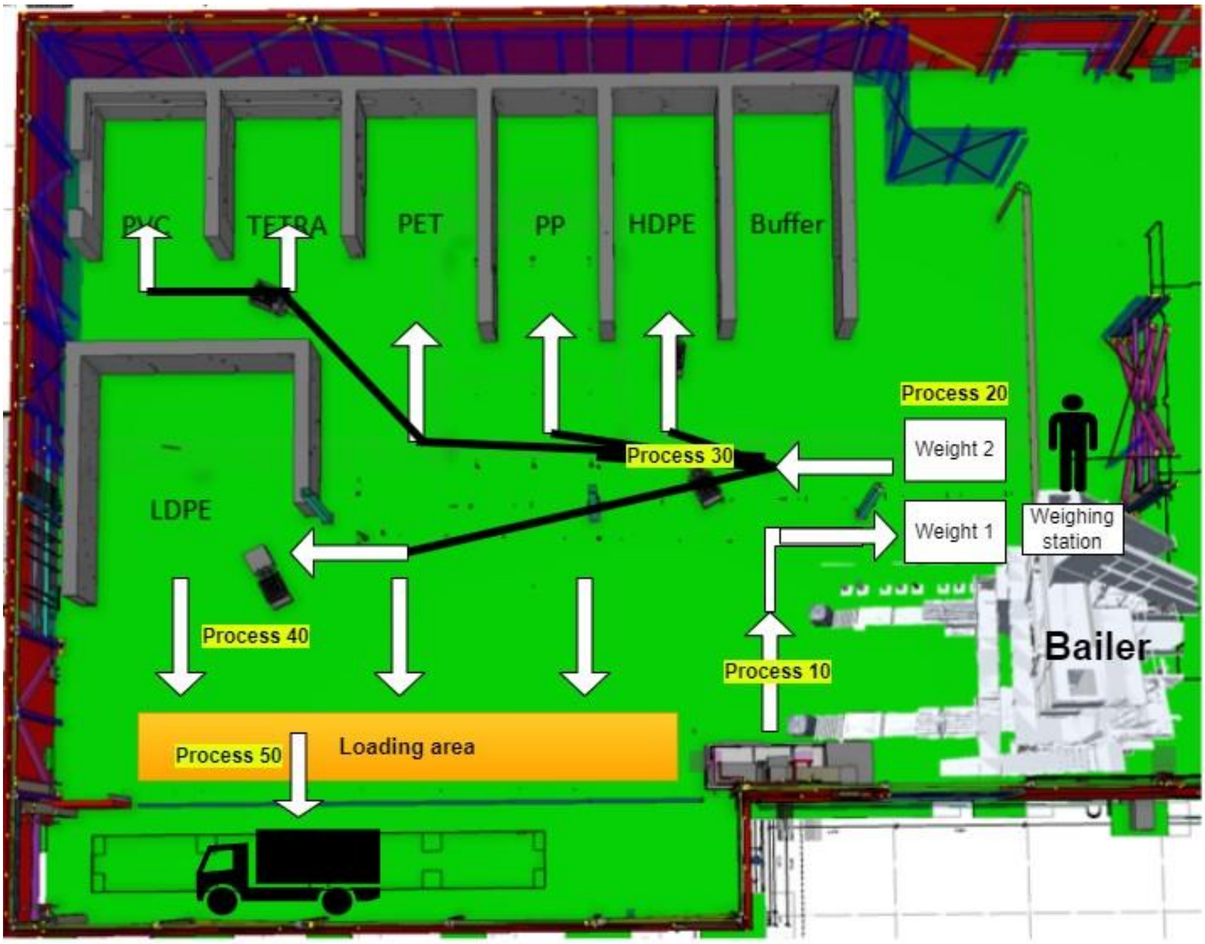


Figure 19: Layout of OBD (Resource Denmark, 2024)

Process 10 begins with the forklift driver picking up a sorted bale from the bailer and placing it on one of the two weights, at the weighing station, where process 20 begins. Process 20 logs the data and places the label on the sorted plastic bale. Process 30 begins as the same forklift driver from before, picks up the bale and places it in inventory. The second forklift driver picks up a bale from inventory and places it on the loading area. Process 50 begins by the same forklift driver from process 40, picks up the bale and inserts in into a truck.

Additionally, a visual representation of the plastic type labels placed at the weighing station of P20 worker. This is the label where the date and weight are manually written and pasted on each bale.

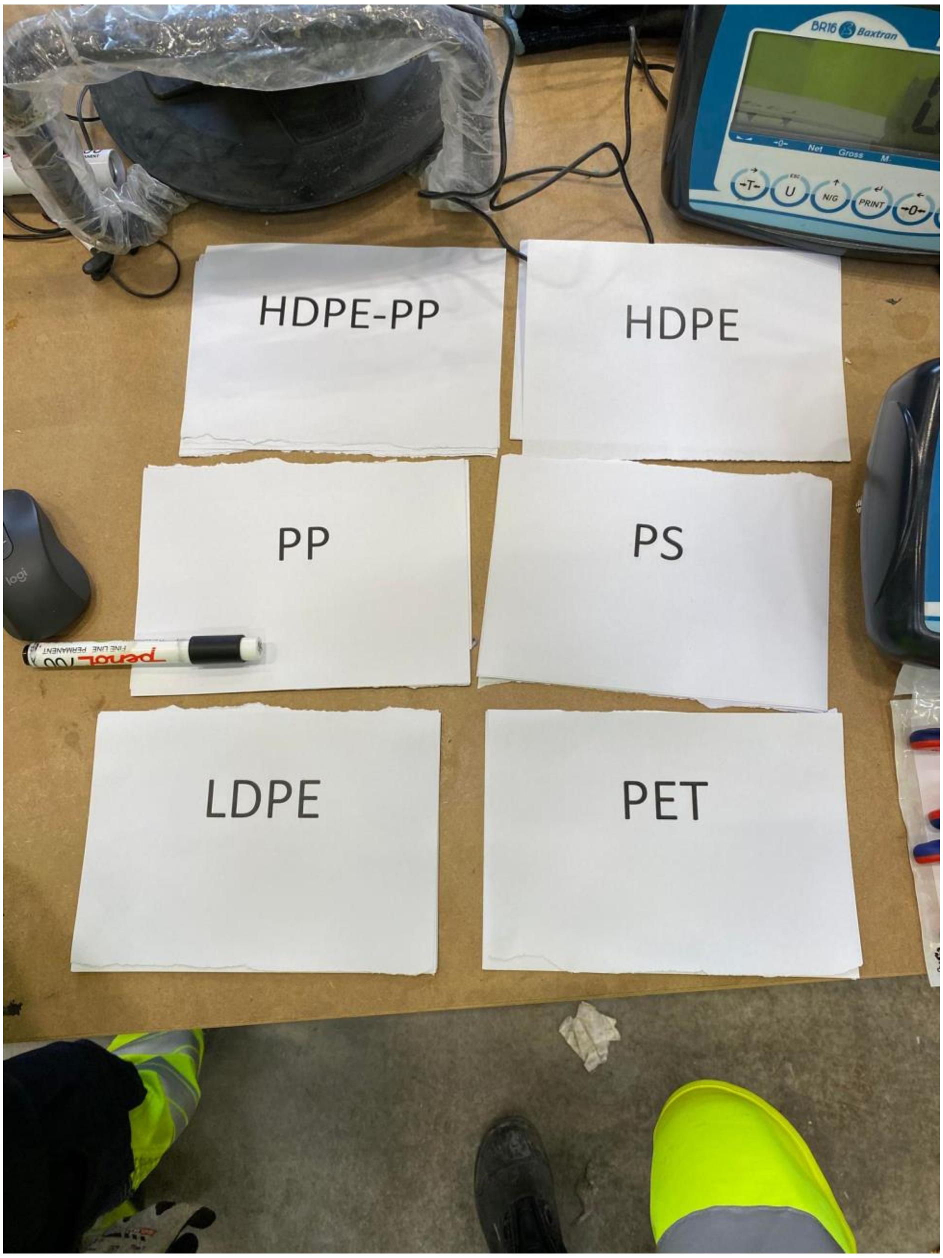


Figure 20: Preprinted A4 bale labels

8.12 Appendix 12: Interview with potential customers

This appendix showcases all three interviews with the potential customers.

8.12.1 RC Plast

The interview was conducted on April 15th 2024 with the production manager at RC plast (Manager P. , 2024).

Interveiw:

Aji: Hej *Name*, du snakker med Aji ude fra Resource Denmark, som var på besøg hos jer i efteråret.

Production manager : Hej Aji, ja det kan jeg godt huske.

Aji: Jeg ringer fordi jeg er i gang med at lave min kandidat opgave ude hos Resource og på nuværende tidspunkt kigger på vores label proces og vil finde ud af hvilke data er nødvendige for jer når i køber sorteret plastik fra jeres leverandør.

Production manager: Det lyder godt, jeg har faktisk også godt været derude efter i er gået live. De data som vil være værdifulde for os er følgende:

- Oprette varer nummer per plastik
- Tekst som matcher varer nummer, så man har både plastik, varer nummer og navnet på den
- Renheden af ballen, kom med en afgræsning fremfor et specifikt tal
- Batch nummer, det repræsenterer også datoen for hvornår ballen er blevet lavet
- Ballens vægt
- Operatørens ID

Og så en QR-kode eller stregkode som indeholder alle de her informationer

Aji: Super tusind tak for det!

Production manager : Lige pt bruger vi ERP-programmet Business Centreal, som er et simpelt ERP program, som udbydes af Vektus, det synes jeg du skal kigge ind i, hvis det vækker interesse.

Aji: Tusind tak for det, det vil jeg gøre efter jeg har interviewet flere potentielle kunder.

Production manager: Godt nok, hvis du er interesseret i at finde ud af hvordan det virker er du velkommen til ringe eller booke mig en dag så kan du komme og kigge på det herude.

Aji: Det vil jeg gøre – God dag.

8.12.2 Genplast

The interview was conducted on April 15th 2024 with a sales employee at Genplast (Genplast, 2024).

Interview:

Aji: Hej, jeg hedder Aji og jeg er i gang med at skrive mit speciale for Ressource Denmark, som grov sortere plastik affald og kan i se at i bruger genanvendelig plastik til jeres plast emballage?

Sales employee: Ja det gør vi.

