Hospital Waste Management

- Handling of plastic waste produced at hospitals in Region Nord -

Master thesis report

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STUDENT REPORT

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Abstract:

The EU introduced new laws and regulations regarding waste handling that Danish hospitals had to follow. The problem hospitals faced was to make a solution that could fulfil these laws and regulations. The pilot project, by standardizing the same solution to all hospitals, turned out not to work due to the different infrastructures of the hospitals. This project analyzed the current problems of waste generation within hospitals focused on Region Nord and the currently existing solutions for waste sorting. Theoretical and practical knowledge was collected during hospital visits and meetings with sorting personnel. Based on findings, a modular structure was made from this knowledge that could provide manager and management customized solutions for each hospital and department. A solution catalogue was developed using the proposed modular structure. A cost benefit analysis was performed to see how much the Hjørring Hospital could earn monthly.

Contents

Preface

The introduction and parts of the problem analysis were written in calibration with two other groups [27], [1]. Page 1 - 18 contains elements from the shared work. However, changes were made to the original shared work.

Aalborg University, June 9, 2023

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Chapter 1

Introduction

In modern industry, becoming green, recycling and reusing are getting more and more in focus. Recycling and reusing waste are essential to reduce the amount of waste ending in landfills and the environment. Recycling and reusing waste can conserve natural resources, reduce pollution, and save energy. It is essential to reduce waste as much as possible in a sustainable and green way to manage it. However with the rapid industrialization waste generation have increased and with the increase, focus on recycling and reuse of waste, has become more difficult for regular citizens, companies and regulators to distinguish between the different types and fraction of waste.

The European Union(EU) produces more than 2.5 billion tonnes of waste every year. Therefore the EU is updating their legislation on waste management to encourage countries and companies to move to a more sustainable model and way of handling their waste. This model is known as the circular economy. [9] Circular economy is a model of production and consumption, aiming to keep products, components, and materials at their highest value and utility at all times to reduce waste, minimise the use of resources and extend the life cycle of products.

In practice, it implies reducing waste to a minimum. When a product reaches the end of its life, its materials are kept within the economy wherever possible due to recycling. These can be productively used again and again, thereby creating additional value.

Circular economy moves away from the traditional linear economy model of "take, make, waste," based on unlimited resources and the theory that waste can be endlessly generated without consequences. The circular economy aims to create a closed loop of products. It promotes efficient use of resources by reusing, repairing, refurbishing, and recycling products and materials to create a more sustainable and resilient economy that benefits both people and the planet. Overall, the circular economy represents a shift towards a more sustainable and responsible way of using resources. [15]

Using circular economy in hospitals can reduce the amount of waste produced, promote sustainable practices, and go under the waste management category. Hospital waste management is a process that assists in maintaining proper hospital hygiene and the safety of healthcare workers and communities. The process involves sorting, collection, storage, transport, and disposal. Region Nord needs to work on implementing waste sorting in local hospitals. The cause for the problem is many, like unclear waste standards, it is difficulty to sort by the personnel, and so on. Due to these conditions, the potential for exploring and analyzing the solutions is vast.

A more effective and extensive sorting of waste in general, it can greatly help to increase the overall amount of recycling. This separation is more feasible in some industries due to the presence of specific types of waste. In the medical industry and especially in hospitals, due to the wide presence of hazardous objects that include sharp objects and objects contaminated with infectious substances, separation is more challenging than other industries, and hospitals burn waste in most cases.

1.1 Waste sorting

Waste can be separated based on different categories that have been determined by different institutions in different parts of the world and according to the needs of the geographical location or industry. In Denmark, different categories have been determined for waste separation, which includes up to 88 different categories, but the most common ones include 10 categories, which can be seen in Figure 1.1.

Figure 1.1: Waste sorting categories in Denmark

1.2 Hazardous waste

Considering this general categorizing system in Figure 1.1, according to WHO website, of the total amount of waste generated by health-care activities, about 85% is general, non-hazardous waste comparable to domestic waste. The remaining 15% is considered hazardous material that may be infectious, chemical or radioactive. Hazardous waste are categorized as follows:

- Infectious waste
- Pathological waste
- Sharps waste
- Chemical waste
- Pharmaceutical waste
- Cytotoxic waste
- Radioactive waste

1.3 Initial problem formulation

How can a system be designed to automate sorting of waste in hospitals without interfering with the day-to-day work of the personnel?