Aji: Jeg ringer egentligt for at samle data til hvilke data vil være nødvendige for jer for at købe en balle grov sorteret plastik.

Sales employee: Ja, det kan jeg da godt svarer på, har du noget at skrive ned med?

Aji: Yes

Sales employee: Jeg tænker leverandør navn er meget vigtigt for os og country of origin. Vi vil også gerne have de her informationer ved at scanne ballen. Så tænker jeg typen af plastik er især vigtigt samt hvor meget det vejer og datoen for hvornår ballen blev lavet.

Aji: Okay, jeg har snakket med en anden plastik producent og de nævnte fx datoen for hvornår produktet er lavet også var vigtigt, hvad tænker du om det?

Sales employee: Ja det er rigtigt, datoen og tiden, hvis det er muligt kunne være brugbart.

Aji: Okay super, det notere jeg også ned, har du nogle flere eller føler du at du er kommet godt igennem de vigtigste data som skal være på en label?

Sales employee: Det tænker jeg er det hele, ellers er der selvfølgelig kontrakten hvor der er mange flere informationer på ift til aftalen og antallet af styks.

Aji: Ja det forventer jeg også, men hvis der ikke er mere, så vil jeg sige tusind tak for dit input og ha en rigtig god dag.

Sales employee: Tak for det og held og lykke med din opgave.

8.12.3 Stena Recycling

The interview was conducted on April 15th 2024 with a communication employee at Stena Recycling (StenaRecycling, 2024).

Aji: Hej, jeg hedder Aji og jeg er i gang med at skrive mit speciale for Ressource Denmark, som grov sortere plastik affald og kan i operer indenfor det danske plastic recycling industry.

Communication employee: Ja det har du ret i. Vi baner veje mellem virksomheder til at oprette recycling partners.

Aji: Jeg ringer egentligt for at samle data til hvilke data vil være nødvendige for jer for at købe en balle grov sorteret plastik.

Communication employee: Okay, jamen det vi oplever hos kunder, som får plastic baller er, at især plast typen star klart, vægten af ballen, hvem som leverer ballen er også vigtigt hvis man har forskellige leverandør, datoen også.

Aji: Jeg har snakket med andre kunder også, har i nogen præferancer ift til hvordan data skal stå eller om man skal kunne scanne og få oplysningerne.

Communication employee: For dem jeg har oplevet er det ikke så vigtigt, så længe en af delene er der.

Aji: Tusind tak for det, og ha en rigtig god dag.

Communication employee: Tak og i lige møde, pøjpøj med din opgave

8.13 Appendix 13: Universal codes for plastic type

This appendix showcases the different plastic code which is universal for all countries (SP Group, 2024). This is a universal code, so not only for Denmark.

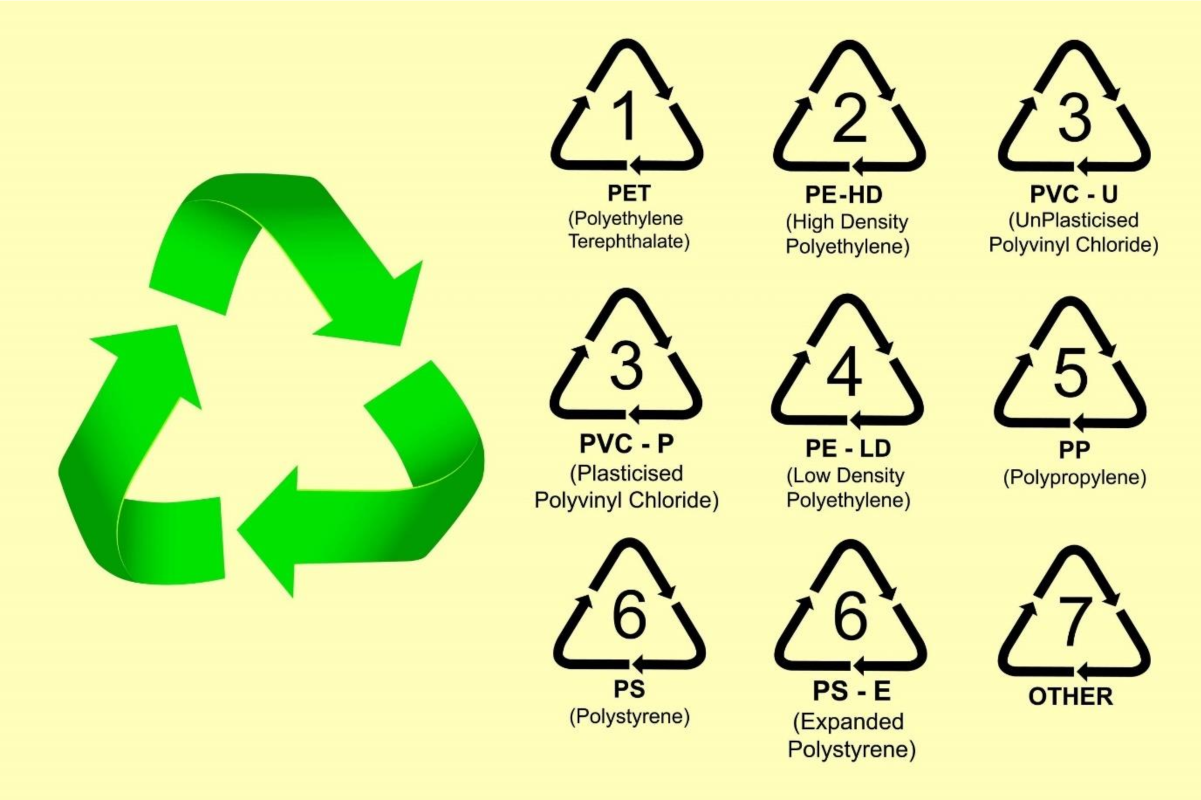


Figure 21: Universal code for plastics (Manager T. , 2024)

8.14 Appendix 14: *UWUK* -machine information

This appendix serves the purpose of showcases the product catalogue of the *UWUK* -machine, and the communication stream with the internal source at Unotech regarding the capabilities of the *UWUK* -machine.

Product catalogue (Unotech LM Group, 2024):

Email with sales employee at Unotech (Unotech LM Group, 2024):

I refer to your mail and to our telephone call and thank you for your interest in our products and for all given information.

@General description and additional requirements
As written in our brochure, the UWUK is a fully automatic device for data collecting as well as labeling bales in a subsequent step. The construction of the UWUK is modular and consists of two almost independent systems. The weighing device is called UWUK/W. The labeling device is called UWUK/L. Nevertheless the UWUK/L is only available in connection with UWUK/W. In contrast to this the data collecting unit UWUK/W is also available as a single device. It's important, that the UWUK/W is always prepared for retrofitting the labeling device UWUK/L.

Of course it's clear that high quality devices regarding the data collecting and labeling are absolutely needed. Nevertheless please find below some additional topics beside data collecting and labeling which also have to be taken into account:

- A data collecting and labeling device is an additional unit, which is helpful but also not necessary needed for the main process (sorting and baling). Because of this you need an easy solution to keep the high availability regarding the upstream processes up.
- Easy maintenance
- Easy handling
- A functioning register
- Easy removal of broken or faulty bales
- The amount of generated data
  In regards to UnoTech we use UBIS (UnoTech baler information system). For instance you have the opportunity to get the following data: e.g. material, operator, time, specific bale number, energy consumption, length, weight, specific bale weight (kg/m³) or a barcode.

Weighing and labeling is a more and more upcoming topic and it would be a pleasure for us to get the opportunity for a presentation of our solution based on the requirements above.

@Questions from your side

- *Can the UWUK machine be integrated with the UPAMAT and bunker system in a way that it knows which material who is baled?*

Yes. The baler gets its complete information from the sorting line. The two devices UWUK and baler are a closed system. In regards to data collecting and labeling there is only a communication between these two devices. Against this background the baler is connected via pn/pn coupler with the sorting line and gets the information which material will be chosen, regardless of the specific bunker, from it. These information will be send to the UWUK. The sorting line is the leading system and communicates to the baler what has to be done next.

- *When changing baling from one bunker (e.g. HDPE bunker) to another bunker (e.g. PP bunker) can UWUK process correct labels for from the first bale with new material?*

Yes. Nevertheless a correct register is/was one of the most difficult interfaces.

- *Is it possible to attach an RFID tag to this band (pic. below) or is it only printing/labelling of barcode/QR code + text.*

We don't have a device for RFID tags yet. At the moment it is printing/labeling of barcode + text. Of course, you can install the UWUK/W and organize a labeling with an RFID tag by your own. Please keep in mind that in this case also the register has to be adapted.

@Budget price
The budget price for UWUK/W is about 130.000,00€
The budget price for UWUK/L is about 125.000,00€

I will prepare a first offer until the middle of next week. I'm sorry that I can't send it earlier. Due to internal software problems it takes a little bit longer.

- Hvad forventer vi prisen er på UWUK maskinen?
- Kræver det noget yderligere mendarbejder træning at håndtere maskinen? Ja operatører må få trening bade bruk og ettersyn av maskinen. Jeg tenker dette gjennomføres i løpet av en dag.
- Hvad tænker vi kan være cyklus tiden på at ballen går ind til UWUK maskinen og igen er ude og klar til at blive hentet af en forklift? UWUK installeres i enden av eksisterende baler maskin og plastballene veies og merkes forløpende slik jeg forstår maskinen. Vil således ikke medføre ekstra arbeid, forsinkelser eller håndtering for operatører.
- Hvor lang tid forventer vi at det vil tage for at implementere UWUK maskinen? Jeg regner med at du tenker på når maskinen kan være levert og montert i Esbjerg? Dette vet vi mer om når jeg har hatt et avklaringsmøte med Unotech. Jeg har skrevet ønsket implementering Q3/2024, men vi får se hvilke svar vi får.

8.15 Appendix 15: Interview with Sales Manager of Vektus

The interview was conducted on April 15th 2024 with the Sales Manager at Vektus (manager, 2024).

Interveiw:

Aji: Hej, jeg hedder Aji og jeg er I gang med at skrive min kandidat opgave for Resource Denmark. Jeg har blevet anbefalet til at ringe til dig fra en af jeres kunder, RC Plast, angående Business Central ERP system som i implementere for virksomehder.

Sales Manager. Ja, det er mig som styrerede det project hos RS Plast.

Ajivan: Jeg ringer fordi jeg gerne vil høre hvad prisen er for at implementer sådan et program til Resoruce Denmark, som er en nyopstartet virksomhed?

Sales Manager: Det kommer helt an på hvor langt I er med at udvikle jeres ERP system.

Ajivan: Faktisk har Resource Denmark købt adgang til Microsoft 365, men har ikke udviklet det yderligere. Vi skal bruge et ERP system til lagerføring ude I Exit området nemlig.

Sales Manager: Nå ja okay, altså man skal jo ind og nærstuderer jeres virksomhed før man kan komme med et ordenligt tilbud alt efter hvad I har behov for og hvor mange timers arbejde det kræver at sætte en hel virksomhed op. For at i kan udnytte lager systemet, skal vi stadig få det hele sat op, finans, kunder, leverandør osv. For at stille sådan et projekt op vil jeg nok estimere omkring 50-80 timer skal ligges i projektet, hvor yderligere 50 timer måske kan blive lagt på baseret på firmaet nuværende situation. Ift til prisen regner vi jo baseret på konsulent timer vi burger på det, så jeg vil tro den ligger på den 1,000,000 inversting for både konsulent timer, opsætning, og træning som kan gøres in house. Implementeringen tagernok omkring 3-6 måneder, men det kan jo implementers samtidig med jeres nuværende metode af logge lager, så det stopper ikke jeres production på nogen made. Jeg tænker også implementering af Tasklet håndholdt RFID tags reader vil passe godt til jeres case.

Ajivan: Tusind tak for det, det vil jeg bruge til mit projekt. Jeg er helt indforstået det er estimationer det her, da I ikke har været ude og se operationen, men tænker jeg kan anvende de her tal, som et estimate for mit projekt. Tak for det.

Sales manage: Ja præcis. Og hvis der er noget mere tager du endelig bare fat eller skriver en mail. Held og lykke med opgaven.

8.16 Appendix 16: Vertical view of *BC* PFC

This appendix showcases the vertical view of the *BC* alternative, if this alternative were to be implemented in the OBD.

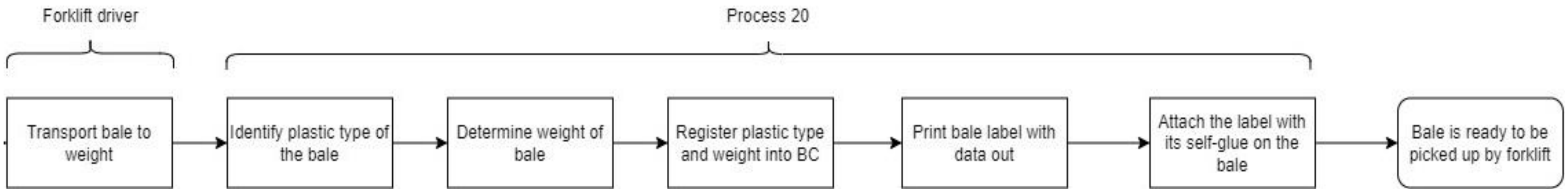


Figure 22: Vertical view of BC PFC (manager, 2024) (Microsoft, 2024)

The text in Box 1: Bale enters outbound department
The text in Box 2: Transport bale to weight
The text in Box 3: Identify plastic type of the bale’
The text in Box 4: Determine weight of bale
The text in Box 5: Register plastic type and weight into BC
The text in Box 6: Print bale label with data out
The text in Box 7: Attach the label with self-glue on the bale
The text in Box 8: Bale is ready to be picked up by forklift.

8.17 Appendix 17: Vertical view of *Overhead crane* PFC

This appendix showcases a vertical view of the *Overhead crane* PFC if this alternative were to be implemented at Resource Denmark's OBD.

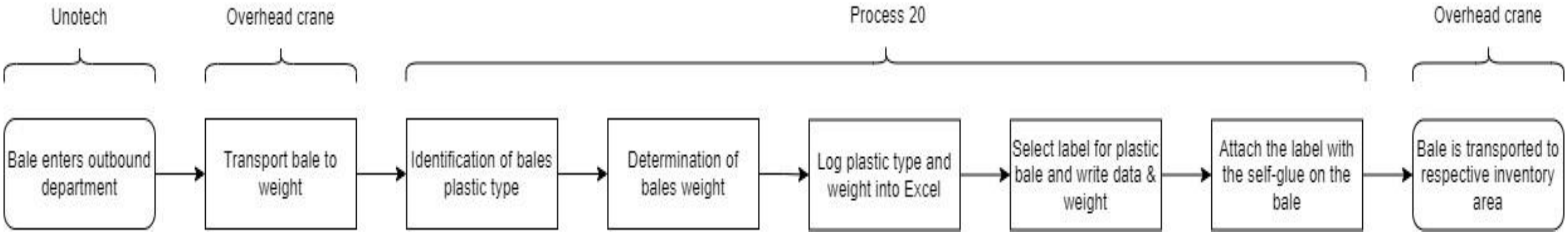


Figure 23: Vertical view of Overhead crane PFC (Mazzella companies, 2024)

The text in Box 1: Bale enters outbound department

The text in Box 2: Transport bale to weight

The text in Box 3: Identify plastic type of the bale

The text in Box 4: Determine weight of bale

The text in Box 5: Register plastic type and weight into Excel

The text in Box 6: Select label for plastic bale and write data & weight

The text in Box 7: Attach the label with self-glue on the bale

The text in Box 8: Bale is transported to respective inventory area

8.18 Appendix 18: Criteria for MCDM

This appendix showcases all the best criteria for supplier selection based on a case study of 49 articles and the full explanation for the choice of each criterion.

Criteria	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}	A_{13}	A_{14}	A_{15}	A_{16}
Cost	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Quality	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Delivery	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Worker safety and health	x		x			x	x	x	x					x		x
Technology		x	x		x	x	x	x	x	x	x		x	x	x	x
Flexibility		x						x	x	x		x	x	x	x	x
Environmental Affairs		x	x	x			x		x	x				x	x	x
Financial Stability		x				x			x	x	x	x	x	x	x	x
Reliability		x	x					x		x		x	x	x	x	x
Risk		x	x					x						x	x	
Packaging and Transport Quality		x			x	x	x	x		x	x					
Production capacity		x	x					x						x	x	
Location		x	x		x	x			x	x			x		x	x
Communication System		x	x				x	x		x		x	x		x	x
Repair Service			x		x	x		x		x				x		x
R&D								x	x	x				x	x	x
Service		x	x	x				x		x	x			x	x	x
Repair Service			x		x	x				x	x			x	x	x
Market Position					x				x			x	x	x		
Warranty / Claims		x	x			x	x									
EMS	x								x							
Green Supply Chain	x								x	x					x	x
Suppliers of supplier	x														x	x
Worker Dismissal	x		x													
Response Speed		x						x								
Lead Time		x						x					x			x
Past Experience		x						x								
Reputation		x	x					x		x			x			
Building And Facility		x			x	x										
Relationship		x											x	x		x
Expiration Date		x														
Regulatory Compliance		x			x	x										
Payment Terms		x											x	x	x	x
Waste Management		x								x						x
Waste Handling		x								x						x
Efficient Material Handling		x			x											
Supplier Capacity		x						x				x			x	
Management and Organisation		x	x													
Attitude			x		x	x					x					
Commercial Plans			x													
Process Improvement			x													
Product Development			x													
Professionalism			x		x	x	x									
Green Manufacturing System				x					x							x
Green Image				x					x							x
Cooperation				x	x			x					x			
Performance History					x			x				x				
Training Aids					x	x										
Electronic Data Interchange (EDI)							x	x								
Culture							x	x								
Trade Restriction							x	x								
Skill level of staff								x				x	x			
Self audits								x								
IT Standards							x	x								
Emergency orders										x			x			
Order cycle time										x			x			
Sales Support													x			

Table 50: List of criteria for supplier selection (Aksel Rasmussen, 2022)

It is important to remember that these criteria and case study of 49 articles showcase the appliance of the criteria for supplier selection. Therefore, it is not possible to compare 1:1 with Resource Denmark's case of investing in new equipment to enhance capacity. But although it is different research topic, it is possible to draw parallels, as selecting a supplier and investing in machinery have shared features such as cost, technology, attitude etc. To apply these criteria to this project, the purpose of the criteria will be redefined. An example can be seen in "production capacity". For supplier selection this would mean the capacity of the suppliers and how much raw material they have capacity to supply to the manufacturer. In this case of Resource Denmark this criterion would include the ability to reallocate Resource Denmark's current capacity.

Based on this case study of 49 the following criteria has been chosen (Aksel Rasmussen, 2022):

7) **Cost**

   It is imperative to generate a profit to run a successful company. To implement changes that require an investment, a business must account for the associated implementation cost (Zhang, 2024). As Resource Denmark is a newly established company, they operate within a specific budget aimed to creating an effective and scalable organization (director, 2024). Despite this allocated budget, the company wish to adopt a culture of continuous improvements, recognizing that change will inevitably occur. This perspective is driven by the fact as none of the current workers have prior experience operating a sorting plant. Instead of aiming to maximize profits, companies are advised to reinvest their profits to develop valuable products and services for the customers. By focusing on this, companies can obtain more market share, which can result in higher profit in the long term (Entrepreneur, 2015).

8) **Number of potential risk areas**

   In the OBD, workers handle plastic bales weighing up to 557 kg (Resource Denmark, 2024) (Wastecare, 2024). The bales can therefore be classified as heavy materials, which could easily harm the worker if handled improperly. Resource Denmark prioritizes a safe working environment as part of their long-term vision (Manager O. , 2024). Although accidents are relatively infrequent in this industry, they can lead to severe life-threatening injuries when occurring (Resource Denmark, 2024). Therefore, processes within the OBD must have a minimal potential risk areas and comprehensive control systems.

9) **Employee training**

   It is important to establish if additional training is required by the modification. This requirement varies depending on the alternative, as minor adjustment might not require additional training, while bigger projects require training sessions.

10) **Opportunity to reallocate capacity**

As all the current processes in the OBD, beside P20, lack the capacity to handle the projected number of bales entering the OBD, it is important to implement a solution which provides the opportunity to reallocate capacity (Manager O. , 2024). If it is not possible to reallocate capacity, Resource Denmark would experience unhandled bales within the outbound department. This would lead to loss in revenue and potentially cause an unsafe working environment.