Chapter 2

Problem Analysis Part 1

2.1 Motivation

Due to a new law (source), all Danish companies and hospitals are required to implement sorting and disposal of the waste they produce. The law states that sorting should be divided into 10 fractions (source) but does not state how companies should do the sorting and disposal. Thus there are no common solutions or methodologies on how it should be done. Hence many companies have different approaches to sorting and are at different stages in their implementation of their sorting systems. Furthermore, different companies have different distribution of generated waste types, where the problem of waste generation becomes even more prominent when looking at larger companies that consist of many departments, such as hospitals, where the amount and distribution of waste can vary vastly. Providing a general solution that could fit all types of industries in Denmark would be a rather unmanageable task for a semester project. Therefore looking at a specific industry, such as hospitals, would be more obvious, where different special types of waste as hazardous types would be accounted for. Just hospitals in *Region Hovedstaden* produce 2 tons of waste every hour, while there are more than 50 hospitals nationally and more than 20.000 hospitals in Europe that could benefit from having a common solution for waste sorting in a hospital context.

According to the goals set by the EU, 55% of all waste produced must be reused before 2030. In 2035 that number will be 65%. In 2022 $\sim$18% of waste was reused, meaning an increase of $\sim$37 percentage points over an eight-year period must be carried out. Which is is an increase of $\sim$205% percent over just eight years. In order to achieve these goals, significant actions must be taken.

Region Nordjylland measures its production of waste in units of CO_2-eq. The categories they put their waste into are seen in Figure 2.1.

Regionens samlede udledning per forbrugsområde 2017-2020	2017	2018	2019	2020	% udvikling 2019-2020
Patientartikler	83.391	76.343	77.229	80.454	4%
Øvrige indkøb og aktiviteter	29.442	29.545	31.700	31.083	-2%
Bygninger og arealer	30.579	31.233	26.628	23.808	-11%
Udstyr	8.074	7.856	8.097	11.271	39%
Transport	12.188	10.862	9.323	7.565	-19%
Forplejning	8.439	8.156	7.540	6.775	-10%
COVID-19	0	0	0	5.085	-
Total	**172.112**	**163.996**	**160.518**	**166.042**	**3%**

Figure 2.1: Description of what categories region Nordjylland produces the most CO_2.[13]

Figure 2.1, shows that patient articles in 2020 contributed 80.454 units of CO_2-eq to the environment. Where the existing categories combined contributed 85.587 units of CO_2-eq. The biggest impact in terms of reducing CO_2-eq emissions can then be achieved by improving the amount of recycling happening in the patient article sector compared to any other of the described sectors. Close to 50% of all the CO_2-eq produced by Region Nordjylland comes from the single category of Patient articles. None of the other categories comes close to contributing as much CO_2-eq55 f7 as patient articles. For this reason, this category of waste will be the main focus of the project moving forward. Patient articles are, however still a big category, so the next step will be to document the types of waste in this category. The category contains the following elements: [13]

- Medicine.
- Packaging made predominantly from plastic, secondly paper.
- Syringes, IV bags, and other plastic medical equipment.
- Band-aids, cotton, medical tape, etc.

COWI, an independent consultant company from Denmark, came up with the following data on waste produced, seen in Figure 2.2.

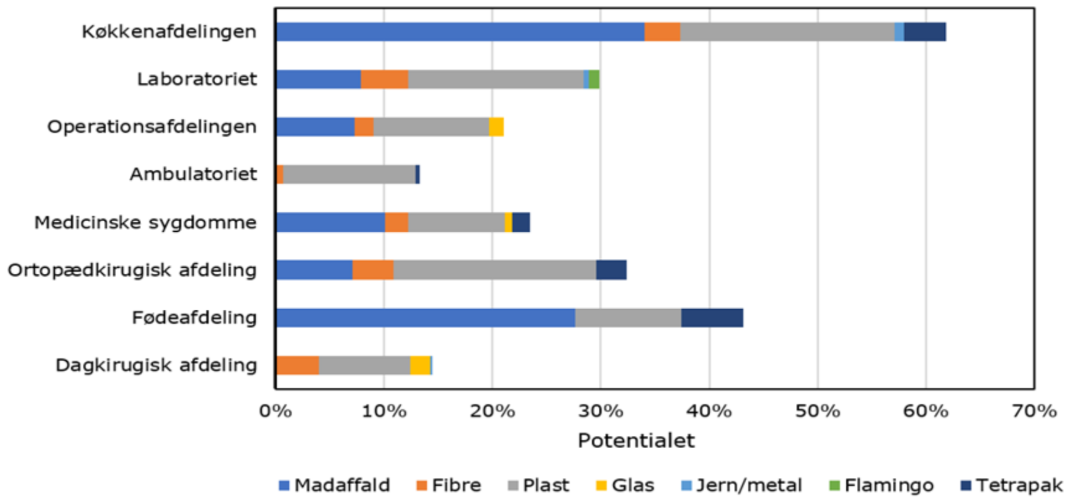

Figure 2.2: Potential of different types of waste in different departments of Sygehus Sønderjylland and Dagkuriusk Afdeling from Aabenraa. [4]

Figure 2.2 describes the amount of reusable waste being sent to be burned instead of reused. The figure provides a overview of the potential for reusable waste in each department but lacks data describing the volume produced in each department. By concluding Figure 2.2 alone risks, the focus will be on a small insignificant department that produces a minuscule amount of waste compared to the other larger departments. For this reason, the conclusions drawn from the figure must be considered with additional data in mind. This is where data from Figure 2.1 becomes relevant since this figure provides tangible quantitative data on how much waste is produced at Region Nordjylland. From the data provided, COWI 2.2 suggests that the most significant potential for reusing waste lies in the kitchen department of the hospitals, but when considering the data from Region Nordjylland, the kitchen department is the smallest contributor to CO_2 levels, when the COVID-19 sector is ignored, due to this issue no longer being as relevant in the year 2023. There are some apparent faults when comparing the data from these two analyses. Firstly, they are made by different organizations with different standards for categorizing waste. Secondly, the analyses were conducted 2 years apart. Thirdly, one analysis provides data on hospitals in Region Nordjylland, while the other provides data on hospitals in Region Syddanmark. It is needless to mention that using data with such significant differences is not ideal, but no better data is currently available. Therefore the following assumptions are made:

- Waste types produced at different hospitals in Denmark will be similar. E.g., all hospitals produce plastic, paper, food waste, etc.
- The distributions of waste at different hospitals in Denmark will be similar

when comparing similar departments. E.g., the kitchen departments will produce similar distributions of food waste and plastics.

Plastic and food waste is the predominant type of waste produced in large amounts across all departments, which means these have the most potential for reusable material. It is important to note how small a part of the category metal has the potential to be reusable across the different departments.

2.2 No available data

As discovered in the previous section, the generated waste can be separated into many categories, where the paramount ones are plastic and food waste. However, more data is needed on how the health sector handles its waste (Source by Lisa). This is a problem for two main reasons:

- Without adequate data on what types of waste are being produced in what amounts, it is challenging to develop a sorting system that can adequately accommodate the waste.
- Without adequate data on how much waste is sorted into what categories at a given time, it is impossible to evaluate the performance of new sorting initiatives.

According to *Affaldsstrategi - Region Nordjylland*, one of the new sorting initiatives' objectives is to develop a system to evaluate and get data about how much waste is sorted into the different categories to be recycled and how much waste is being sent to combustion, without such a system, getting feedback from any action on waste handling and any recycling initiative after its implementation is challenging. As stated by *Affaldsstrategi - Region Nordjylland*, feedback is essential when implementing new systems [8] to identify if a given project on waste handling is reasonable for further development, or if resources shall be redirected on other projects.

This problem is visualized in Figure 2.3 and will be referred to as **The Problem Chart**. This will be used throughout the project as more problems regarding waste handling are identified. These and their related context to each other will be added to the figure.