11) Sorting delay

As changes and adjustments can vary significantly in their implementation time, it is crucial to estimate and schedule this period. Failing to estimate it, could result in encountering unexpected delays and slow the sorting capacity. Having an established time frame for each alternative will be beneficial. This allows the company to plan accordingly, minimize disruption to the operation, and efficiently implement the alternative.

12) Employee satisfaction

The final criterion is focused on the worker's routine following the implementation of the modifications. Resource Denmark aims to cultivate a positive working environment where the workers are motivated (director, 2024). The company strives to foster an inclusive environment, creating processes which allows the workers to express themselves and stay motivated

8.19 Appendix 19: AHP method explanation

Develop by Thomas L. Saaty in 1980, AHP is a structured method for organizing and analysing complex decisions. This method converts subjective assessments of relative importance into a series of pairwise comparisons, facilitating a comprehensive evaluation of each element in a hierarchical structure. This method is particularly effective in blending both subjective and objective assessment data, providing a robust framework for making well-informed decisions in project management and other scenarios (Saaty, 1980) (Apichat Sopadang, 2016) (Ming-Chyuan Lin, 2007). Through the application of AHP, the criteria weights will be systematically derived, ensuring that the selection process align with Resource Denmark's strategic objectives and operational priorities.

To accurately assign weights, each criterion will be compared against the others in pairwise comparison format (Saaty, 1980). This approach leverages the collected qualitative data to determine not only which of the two factors is more important but also to what extent. Such a pairwise comparison facilitates the translation of qualitative assessments into quantitative weights. These weights reflect the significance of each respective criterion, encapsulating both objective and subjective valuations from the stakeholders' perspective (Saaty, 1980).

Additionally, a pivotal component of the AHP method is the Consistency Ratio (CR). The CR evaluate the dependability of the pairwise comparisons by examining the consistency of the judgement made from qualitative data (Saaty, 1980) (Apichat Sopadang, 2016) (Ming-Chyuan Lin, 2007). Calculating the CR is crucial as it verifies that the weight determinations are coherent and also maintain a logical consistency throughout the decision-making process. By calculating the CR value ensures the final decision is both justifiable and reliable based on Resource Denmark's goals and operational requirements.

Here are the steps to determine weights for the chosen criteria using the AHP method (Saaty, 1980).

Step 1: State the decisions problems and the goal of the analysis. This is the top level of the hierarchy. Defining the problem and goal ensures that the analysis is focused on that and that all stakeholders have a common understanding of what is begin evaluated and which criteria is being weighted.

Step 2: Decompose the problem into a hierarchy of criteria and sub criteria (if presents). Sub criteria are not present for this project. Structuring the hierarchy helps to organize the decision elements logically and ensures that each aspect of the problem is systematically considered.

Step 3. Pariwse comparison. Performing a pairwise comparison for each criterion in relative importance to each other allows a detailed evaluation of the relative criterion. This step captures the subjective judgement of stakeholders and translate it into quantitative data.

Step 4. Construct the pairwise comparison matrix. Constructing the matrix organizes the pairwise comparison into structured format, which is crucial for latter steps. The reciprocal nature of the matrix ensures consistency in the comparisons.

Step 5. Normalize the pairwise comparison matrix. To normalize the matrix, use the following Equation (Saaty, 1980) (Apichat Sopadang, 2016) (Ming-Chyuan Lin, 2007):

$$b_{ij} = \frac{a_{ij}}{S_j} \tag{12}$$

- b_{ij} is the normalized value of the i-th row and j-th colum.
- a_{ij} is the value in the i-th row and j-th column of the pair-wise comparison Table.
- S_j is the sum of the values in the j-th column.

Normalizing the matrix converts the raw pairwise matrix into a consistent scale. This step is crucial as it ensures that the comparisons are proportional and can be analysed on a common scale. The normalized values show the relative importance of each criterion compared to other criterion in a consistent and comparable manner.

Step 6: Calculate the priority vector (weights). This is done by averaging the normalized values of each row using the following equation (Saaty, 1980) (Apichat Sopadang, 2016) (Ming-Chyuan Lin, 2007):

$$\omega_i = \frac{1}{n}\sum_{j=1}^{n} b_{ij} \tag{13}$$

The priority vector represents the relative weights of the criteria. This step synthesizes the information from the normalized matrix to provide a quantitative measure of the importance of each criterion. The weights indicate the priority of each criterion in achieving the goal previously set.

Step 7. Check the consistency. This is done to assess the consistency of the judgement using the consistency index (CI) and the consistency ratio (CR). This is done to ensure that the pairwise comparisons in step 3 are logically consistent. This step is important to validate the judgements. A low consistency ratio, below 0.1, indicates that the comparisons are consistent, and the resulting weights are reliable.

To pairwise compare each criterion, the following scale is used. The scale can be seen in Table 51 (Saaty, 1980).

Importance	Importance description
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values
1/3, 1/5, 1/7, 1/9	Value for inverse comparison

Table 51: Scale for pairwise comparison

The scale for the AHP ranges from one to nine. A score of one signifies equal importance between the Criteria X and Criteria Y. As the scale increases, the value assigned indicate progressively greater importance of Criteria X over Criteria Y: three for moderate importance, five for strong importance, and seven for very strong importance. The highest score, nine, denotes extreme importance of Criteria X over Criteria Y. Intermediate values such as two, four, six, and eight offers a finer gradation between the main scores, allowing for nuanced assessment of relative importance that might not exactly align with the main odd numbered scores. The scale also includes fractional values such as 1/3, 1/5, 1/7, and 1/9, which is used where Criteria Y is considered more important than Criteria X.

8.20 Appendix 20: Comprehensive analysis of the pairwise comparison

This appendix serves the purpose of explained each cell value in-depth, based on primary data collected though onside observations, unstructured interviews with white- and blue-collar workers. This data is observed during the authors internship period, therefore this mainly is based on experience when designing the layout of the IBD and inventory analysis.

Pair-wise comparison i-row / J colum	Price	Reduction of risk	Employee training	Capacity re-allocation	Sorting delay	Working routine
Price	1	1/5	3	1/5	1/3	1
Reduction of risk	5	1	7	1	7	7
Employee training	1/3	1/7	1	1/7	1/5	1/3
Capacity reallocation	5	1	7	1	5	5
Sorting delay	3	1/7	3	1/5	1	3
Working routine	1	1/7	3	1/7	1/3	1
Sum	15,3	2,62	24	2,68	13,86	17,33

Price:

Price -> Reduction of risk areas: a scores of 1/5 has been gives, imping the reduction of risk areas are strongly more important the investment price. Resource Denmark has been given a budget to execute the start up the project. Based on site observations and discussions with white collar workers, they have stated multiple time, all the processes must be safe to work with, that is the main priority, they would invest more money to perform the process safety than risk the workers' health and process effectiveness.

Price-> employee training: Price has a moderate importance compared to the required employee training. This is due to Resource Denmark are eager to invest in their workers and already has sent their workers to various courses focusing on the plastic industry and making processes effective and efficient. This is to create a motivated staff and adaptable to changes. Therefore, the required need of training is not that important as Resource Denmark see this as an opportunity to give the workers more knowledge. Therefore, the price of the implementation is seen ad moderate importance compared to the required employee training.

Price -> capacity reallocation: The ability to reallocate capacity is strongly more important that the price. This is due to the main objective of collaboration with Aalborg university is to create processes which has sufficient capacity in the OBD. The main goal is to ensure that the sorting plant set the sorting capacity and the inbound and outbound does not create a bottleneck for the sorting plant. The price is much less important than the ability to reallocate the current P20 workers capacity, as Resource Denmark is happy to invest in machinery or equipment or software which ensures capacity can be reallocated in the OBD, so all the sorted plastic bales coming from the plant can be handled and sold.

Price -> sorting delay: The sorting delay is estimated to be moderately more important than the price. This is based on the fact that Resource Denmark are currently in the hot commissioning phase, and during this phase Eggersmann are present. The purpose of this phase is to calibrate and set the machinery to the wishes of Resource Denmark, and to do so multiple testing is required of the sensors and machinery. By investing in additional machinery or software which could slow the sorting capacity, would make decrease the opportunity to exploit the focus on the hot commissioning phase and potentially push it back further. This would lead to loss in revenue, and potentially not a through hot commissioning phase as Resource Denmark wished.

Price -> working routine these two criteria has been voted equal importance. Both are important criteria, as price of an investment will be a small bump on the long road of Resource Denmark, and the working routing is also important, it is important to have workers who are motivated and conduct the processes successfully. Both are equally important, and the workers are highly motivated, and the upper-level management has prepared them for processes will change in the future based on new knowledge the workers will gain, and they are open for it. If they were against changes at Resource Denmark, this would have a higher significance than price.

Reduction of risk

Reduction of risk -> price: This is already established

Reduction of risk-> employee training: Reduction of risk->employee training: Reduction of risk is of very strong importance compared to the amount of employee training. While the amount of employee training is a single setback, implementing processes with many risks are permanent. As Resource Denmark operates with heavy materials, this is a very strong importance compared to a single investment of employee training spanning a couple of days, compared to conducting processes spanning many years of risk.

Reduction of risk->Capacity reallocation: This is scored equal importance as both factors play a crucial role in the long-term view of Resource Denmark. They wish to create processes with minimal risk and effective processes and have sufficient capacity to do so for the long term, therefore they share equal importance.

Reduction of risk-> sorting delay: As with the employee training, the sorting delay compared to the Reduction of risk is much less important, as the sorting delay is temporary and effect the short-term planning.

Reduction of risk->working routine having a process with a low risk is also much more important than having fun and motivated processes. AN example for this is that dangerous and playful activities can create worker experiences and fun working environment, but Resource Denmark would much rather ensure a safe working environment and then hereafter focus on how to motivate the workers, as the workers safety in much more important than their subjective attitude for the process.

Employee training

Employee training->price: already established.

Employee training-> reduction of risk: already established.

Employee training->capacity reallocation: The employee training is estimated to be very less important than reallocation capacity, as the duration of employee training is affecting the short-term planning compared to the reallocation of capacity which will affect the long-term planning. Resource Denmark prioritised to focus on implementing solutions which are future proof and scalable and if there is need for additional training this is not an obstacle compared to creating scale able processes.

Employee training -> sorting delay: the sorting delay is determined to be strongly more important than the required employee training. This is because Resource Denmark can send employees to the required training (internal or external) in turns, so the sorting can still keep going, while the sorting delay to implement a machine or something, would slow the whole process down. Therefore the sorting delay is more important than the required employee training.