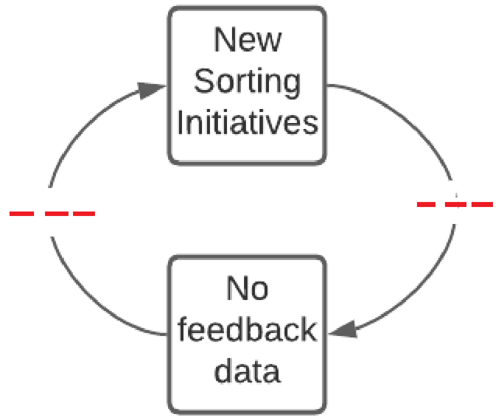

Figure 2.3: The problem chart, when no feedback data is gathered when carrying out new initiatives.

2.3 Current ways of Sorting

As the problems within waste generation have been identified, the following sections will introduce different solutions for the problem, where types of sorting, such as mechanical, vision-based and manual, will be described.

2.3.1 Mechanical sorting

Mechanical sorting is sorting materials using their different mechanical properties like size, shape, density and ferromagnetic. Some of more common mechanical methods are described bellow:

- Disc or Star screen:
  Star screen named after the star-shaped rubber discs located on the shafts. The star discs have a certain gap length between each other. The materials with large dimensions move forward as the discs rotate, and the ones with smaller dimensions fall through the gaps. Star screens can be manufactured according to the required capacity and in different sizes. It can separate fine particles from inert materials such as sand, stone and glass in domestic garbage and kitchen waste.

- Air separator:
  Air separator machine is mainly used to the aerodynamics, the light material, middle material and heavy material will be sorted out under the positive and

negative air pressure. light materials will be taken up or horizontally into the settling tank, then discharged by the belt conveyor. The heavy material is down to the conveyor for the upward air pressure can not bear the weight, they will be discharged by conveyor.

- Bouncing Screen Ballistic Separator:
  The heavy ballistic separator is sorted material by different size/ shape/ density machine. its tough sorting used to construction waste, kitchen waste after squeezing water, paper recycling industry etc. The bouncing screen drives the sieve plate to move up and down through the eccentric shaft (crank gear, etc.), so that the solid waste on the sieve plate is shaken into heavy, rolling 3D material parts (such as plastic bottles, wood, cans, etc.) and light, The flat 2D material part (film, paper, cardboard) and the under-screen material part (sand, food residue) are convenient for subsequent processing. According to the characteristics of the above equipment and the complex characteristics of solid waste, it is mainly used in the domestic construction and decoration waste front-end pre-sorting, domestic waste incineration slag light material, and some industrial waste sorting systems.

- Double shaft shredder:
  Double shaft shredder is one kind of low speed, high torque tearing machine, its widely used to waste metal, bulky waste or MSW, industrial waste and domestic scrap. through bit to reduce the size of material, improve density to save the transportation charge. The reducer and rotor connection takes Germany type meets DIN5480 standard. It's mainly used for the industrial waste, domestic waste, scrap metal, medical waste, solid waste etc.

- Over Belt Magnetic Separator:
  Magnets can separate iron, steel, and other ferromagnetic materials from non-ferrous metals. Permanent magnets or electromagnets will generate the magnetic field. Ferrous materials lift and stick to the magnetic band. After being removed, they drop off into a skip.

  Magnetic separation is generally effective for ferrous materials. It won't work on metals like stainless steel, copper, and aluminium, though. Its mainly used to the industrial waste, domestic waste, scrap metal, medical waste, solid waste etc. It is suitable for all belt conveyors, vibrating feeders and occasions where there is more iron above the chute. It is generally configured in the renewable resource industry or mobile crushing and sorting stations.

2.3.2 Vision Based Sorting

Vision based sorting uses a combination of lights and sensors to illuminate and capture images of the objects. Image processing is then used to identify material characteristics, and a computer algorithm determines whether objects should be sorted or not depending on the purpose. This is also called Computer vision (CV), commonly used in recycling facilities to sort various types of waste materials.

The process typically uses a conveyor belt that carries the waste through cameras and sensors to identify the objects either based on its shape, colour, and other visual features, depending on which is used. When the objects have been identified, they can be sorted using either a mechanical system or robots that separates them into their different categories based on the criteria set by the sorting system.