Employee training->working routine: the working routine is moderate more important than the employee training. This is because once again because the employee training period is short while the working routine will affect the long term vision. The employee training period will be maximum days or month, while implementing processes which will effect the next couple of years.

Capacity reallocation

Capacity reallocation-> Price: already established.

Capacity reallocation-> Reduction of risk: Already established.

Capacity reallocation->Employee training: Already established.

Capacity reallocation->Sorting delay: The capacity strongly importance compared to the sorting delay, as Resource Denmark has stated it is a priority for them to implement solutions which creates capacity, and are accepTable for it will slow the processes down due to implementing changes which will benefit them in the long run

Capacity reallocation->working routine: this is also strongly importance, as the priority is to create processes which has the capacity to cope with the plant sorting capacity and hereafter how to improve the processes can be discussed with the workers.

Sorting delay

Sorting delay->working routine: here the sorting delay is valued moderate importance. This is contradicting as sorting delay is short team effect while working routine is long term. But the reason for this score is based on the interaction in the initiation phase of Resource Denmark multiple cases showcase the importance of beginning the operation and hereafter improving the processes as more knowledge is gained. Therefore based on these observations for

Resource Denmark the sorting delay has been evaluated to be moderate importance compared to the focus of creating positive working routines from the beginning without knowledge.

8.21 Appendix 21: Calculation of CR value

To establish the CR, first the Consistency Index (CI) must be calculated. This is calculated by applying the following formulars (Saaty, 1980) (Apichat Sopadang, 2016):

$$Weighted\ sum\ matrix = Original\ pair - wise\ comparison * criteria\ weight$$

$$Ratio\ of\ one\ factor = \frac{Sum\ of\ Weighted\ sum\ matrix}{Respective\ Criteria\ weight} \quad (14)$$

$$\lambda_{max} = \frac{Ratio\ of\ factor\ 1 + Ratio\ of\ factor\ 2 \ldots + Ratio\ of\ factor\ 6}{n} \quad (15)$$

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (16)$$

As original pair-wise comparison and each criteria weight have been determined it is possible to calculate the CI value. The weighed sum matrix can be seen in Table 52.

Consistency calculation	Price	Reduction of risk areas	Additional employee traning	Opputunity for capacity reallocation	Sorting delay	Employee satisfaction	Weigthed Sum value
Price	0,0704172	0,075972756	0,102299479	0,06731891	0,038592244	0,063247913	0,417848502
Reduction of risk areas	0,352086002	0,37986378	0,238698785	0,336594549	0,810437125	0,442735389	2,560415629
Additional employee traning	0,0234724	0,054266254	0,034099826	0,048084936	0,023155346	0,021082638	0,2041614
Opputunity for capacity reallocation	0,352086002	0,37986378	0,238698785	0,336594549	0,578883661	0,316239563	2,202366339
Sorting delay	0,211251601	0,054266254	0,102299479	0,06731891	0,115776732	0,189743738	0,740656715
Employee satisfaction	0,0704172	0,054266254	0,102299479	0,048084936	0,038592244	0,063247913	0,376908026

Table 53: Weighted sum matrix

Using the weighed sum value, it is possible to calculate the ratio for each factor with formular 14.

Consistency calculation	Ratio
Price	5,9339
Reduction of risk areas	6,74035
Additional employee traning	5,98717
Opputunity for capacity reallocation	6,54308
Sorting delay	6,39728
Employee satisfaction	5,95922

Table 52: Consistency ratio

With the use of the Ratio, it is possible to calculate the Lambda max value:

Lambda Max	6,260167332

With the Lambda Max value, it is now possible to calculate the CI using formular 166.

Consistency Index (C.I)	0,052033466

Therefore, it can be concluded that the CI value for this pair-wise comparison matrix is 0.052.

Using the CI value, it is possible to calculate the CR. With the following formular:

$$CR = \frac{CI}{Random\ Index} \tag{17}$$

The Random Index (RI) is a standards number found in the AHP Table. The Table is shown in Table 59.

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Table 54: Random Index (Saaty, 1980)

As there are six factors in this pair-wise comparison matrix, the RI is 1.24.

Thereby is possible to calculate the CR value and is 0,041. As this is under 0,1, the CR value is Acceptable.

8.22 Appendix 22: TOPSIS method

The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is a MCDM method, which identifies the best option from a set of alternatives. This is done by comparing each alterative against the ideal solution that has the best values for each criterion. The goal is to rank the alternatives based on their geometric distance from this ideal solution as well as from the negative ideal solution. This method allows stakeholders to select the optimal solution by considering all relevant criteria in a systematic and balanced manners (Apichat Sopadang, 2016) (Ming-Chyuan Lin, 2007) (Thakkar, 2021).

To conduct a TOPSIS analysis, the alternatives which must be compared must be identified along with the criteria and their respective weights.

Step 1: Construct a decision matrix. This matrix must showcase each row which represents the alternatives and columns represent a criterion. The raw data of the alternative value for the respective criteria must be determined (Apichat Sopadang, 2016).

Step 2: Normalize the decision matrix. Normalizing the decision matrix coverts the raw data into a dimensionless matrix and allows for comparison across different criteria scales. The normalized values show the relative performance of each alternative under the respective criteria on a common scale (Apichat Sopadang, 2016).

The formular to normalize the decision matrix is the following (Apichat Sopadang, 2016):

$$\bar{X}_{ij} = \frac{X_{ij}}{\sqrt{\sum_{j=1}^{n} {X_{ij}}^2}} \tag{18}$$

- $\bar{X}_{ij}$ is the normalized value for the i-th alternative under the j-th criterion.
- X_{ij} is the original value for the i-th alternative under the j-th criterion.

Step 3: Calculate the weighted normalized matrix. This step incorporates the importance of each criterion into the analysis, reflecting their relative significance in the decision-making process. The weighted normalized values represent the adjusted performance of each alternate considering their respective criteria weight. To conduct this step the following Equation is applied (Apichat Sopadang, 2016):

$$V_{ij} = \bar{X}_{ij} * W_j \tag{19}$$

- V_{ij} is the weighted normalized value from the i-th alternative under the jth criterion.
- $\bar{X}_{ij}$ is the normalized value for the i-th alternative under the j-th criterion.
- W_j is the weight assigned to the j-th criterion.

Step 4: Determine the ideal and negative ideal solution. The ideal solution represents the best values for each criterion. It is important to remember the highest value is not necessarily the ideal solution. The negative ideal solution consists of the worst values for each criterion. These two values serve as a benchmark for evaluating each alternative. Based on the values calculated using Equation 6, these values should be determined.

Step 5. Calculate the Euclidean distance from ideal and negative ideal solution. These distances quantify how close each alternative is to the ideal and negative ideal solution. The short the distance is to the ideal solution, the longer the distance is to the negative ideal solution, the better the alternative. Using this Equation the distance from the negative and ideal solution is calculated for each scenario (Apichat Sopadang, 2016):

$$S_i^+ = \left[\sum_{j=1}^{m} \left(V_{ij} - V_j^+\right)^2\right]^{0,5} \tag{20}$$

- S_i^+ is the distance of the alternative i from the ideal solution.
- V_{ij} is the weighted normalized value from alternative i under criterion j.
- V_j^+ is the ideal value under the criterion j.

The Equation for calculating the Euclidean distance to the worst value is by applying Equation 21 (Apichat Sopadang, 2016).

$$S_i^- = \left[\sum_{j=1}^{m} \left(V_{ij} - V_j^-\right)^2\right]^{0,5} \tag{21}$$

- S_i^- is the distance of alternative i from the negative solution.
- V_{ij} is the weighted normalized value from alternative i under criterion j.

- V_j^- is the negative value under criterion j.

Step 7. The last step is to calculate the performance score. The performance score indicates how each alternative perform relative to the ideal solution. The higher the performance score for the respective alternative, the closer it is to the ideal solution, making it more desirable. The Equation to calculate the performance score is the following (Apichat Sopadang, 2016):

$$P_i = \frac{S_i^-}{S_i^+ + S_i^-} \tag{22}$$

- P_i is the relative closeness to the of the alternative to the ideal solution.
- S_i^- is the distance of the alternative from the negative solution.
- S_i^+ is the distance of the alternative from the ideal solution.

Why TOPSIS is Ideal for This Project

TOPSIS is particularly suiTable for this project due to its unique ability to provide a balanced evaluation of multiple conflicting criteria, such as cost, capacity reallocation, training requirements, and operational impact. While other MCDM methods also handle multiple criteria, TOPSIS stands out for several reasons (Apichat Sopadang, 2016) (Ming-Chyuan Lin, 2007) (Thakkar, 2021).:

Geometric Distance Calculation:

TOPSIS evaluates each alternative by calculating its geometric distance from an ideal solution (the best possible scenario) and a negative-ideal solution (the worst possible scenario). This dual consideration offers a more nuanced and balanced assessment compared to methods that might focus only on ideal conditions (JSTOR).

Incorporation of Relative Closeness:

The method ranks alternatives based on their relative closeness to the ideal solution, considering both the proximity to the ideal and the distance from the worst scenario. This ensures that the selected alternative is not only the best among the options but also farthest from the worst-case scenario, providing a comprehensive evaluation of potential outcomes.

Efficiency and Clarity:

TOPSIS is computationally efficient, making it suiTable for projects with multiple criteria and alternatives. It provides clear, defensible rankings that are easy to communicate and understand, which is crucial for stakeholder engagement and support.

Straightforward Integration of AHP Weights:

By using the weights calculated through the Analytic Hierarchy Process (AHP), TOPSIS seamlessly integrates both qualitative and quantitative criteria into its evaluation framework. This integration ensures that the method aligns with the strategic priorities and operational goals of Resource Denmark (JSTOR).

Balanced Decision-Making:

The method's ability to consider both positive and negative aspects of each alternative ensures a balanced decision-making process. This is particularly important for Resource Denmark, where balancing cost, efficiency, and safety is crucial.

These features make TOPSIS an ideal choice for this project, ensuring a robust, transparent, and balanced evaluation of alternatives based on the specific criteria relevant to Resource Denmark's needs.

8.23 Appendix 23: Comparison values of each alternative

This appendix will explain the values within each cell of the raw data Table of each alternative.