The CV can be used along a model or a neural network that can be trained to identify various types of plastic. Along with innovative deceives, this can aid users in determining the types of plastic for proper classification. Applied with a robotic solution, this can sort the plastic automatically into bins. [6] The CV system and a waste detection algorithm function as the eye and brain, enabling the robots to detect and identify the waste materials on the conveyor belt and can sort the waste automatically. [25]

CV systems are highly effective at identifying both quickly and accurately. For the recycling industry, vision-based sorting can be an essential tool since it can improve waste management operations' efficiency and effectiveness while promoting sustainable practices. Additionally, these systems can reduce the amount of contamination in the recycling streams, improving the quality of the recycled materials and reducing waste.

2.3.3 NIR scanners

A NIR scanner is a device that uses near-infrared (NIR) spectroscopy to analyze materials. It analyses the absorption and reflection of near-infrared light to identify and quantify the chemical composition of materials. NIR typically consist of a light source that emits near-infrared radiation, a detector that measures the amount of radiation absorbed or reflected by the material, and a computer system that processes the data and generates a report on the material's composition. https://recyclinginside.com/recycling-technology/separation-and-sorting-technology/

2.4 Current ways of sorting in different regions

In order to find suitable solutions for the problem, the current state and how they sort waste in different Danish Hospitals will be researched. The knowledge was gathered through desktop research or hospital visits. This research will be used to find solutions that can be implemented depending on the current state of the hospital.

The discovered established manual sorting systems are based on data gained from sources by *Sygehus Sønderjylland* and *Region Hovedstad*, as well as visits to *Aalborg blood Bank* and *Hjørring Hospital*.

Sygehus Sønderjylland in Aabenraa

According to an analysis made by *COWI* of the hospital in Aabenraa [16], the amount of improperly sorted waste is directly dependent on the busyness of hospital personnel, where during heavily loaded days, there is limited or no sorting of waste. Therefore *COWI* suggested a solution to provide a more convenient way to sort.

According to the same article [16] part of the problem is that the medical personnel must transport the collected waste to a specific waste room, called "flushing room", within the hospital and then sort it. *COWI* suggested a solution to the problem by introducing mobile waste trolleys, as seen in Figure 2.4.

Figure 2.4: The mobile waste trolley proposed by *COWI* that enables the hospital personnel to sort waste directly at place of use. [16]

These trolleys would be placed within every part of the hospital with proper waste-type containers installed, making this solution adaptive for the different departments and their needs. Furthermore, these trolleys enable the personnel to sort waste on the spot, reducing transportation time and eliminating the need for additional time to sort the collected waste in the flushing room. This presents a new problem to the problem chart seen in Figure 2.5.

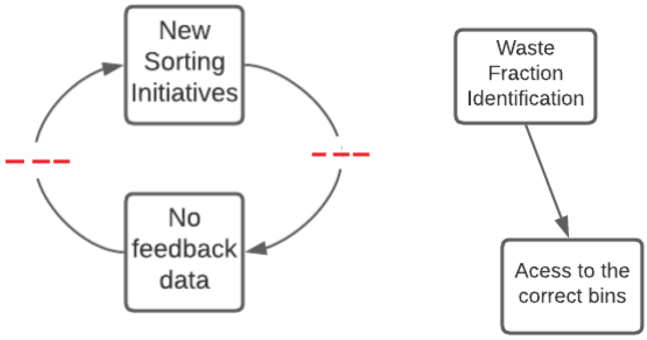

Figure 2.5: Problem chart: Not having access to correct bin for a given type of waste.

Region Hovedstaden

The solution within *Region Hovedstaden* is more comprehensive than the one developed by *COWI* for the hospital in Aabenraa, which consist of increased recycling, efficient logistics, communication, and education of personnel on the waste recycling topic. [16] *Region Hovadstaden* have introduced racks and bins for the different types of waste in all hospital departments to redirect as much trash as possible to be recycled instead of burned. The distribution of the bins is different for each respective department, making this solution similar to the configurable mobile trash trolleys proposed by *COWI*. To further increase the efficiency of these bins, a set of colour-coded pictograms was developed by *Region Hovedstaden*, See as Figure 2.6.