Data of alternative	Price (DDK)	Capacity reallocation	Nr. Of risk areas	Need of training (days)	Sorting delay (days)	Worker satisfaction
UWUK	2,902,435	Yes	3	1	5	5
Equipment upgrades	143,250	Yes	6	1	0	2
BC	1,000,000	No	6	3	0	3
Overhead crane	7,000,000	Yes	9	10	31	5

Table 55: Raw data of alternatives

The price of each alternative is stated in the description and analysis of each alternative. Along with the prices the ability to reallocate capacity is also stated based on each respective PFC. The need of training days is also stated for each alternative along with the expected sorting delays.

The worker satisfaction is based on the following scale:

1) Unhappy and highly demotivated to conduct the process.
2) Prefer to conduct the old P20 process compared to the alternative.
3) Same level of excitement for this alternative as the current process.
4) Exited to try new alternative compared to current alternative.
5) Do not require any dedicated worker, as the process can work itself.

The *UWUK* -machines and *Overhead crane* scores 5, as this eliminates the need for a dedicated worker.

The *Equipment changes* score a 2. As a testing sample was present at Resource Denmark, it was possible to interact with the blue-collar workers and record their first-hand experience with the upgraded process if this alternative were to be implemented. The workers were not keen on logging every single bale and tagging an RFID tag on it, additionally going in and out of the forklift each time will also demotivate them to work. They preferred the current option for now.

The *BC* alternative has gotten a score of 3, which indicates the same level of excitement as the current process. This is because implementing this alternative, does not change anything regarding process 20's activities.

Prices:

***UWUK* alternative**: sales price for the *UWUK* -machine (Unotech LM Group, 2024)+ ERP system (manager, 2024). An ERP system is required to the Unotech bailer can send data directly through to the ERP system.

$$UWUK\ alternative: 1{,}902{,}435\ DKK + 1{,}000{,}000\ DKK = 2{,}902{,}435\ DKK$$

Equipment upgrades: Sales prices of 1.5 million RFID tags (Alibaba, 2024) + claps with weight scale (Lifttruck, 2024), and RFID tag reader (Link-labs, 2024).

$$Equipment\ upgrades\ alterantive: 104{,}000\ DKK + 20{,}000 DKK + 19{,}250\ DKK = 162{,}500\ DKK$$

BC: The initial investment price of 1,000,000 DKK (manager, 2024) stems from the interview with the Sales Manager at Vektus.

Overhead crane: The investment of 7,000,000 DKK stems from the selling price of the crane from Mazzella, which sells *Overhead crane*s to many different industries (Mazzella, 2024).

8.23.1 Number of risk areas for each alternative

The main goal of this PFMEA analysis for the alternative methods of conducting P20 is to identify the potential risk areas for each alternative. By determining the potential risk areas, it is possible to compare the amount of risk each alternative has and give a valid and accurate score for each alternative in the scoring matrix.

As previously, the PFMEA analysis will consist of a RPN value, which is based on each potential risk areas Severity, Occurrence, and Detection values. These values are based on primary & secondary data from the alternatives. As none of these alternatives have been implemented, these potential risk areas are not based on empirical data collected at Resource Denmark.

In the Table 13, the PFMEA analysis for each alternative is presented.

UWUK

Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Causes(s)/Mechanism(s) of Failures	Occur	Process Control	Detection	RPN
Malfuntion of machine	Delays sorting	8	Failure of software or hardware	5	Identification of failure by workers	3	120
Ink in label maker finishes	Unable to identify the weight and type of plastic without furthur inspection	8	Lack of checking up on ink base	4	Morgen check on ink	2	64
Weight scale not accurate	Customer does not recieve the right amount of tons	8	Failure of software or hardware	3	Sample test bales on current weight	6	144
Total							**328**

Weights in forklift and RFID tags

Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Causes(s)/Mechanism(s) of Failures	Occur	Current Process Control	Detection	RPN
Weights are inaccurate	Customer does not recieve the right amount of tons	6	Weight scales are not calibered	3	Calibrate weights each Monday morning	5	90
Human and forklift clash	Damage to human and forklift	10	Failure of forklift sensors and human awareness	2	Eye contact and walkie talkie	6	120
Wrongfull notation of weight	Inaccurate data of inventory	6	Stressfull situations when operating with high pace human errors can occur	2	None	10	120
Wrong identification of plastic type	Customer does not recieve right plastic type	7	Stressfull situations when operating with high pace human errors can occur	2	None	4	56
RFID tag falls off plastic bale	Unable to identify the weight and type of plastic without furthur inspection	6	The strip attaching the RFID tag to the bale is damaged	2	Worker straps on the RFID tag strongly	3	36
Phone out of charge to create RFID tag	Delays sorting	7	Worker has not charged his/her phone	1	Company policy stated to always have phone at you side	2	14
Total							**436**

BI

Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Causes(s)/Mechanism(s) of Failures	Occur	Current Process Control	Detection	RPN
ERP system crashes	Delays sorting	6	Laptop experience overload and crashes	2	None	3	36
Wrongfull notation of weight	Inaccurate data of inventory	7	Stressfull situations when operating with high pace human errors can occur	4	None	10	280
Wrong identification of plastic type	Customer does not recieve right plastic type	8	Stressfull situations when operating with high pace human errors can occur	3	None	7	168
Label falls of plastic bale	Unable to identify the weight and type of plastic without furthur inspection	3	The glue from the label is not strong enough	7	Worker finds a flat surfase to attatch the label	7	147
Ergonomic damage to worker	Ressource Denmark responsible for insurance	7	Not using the right equipment for standing and sitting	2	None	2	28
Equipment out of charge	Delays sorting	7	Handheld scanner is not charged	2	None	3	42
Total							**701**

Overhead crane							
Potential Failure Mode	**Potential Effect(s) of Failure**	**Severity**	**Potential Causes(s)/Mechanism(s) of Failures**	**Occur**	**Current Process Control**	**Detection**	**RPN**
Worker walks into crane area	Injuries to the worker	10	Failture of crane operator to detect worker	2	Eye contact and walkie talkie	3	60
Malfuntion of machine	Delays sorting	8	Failure of software or hardware	2	None	3	48
Bales are incorrectly lifted	Damage to bale	10	Failure to attached crane correctly to bale	2	None	4	80
Wrongfull notation of weight	Inaccurate data of inventory	7	Stressfull situations when operating with high pace human errors can occur	4	None	10	280
Wrong identification of plastic type	Customer does not recieve right plastic type	8	Stressfull situations when operating with high pace human errors can occur	3	None	7	168
Label falls of plastic bale	Unable to identify the weight and type of plastic without furthur inspection	3	The glue from the label is not strong enough	7	Worker finds a flat surfase to attatch the label	7	147
Ergonomic damage to worker	Ressource Denmark responsible for insurance	7	Not using the right equipment for standing and sitting	2	None	2	28
Excel sheet with data crashes	Loss of inventory records	8	Laptop experience overload and crashes	2	None	5	80
Placing the bale in wrong inventory	Customer does not recieve right plastic type	8	Stressfull situations when operating with high pace human errors can occur	3	None	7	168
Total							**1059**

Table 56: PFMEA of all alternatives

Table 22 showcases, the alternative with the most potential risk areas is the *Overhead crane* solution. This alternative also has a RPN value of 1059, which is the highest among the alternatives. As this alternative does not change the current processes 20, the potential risk areas from the current process are present.

The second highest alternative with most potential risk areas are both the implementation of weight scales in forklift & RFID tags and implementation of *BC* system. Three out of the six potential risk are the same, as these two alternatives require manual identification of plastic type & weight and logging of these into an inventory system. Even though these have the same amount of potential risk areas, the *BC* alternative has the higher RPN value.

The alternative with the least potential risk areas is the implementation of the *UWUK* -machine. This alternative only has three potential risk areas, which combines results in a RPN value of 463. The low amount of risk areas originates as this alternative is a change compared to the current P20. As this is a change, it does not include any of the risk areas which the current P20 includes. It can also be seen the Detection collum has a low grade, meaning implementing these mentioned control systems to the risk areas would minimize the danger of the potential risk happening. Comparing this Detection collum score with the other alternatives, it can be seen in total it is much lower. This indicates, with these low amount of potential risk areas, there is also a great chance of minimizing the risk of happening, as this risk can be controlled by using the mentioned process control actions.

Each alternatives conclusion of potential risk areas will be used to evaluate the degree of risk each alternative has, in the scoring matrix. The scoring matrix will be the deciding factor for which alternative would be most suiTable for Resource Denmark’s vision for the future and long-term plans.

8.24 Appendix 24: All possible reallocation options for *UWUK* alternative

This appendix showcases the different worker allocation possibilities which has been investigated for the in-depth capacity analysis.

Process 30 + 50 with two workers and one worker on process 40:

Current vs expected capacity	Shift 1	Shift 2	Shift 3	Shift 3 + weekend
Process 20				
Worker capacity (bales)	65.253	129.435	197.897	240.686
Expected capacity (bales)	46.048	90.610	138.143	167.851
Difference	**19.205**	**38.825**	**59.754**	**72.834**
Process 30 + 50				
Worker capacity (bales)	47.459	83.669	125.855	168.744
Expected capacity (bales)	46.048	90.610	138.143	167.851
Difference	**1.411**	**- 6.941**	**- 12.288**	**892**
Process 40				
Worker capacity (bales)	72.920	143.487	218.759	265.804
Expected capacity (bales)	46.048	90.610	138.143	167.851
Difference	**26.872**	**52.877**	**80.616**	**97.953**

Table 57: P30+50

Process 40+50 with two workers and one worker on process 30.

Current vs expected capacity	Shift 1	Shift 2	Shift 3	Shift 3 + weekend
Process 20				
Worker capacity (bales)	65.253	129.435	197.897	240.686
Expected capacity (bales)	46.048	90.610	138.143	167.851
Difference	**19.205**	**38.825**	**59.754**	**72.834**
Process 30+40+50				
Worker capacity (bales)	44.346	88.693	135.220	164.300
Expected capacity (bales)	46.048	90.610	138.143	167.851
Difference	**- 1.701**	**- 1.917**	**- 2.923**	**- 3.552**
Process 40+50				
Worker capacity (bales)	58.639	113.829	169.019	206.962
Expected capacity (bales)	46.048	90.610	138.143	167.851
Difference	**12.592**	**23.219**	**30.876**	**39.111**

Table 58: P40+50

These are good possibilities, but it would be more beneficial to have two workers on process 40 and 50, since only one truck can be loaded at a time in the OBD.

All three workers on all three possess:

Current vs expected capacity	Shift 1	Shift 2	Shift 3	Shift 3 + weekend
Process 20				
Worker capacity (bales)	65.253	129.435	197.897	240.686
Expected capacity (bales)	46.048	90.610	138.143	167.851
Difference	**19.205**	**38.825**	**59.754**	**72.834**
Process 30+40+50				
Worker capacity (bales)	56.566	109.884	161.849	198.658
Expected capacity (bales)	46.048	90.610	138.143	167.851
Difference	**10.518**	**19.274**	**23.706**	**30.806**

Table 59: all workers on all Process

This is possible would not be ideal, as the investment increases and safety will lower.

8.25 Appendix 25: All possible reallocation options for *Equipment upgrades* alternative

This appendix showcases the different worker allocation possibilities which has been investigated for the in-depth capacity analysis.

One worker on all:

Current vs expected capacity	Shift 1	Shift 2	Shift 3	Shift 3 + weekend
Process 20				
Worker capacity (bales)	70.272	139.392	213.120	259.200
Expected capacity (bales)	46.048	90.610	138.143	167.851
Difference	**24.224**	**48.782**	**74.977**	**91.349**
Process 30				
Worker capacity (bales)	45.073	88.693	135.220	164.300
Expected capacity (bales)	46.048	90.610	138.143	167.851
Difference	**- 974**	**- 1.917**	**- 2.923**	**- 3.552**
Process 40				
Worker capacity (bales)	72.920	143.487	218.759	218.759
Expected capacity (bales)	46.048	90.610	138.143	95.038
Difference	**26.872**	**52.877**	**80.616**	**123.721**
Process 50				
Worker capacity (bales)	42.205	83.049	126.615	-
Expected capacity (bales)	46.048	90.610	138.143	95.038
Difference	**- 3.843**	**- 7.561**	**- 11.528**	**- 95.038**

Table 60: One worker for all

P30+50= 2 workers:

There is a reallocation possibility here. But process 30 & 50, are not subsequent processes,

Current vs expected capacity	Shift 1	Shift 2	Shift 3	Shift 3 + weekend
Process 20				
Worker capacity (bales)	70.272	139.392	213.120	259.200
Expected capacity (bales)	46.048	90.610	138.143	167.851
Difference	**24.224**	**48.782**	**74.977**	**91.349**
Process 30+50				
Worker capacity (bales)	47.811	92.809	137.807	168.744
Expected capacity (bales)	46.048	90.610	138.143	167.851
Difference	**1.763**	**2.199**	**- 336**	**892**
Process 40				
Worker capacity (bales)	159.953	143.487	218.759	218.759
Expected capacity (bales)	46.048	90.610	138.143	95.038
Difference	**113.905**	**52.877**	**80.616**	**123.721**

Table 61: 30+ 50

meaning there will be a lot of transportation time. Based on this no more capacity analysis will be made unless they are subsequent process of each other, which only can be 30+40, but still 50 is missing capacity, therefore there is no more options.

8.26 Appendix 26: Initial investment for both alternatives

This appendix serves the purpose of showcasing the initial investment price for both alternatives.

Initial investment for *UWUK* alternative (Unotech LM Group, 2024) (manager, 2024) (Manager O. , 2024) (Toyota Material Handling, 2024):

Initial investment (UWUK)		
UWUK machine	1.902.435	DKK
ERP system	1.000.000	DKK
Toyota forklift	703.886	DKK
Total	3.606.321	DKK

Table 62: Initial investment price of UWUK alternative

The current Toyota forklift price can be seen in the following illustration:

TOYOTA
MATERIAL HANDLING

OVERSIGT
Tilbud nr.: OCMOVZ_221102/TA
21-04-23 | 3

Salg

LINJE NR.	KUNDENS REFERENCE	MODEL	PRIS/MASKINE	ANTAL	TOTAL PRIS
1		9FBM35T	DKK 703.886	3	DKK 2.111.657
2	Quick Shift	9FBM35T	DKK 707.242	1	DKK 707.242
				Total	DKK 2.818.899

DS/Driftsservice

LINJE NR.	KUNDENS REFERENCE	MODEL	BESØG/ÅR	SERVICE/BESØG	KØRSEL/BESØG
1		9FBM35T	3	DKK 2.345	DKK 0
2	Quick Shift	9FBM35T	3	DKK 2.345	DKK 0

Andre produkter salg

LINJE NR.	KUNDENS REFERENCE	MODEL	PRIS	ANTAL	TOTAL PRIS
3		Gaffelflytter	DKK 23.546	1	DKK 23.546
				Total	DKK 23.546

Figure 24: Price of a forklift

Initial investment for *Equipment upgrades*:

Initial investment (Equipment upgrades)		
2x forklift clamps with s	38.500	DKK
1.5 million RFID tags	104.000	DKK
RFID tag reader	20.000	DKK
2x Toyota forklift	1.407.772	DKK
Total investment cost	1.570.272	DKK

Figure 25: Initial investment price of Equipment upgrades

Price of investment for both alternatives

RFID tags: https://www.alibaba.com/product-detail/Rfid-Nfc-Tag-sticker-label-PrinTable_1601082066178.html?spm=a2700.7724857.0.0.29724f9bqlKr5R

RFID reader: https://www.link-labs.com/blog/rfid-cost

Weight scales: https://lifttruck.com/product/safe-weigh-forklift-hydraulic-scale-system/

8.27 Appendix 27: Break even analysis

This appendix will showcase how the breakeven analysis is calculated for both alternatives.

Using this Equation, the BEP can be calculated (Paolo Candio, 2022):

$$Pe = \frac{CF}{cb_u} \tag{10}$$

- Pe is the BEP
- CF is the fixed cost of the respective alternative
- cb_u is the contribution margin (CM)

With the use of secondary data, the fixed cost for each alternative has been calculated. The fixed cost for this project includes indirect labour cost and respective initial investment. The values of these cost can be seen in the following Table (Jobindex, 2024).

Employe montly cost	Jobindex	Unit
Production worker	27.000	DKK
Cost of additional bene	1,44	%
Plant director	68.550	DKK
Managers	53.525	DKK
Electrican	30.785	DKK
Quality engineer	46.881	DKK

Figure 26: Resource Denmark wages

The fixed cost for each alternative can be seen in Table 68.

Fixed cost (Yearly/DKK	UWUK	Equipment upgrades
Initial investment	3.606.321	1.570.272
Indirect wages	1.035.196	1.035.196
Total	4.641.517	2.605.468

Table 63: Fixed cost for each alternative

Based on the calculations in Table 68, it can be seen the yearly fixed cost is approx. 2 million DKK higher in the *UWUK* alternative. This stems from the difference in initial investment cost, as the indirect wages and building expenses remain the same throughout both alternatives.

With the use of primary and secondary data, the contribution margin (CM) for one bale can also be calculated. Resource Denmark's supply chain differs from the traditional supply chain.

While a traditional supply chain buys raw materials and sells their finished goods to create revenue, Resource Denmark receives revenue when receiving mix plastic bales. Additionally selling sorted plastic bales with LDPE, PS, PET, Tetra generates a loss, as these plastic types are a challenge to recycle compared to HDPE and PP, which are solid plastic types. In Table 70, the revenue from accepting mixed plastic bales and selling the respective plastic bales can be seen.

Plastic price			
Material		Price (DKK)	Unit
Feedstock		1,8646	Price/Kg
LDPE	-	1,6781	Price/Kg
HDPE		1,1188	Price/Kg
PP		0,3729	Price/Kg
PS	-	0,0746	Price/Kg
PET	-	1,8273	Price/Kg
Tetra	-	1,7900	Price/Kg

Table 65: Revenue for each type of bale

557	Bale weight	
Bale type		Revenue (DKK)
Feedstock		1.039
LDPE	-	224
HDPE		69
PP		33
PS	-	0,8
PET	-	132
Tetra	-	100
Revenue per bale		683

Table 64: Revenue per bale of 557 kg

Based on these selling prices, it is possible to calculate the expected profit per sorted bale using the average bale weight determined in section 3.4.1.1. Using the mass balance in Table 3.4.2.1, average bale weight, and selling prices per kg, it is possible to calculate the expected revenue per bale inserted into the sorting plant and sorted. As Table 69 showcase the expected revenue of a 557 kg mixed plastic bale is 683 DKK. With the use of the PFC for both alternatives, showcased in Figure 7 and 8, the total handling time can be identified along with the handling time in the IBD. Based on the handling time and number of workers and expected revenue per bale, the CM is calculated for each alternative.

Contribution margin	UWUK (DKK)	Equipment upgrades (DK
Variable cost	102	155
Contribution margin	581	529

Table 66: Contribution margin for each alternative

It can be seen the CM is higher for the *UWUK* alternative. This is due to the requirement of four workers in the equipment upgrade alternative compared to the requirement of three workers for the *UWUK* alternative.

With the fixed cost and CM identified for both alternative, it is now possible to apply Equation 10 and determine the number of bales which must be handled to reach the break-even point. In Table 72 the number of bales which need to be handled to reach the break-even point is calculated.

Break even point	UWUK	Equipment upgrades
Nr of bales to reach BEI	7.983	4.929

Table 67: Break-even point for each alternative

8.28 Appendix 28: Inputs and results of capacity simulation

This appendix will showcase which inputs are added to the capacity simulation for the *UWUK* alternative, using the machine to operate process 20, two workers to operate process 30& 40, and one worker to operate process 50.

It is also coded, to calculate if sufficient capacity is present, without any capacity reallocation, and after showcased process lack capacity, the same simulation is run by exploiting the excess capacity of the two workers operating process 30 and 40 to process 50.