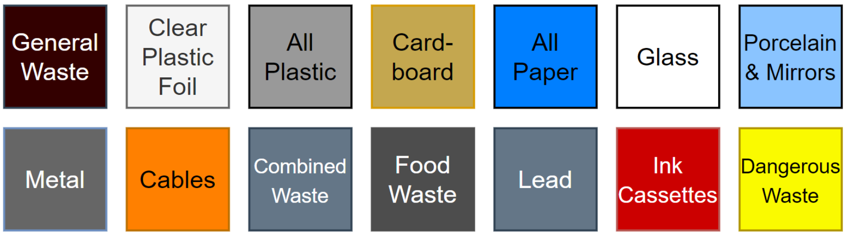

Figure 2.6: The 14 categories of waste created by Region Hovedstaden

The figure shows a total of 14 waste categories. However, the number of waste categories used in *Region Hovedstaden* differ depending on the situation. The primary reason for separating the categories is to simplify the reintroduction of waste into the circular economy. The reintroduction can be performed by exporting the waste to different external companies in the private and public sectors. For instance, cables are separated from the electronics category. Conversely, all plastic types are placed into a single category since the company that *Region Hovedstaden* exports their plastic waste to can handle mixed types of plastic and sort it on their own.

In order to improve communication and education of hospital personnel, physical manuals were developed and placed on the hospital boards with explanations of the different types of waste and which waste bins they belong to. In addition to physical manuals learning e-portal was developed with learning videos and learning modules, while environment-responsible personnel received the task to be also responsible for communication on the waste sorting topic, so other hospital personnel know where they can clarify possible questions on the topic.

Besides waste disposal, hospitals at *Region Hovedstaden* do also consider a broader reuse system, where a separate reuse and donation unit in Ballerup ensures that hospital equipment and furniture at one respective hospital that has completed its life-cycle is not thrown out or disposed of if it has potential to be used at other hospitals, or even to hospitals in other countries that are in need.

The last part of the solution within *Region Hovedstaden* is a logistical system, where they move collected trash within flushing rooms into bigger decentralized waste rooms that contain larger containers. Residual waste is compressed into smaller containers, while other types of waste as paper, metal and glass, are collected into multi-purpose containers of 650 litres. They decided that it would be more cost effective to own the containers and invest in their transport for waste. Where two types of transport are needed, a truck and a hook lift, the number of trucks can be scaled to the size of each hospital. According to them, this is efficient since the truck drivers are familiar with the setup at the hospital and know exactly what goes where. From hospitals, waste is transported to separate recipients, e.g. *Stena Recycling* for waste disposal, while dangerous and contaminated waste is transported to specialized disposal companies. The entire process is mapped in Figure 2.7.

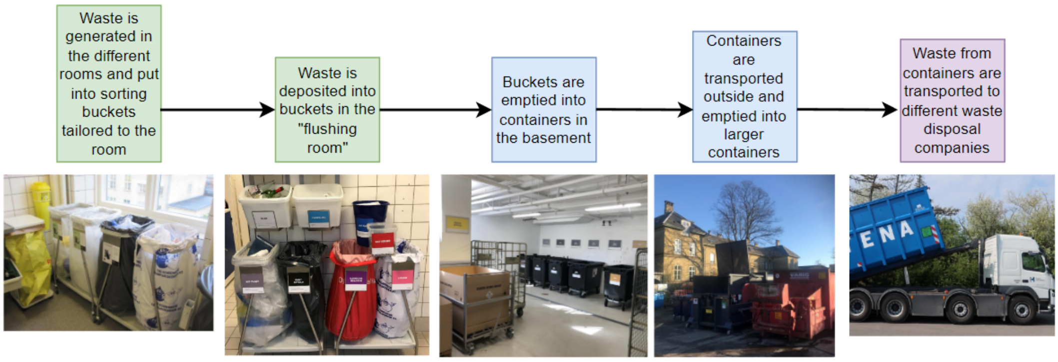

Figure 2.7: General flowchart describing the flow of waste in Region Hovedstaden

As for the future steps, they plan to develop a more strict set of requirements for the suppliers on the packaging and transportation of medical products and equipment, which should ease the whole waste chain.