The application PyCharm is used to run the simulation. The input to the simulation can be seen in the following Figure s:

```
# Define the cycle times for each process in seconds
cycle_times = {
    'Process 20': 70,
    'Process 30': 103,
    'Process 40': 64,
    'Process 50': 110
}

# Define the combined cycle time for processes 30 and 40
combined_cycle_time_30_40 = cycle_times['Process 30'] + cycle_times['Process 40']

# Define the expected output of bales per shift
expected_output = {
    'Shift 1': 46048,
    'Shift 2': 90610,
    'Shift 3': 138143,
    'Shift 3 + Weekend': 167851
}

# Define the available time in seconds per day for different shifts (per week)
available_time_shift_1 = {
    'Mon': 8640,
    'Tue': 20160,
    'Wed': 20160,
    'Thu': 20160,
    'Fri': 18720
}

available_time_shift_2 = {
    'Mon': 28800,
    'Tue': 38880,
    'Wed': 38880,
    'Thu': 38880,
    'Fri': 28800
}
```

```
available_time_shift_3 = {
    'Mon': 48960,
    'Tue': 57600,
    'Wed': 57600,
    'Thu': 57600,
    'Fri': 44640
}

available_time_shift_3_weekend = {
    'Mon': 48960,
    'Tue': 57600,
    'Wed': 57600,
    'Thu': 57600,
    'Fri': 44640,
    'Sat': 28800,
    'Sun': 28800
}


# Convert weekly available time to annual available time (52 weeks in a year)
4 usages
def convert_to_annual(weekly_time):
    return {day: time * 52 for day, time in weekly_time.items()}


available_time_shift_1_annual = convert_to_annual(available_time_shift_1)
available_time_shift_2_annual = convert_to_annual(available_time_shift_2)
available_time_shift_3_annual = convert_to_annual(available_time_shift_3)
available_time_shift_3_weekend_annual = convert_to_annual(available_time_shift_3_weekend)


# Define a function to calculate total available time per year
3 usages
def calculate_total_available_time(time_dict):
    return sum(time_dict.values())
```

```
# Define a function to calculate total required time for handling the expected bales
3 usages
def calculate_total_required_time(cycle_time, expected_bales):
    return cycle_time * expected_bales


# Define a function to check if the process has enough capacity
3 usages
def has_sufficient_capacity(available_time, required_time):
    return available_time >= required_time


# Function to run the simulation and return results as a dictionary
1 usage
def simulate_shift(shift_name, available_time_annual):
    results = {}

    # Process 20
    total_available_time_20 = calculate_total_available_time(available_time_annual)
    total_required_time_20 = calculate_total_required_time(cycle_times['Process 20'], expected_output[shift_name])
    capacity_20_sufficient = has_sufficient_capacity(total_available_time_20, total_required_time_20)
    excess_capacity_20 = total_available_time_20 - total_required_time_20
    results['Process 20'] = capacity_20_sufficient

    # Combined Process 30 and 40
    total_available_time_30_40 = calculate_total_available_time(available_time_annual) * 2
    total_required_time_30_40 = calculate_total_required_time(combined_cycle_time_30_40, expected_output[shift_name])
    capacity_30_40_sufficient = has_sufficient_capacity(total_available_time_30_40, total_required_time_30_40)
    excess_capacity_30_40 = total_available_time_30_40 - total_required_time_30_40
    results['Process 30+40'] = capacity_30_40_sufficient

    # Process 50
    total_available_time_50 = calculate_total_available_time(available_time_annual)
    total_required_time_50 = calculate_total_required_time(cycle_times['Process 50'], expected_output[shift_name])
    process_50_capacity_sufficient = has_sufficient_capacity(total_available_time_50, total_required_time_50)
    missing_time_50 = total_required_time_50 - total_available_time_50
```

```
    missing_time_50 = total_required_time_50 - total_available_time_50
    if not process_50_capacity_sufficient:
        if excess_capacity_30_40 >= missing_time_50:
            excess_capacity_30_40 -= missing_time_50
            results['Process 50 (with help)'] = True
        else:
            results['Process 50 (with help)'] = False
    else:
        results['Process 50 (with help)'] = True

    # Print detailed results
    print(f"Shift: {shift_name}")
    print(f"Process 20 Total Available Seconds: {total_available_time_20}")
    print(f"Process 20 Total Required Seconds: {total_required_time_20}")
    print(f"Process 20 Capacity Sufficient: {capacity_20_sufficient}")
    print(f"Process 20 Excess Capacity: {excess_capacity_20}\n")
    print(f"Combined Process 30 and 40 Total Available Seconds: {total_available_time_30_40}")
    print(f"Combined Process 30 and 40 Total Required Seconds: {total_required_time_30_40}")
    print(f"Combined Process 30 and 40 Capacity Sufficient: {capacity_30_40_sufficient}")
    print(f"Combined Process 30 and 40 Excess Capacity: {excess_capacity_30_40}\n")
    print(f"Process 50 Total Available Seconds: {total_available_time_50}")
    print(f"Process 50 Total Required Seconds: {total_required_time_50}")
    print(f"Process 50 Capacity Sufficient: {process_50_capacity_sufficient}")
    if not process_50_capacity_sufficient:
        print(f"Process 50 Missing Time: {missing_time_50}\n")
    else:
        print(f"Process 50 Excess Capacity: {total_available_time_50 - total_required_time_50}\n")
    if not process_50_capacity_sufficient:
        if excess_capacity_30_40 >= missing_time_50:
            excess_capacity_30_40 -= missing_time_50
            print("Excess capacity from combined Process 30 and 40 can handle the remaining bales in Process 50.\n")
        else:
            print(
                "Insufficient capacity to handle the remaining bales in Process 50, even with excess capacity from combined Process 30 and 40.\n")
    print(f"Final Excess Capacity Summary:")
    print(f"Process 20 Excess Capacity: {excess_capacity_20}")
    print(f"Combined Process 30 and 40 Worker Excess Capacity: {excess_capacity_30_40}")
```

```
    print(
        f"Process 50 Excess Capacity: {0 if not process_50_capacity_sufficient else total_available_time_50 - total_required_time_50}\n")

    return results


# Simulate for each shift and collect results
shifts = ['Shift 1', 'Shift 2', 'Shift 3', 'Shift 3 + Weekend']
shift_times = [available_time_shift_1_annual, available_time_shift_2_annual, available_time_shift_3_annual,
               available_time_shift_3_weekend_annual]

all_results = {shift: simulate_shift(shift, time) for shift, time in zip(shifts, shift_times)}

# Create and display the summary table
import pandas as pd

df_results = pd.DataFrame(all_results).T
print(df_results)
```

The result of running this simulation can be seen in the following Figure s

Shift 1:

```
"C:\Users\ajiva\PycharmProjects\UWUK alternative\.venv\Scripts\python.exe" "C:\Users\ajiva\PycharmProjects\UWUK alternative\UWUK alternative RAW Project.py"
Shift: Shift 1
Process 20 Total Available Seconds: 4567680
Process 20 Total Required Seconds: 3223360
Process 20 Capacity Sufficient: True
Process 20 Excess Capacity: 1344320

Combined Process 30 and 40 Total Available Seconds: 9135360
Combined Process 30 and 40 Total Required Seconds: 7690016
Combined Process 30 and 40 Capacity Sufficient: True
Combined Process 30 and 40 Excess Capacity: 947744

Process 50 Total Available Seconds: 4567680
Process 50 Total Required Seconds: 5065280
Process 50 Capacity Sufficient: False
Process 50 Missing Time: 497600

Excess capacity from combined Process 30 and 40 can handle the remaining bales in Process 50.

Final Excess Capacity Summary:
Process 20 Excess Capacity: 1344320
Combined Process 30 and 40 Worker Excess Capacity: 450144
Process 50 Excess Capacity: 0
```

```
Shift: Shift 2
Process 20 Total Available Seconds: 9060480
Process 20 Total Required Seconds: 6342700
Process 20 Capacity Sufficient: True
Process 20 Excess Capacity: 2717780

Combined Process 30 and 40 Total Available Seconds: 18120960
Combined Process 30 and 40 Total Required Seconds: 15131870
Combined Process 30 and 40 Capacity Sufficient: True
Combined Process 30 and 40 Excess Capacity: 2082470

Process 50 Total Available Seconds: 9060480
Process 50 Total Required Seconds: 9967100
Process 50 Capacity Sufficient: False
Process 50 Missing Time: 906620

Excess capacity from combined Process 30 and 40 can handle the remaining bales in Process 50.

Final Excess Capacity Summary:
Process 20 Excess Capacity: 2717780
Combined Process 30 and 40 Worker Excess Capacity: 1175850
Process 50 Excess Capacity: 0
```

Shift 3:

```
Shift: Shift 3
Process 20 Total Available Seconds: 13852800
Process 20 Total Required Seconds: 9670010
Process 20 Capacity Sufficient: True
Process 20 Excess Capacity: 4182790

Combined Process 30 and 40 Total Available Seconds: 27705600
Combined Process 30 and 40 Total Required Seconds: 23069881
Combined Process 30 and 40 Capacity Sufficient: True
Combined Process 30 and 40 Excess Capacity: 3292789

Process 50 Total Available Seconds: 13852800
Process 50 Total Required Seconds: 15195730
Process 50 Capacity Sufficient: False
Process 50 Missing Time: 1342930

Excess capacity from combined Process 30 and 40 can handle the remaining bales in Process 50.

Final Excess Capacity Summary:
Process 20 Excess Capacity: 4182790
Combined Process 30 and 40 Worker Excess Capacity: 1949859
Process 50 Excess Capacity: 0
```

Shift 3 + weekend:

```
Shift: Shift 3 + Weekend
Process 20 Total Available Seconds: 16848000
Process 20 Total Required Seconds: 11749570
Process 20 Capacity Sufficient: True
Process 20 Excess Capacity: 5098430

Combined Process 30 and 40 Total Available Seconds: 33696000
Combined Process 30 and 40 Total Required Seconds: 28031117
Combined Process 30 and 40 Capacity Sufficient: True
Combined Process 30 and 40 Excess Capacity: 4049273

Process 50 Total Available Seconds: 16848000
Process 50 Total Required Seconds: 18463610
Process 50 Capacity Sufficient: False
Process 50 Missing Time: 1615610

Excess capacity from combined Process 30 and 40 can handle the remaining bales in Process 50.

Final Excess Capacity Summary:
Process 20 Excess Capacity: 5098430
Combined Process 30 and 40 Worker Excess Capacity: 2433663
Process 50 Excess Capacity: 0
```

Summary of the simulation results:

```
Final Excess Capacity Summary:
Process 20 Excess Capacity: 5098430
Combined Process 30 and 40 Worker Excess Capacity: 2433663
Process 50 Excess Capacity: 0

                     Process 20  Process 30+40  Process 50 (with help)
Shift 1                    True           True                    True
Shift 2                    True           True                    True
Shift 3                    True           True                    True
Shift 3 + Weekend          True           True                    True

Process finished with exit code 0
```

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