2.4.1 Region Nordjylland

This region was of higher interest since this project was proposed by Lisa, who works for region Nord and functions as the contact person. According to her *Region Nordjylland* is lacking behind other regions regarding efficient waste sorting methods. She provided data and arranged visits with *Aalborg Blood Bank* and *Hjørring Hospital*.

Before these visits, an initial meeting with Lisa was conducted to narrow down what should be in focus on the visits. This initial meeting was performed with other Manufacturing Technology and Global Business Engineering students who all are writing about waste in the hospital industry. Due to the many participants in this meeting, only the essential and relevant information gained regarding this project will be described.

In this meeting, it was learned that they had previously attempted to develop a standardized waste management system for all of Region Nordjylland. However, this pilot project failed and was shut down. Unfortunately, where this pilot project took place and how much it covered is unknown. The only known factor is that the failed system was about implementing specialized waste buckets within each department. According to Lisa and the waste ambassador at Aalborg Blood Bank, it failed due to lack of management and too harsh standardization. This lack of organizational planning made it difficult for the departments to collect useful data or data in general, meaning the changes' impact was difficult to evaluate and determine their effectiveness.

Furthermore, it was learned that some of the personnel did not always know how to sort the waste wasting their time and especially during rush hours they did not sort the waste at all. Lastly, some departments needed proper space to implement the waste bins required for the system.

The following will describe the information gained from the visits with *Aalborg Blood Bank* and *Hjørring Hospital*.

2.4.2 Aalborg Blood Bank visit

On March 15^{th} 2023, a meeting was conducted with the local waste handling person, referred to as "waste ambassador". At this meeting, it was learned that the waste ambassador and her department had devised their own sorting system, mainly used for plastic. Since it is a small department that primarily produces plastic and bio hazardous waste, they did encounter some initial resistance from management because of the failed pilot project.

However, management gave the waste ambassador permission to try their developed system based on interest from the personnel and a recent study case performed in collaboration with students from Aalborg University (AAU). The only requirement management was that it should not cost anything, affect the workload, or take too much time from personnel day to day work.

With limited space and resources, the waste ambassador uses old or unused bio hazardous plastic containers as bins and hand-labelled pictures of the specific plastic item on the bin to make identifying what goes into which bin easier. Hereafter the required amount of bins was placed into the different rooms in the department, though not optimally due to lack of space. However, they were placed to be easily accessible and where space was available. Resulting in some of the bins were placed in equipment storage rooms rather than in the room where the waste was generated. The bins are then collected at different temporary storage areas, under stairs or behind equipment, around the department and manually transported outside, where the waste ambassador made an agreement with an external company, called *Ragn-sells*, that would pick up the sorted plastic once a week free of charge, required that the plastic was sorted into the 7 different fractions seen in Figure 2.8.

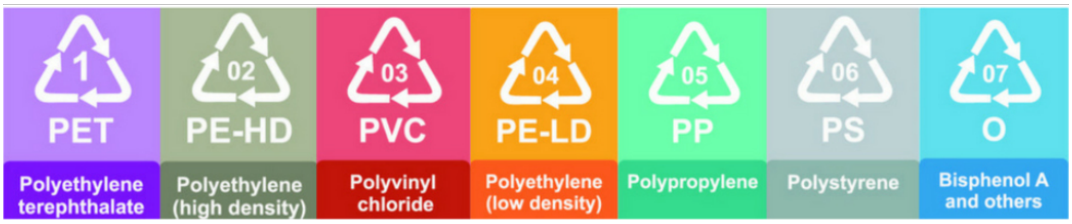

Figure 2.8: The 7 fractions of plastic sorted.

The system is still in its early stages. It has only been going for a little more than a month. However, during this period, the department collected 105kg of plastic, sorted into the 7 fractions. The trash ambassador considered the system a success and looked into implanting something similar in other departments. For the problem chart, the new problems added can be seen in Figure 2.9

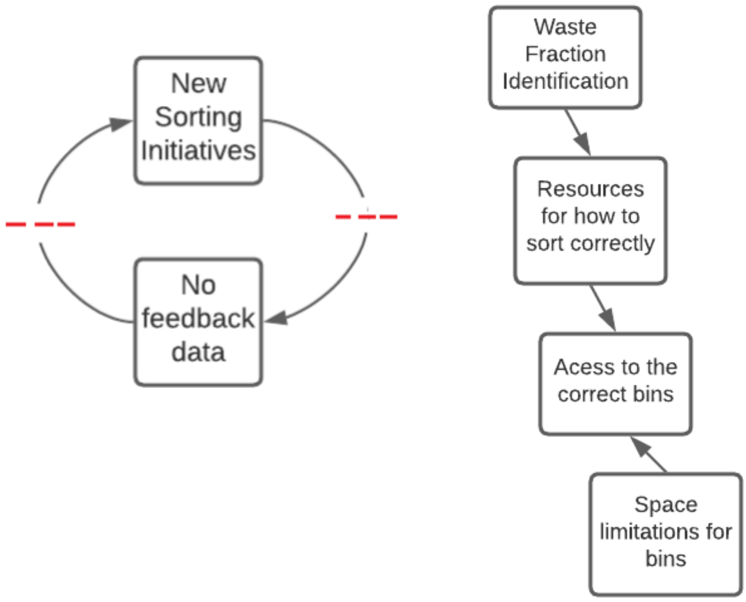

Figure 2.9: Problem chart: Not having knowledge about what type of plastic fraction it is. Having limited space and accessibility for bins.

Meeting reflections

The meeting outcome showed that creative solutions can still flourish even with limited space and resources. Based on the previously failed pilot system indicates that there may be better ways to handle the problem than forcing an overall solution for all departments, regardless of size. Instead, departments should be able to make their own solutions, and management could instead arrange the logistics at the end of the process by managing what happens with the waste when it leaves the facility. This allows the department to make one or multiple suitable solutions for their respective department that can be integrated into logistic solutions determined by management.

It should be mentioned that the solution works so well at Aalborg Blood Bank due to the dedication and positive approach to the problem from the local workforce. Showing management that the local workforce has some good ideas they might need to be made aware of. However, should new initiatives be met with resistance and a negative mindset, or the workforce does not have time or ideas for a local solution. Different standardized solutions that can be applied to different sizes of departments should be available.

2.4.3 Hjørring Hospital visit

A meeting with one of the Porter employees at Hjørring Hospital was conducted on April 25^{th} 2023, where insight into how they collect waste at that location was obtained. They have implemented the ten new sorting labels, set by the Danish government, seen in Figure 1.1, at each floor. Like Aalborg Blood Bank, the employees were responsible for sorting the waste into different fractions. Hjørring Hospital is a larger department that generates many types of waste. They have implemented a waste management system that is further ahead, logistics-wise, than Aalborg Blood Bank. They have specialized waste buckets in their flushing rooms and established logistic collecting of the waste. An example of the waste buckets can be seen in Figure 2.10.

Figure 2.10: Self taken photo of a flushing room at Hjørring Hospital.

Between 2014 and 2018, their "skyscraper" department was renovated. During this renovation, the porters requested to place the flushing rooms in the same room as the elevator, which are only accessible to technical personnel. Making it easier for the porters to change the orange iron cages, the waste is collected into, which is a crucial benefactor to their superior waste collecting logistic system over Aalborg Blood Bank. The orange iron cages and their placement respective to the elevator can be seen in Figure 2.11.

As for the other department not located in the skyscraper, the flushing rooms are located randomly, forcing porters to walk and collect the waste among staff and patients. The porter also mentioned that some flushing rooms are being overtaken to store medicine or medical equipment, forcing them to find other rooms for waste storage. He stated that handicapped restrooms were often used as temporary storage rooms for waste since the patients already had toilets in their rooms.

Figure 2.11: Photo of orange iron cages next to the technical service elevator at Hjørring Hospital.

When all the waste has been collected, they are transported through underground tunnels to their disposal room, where the porter manually sorts it into containers according to the colour code on the bag, see Figure 2.12. It takes two porters between 1,5 to 2 hours to collect the waste from the whole hospital. Waste is collected three times a day, once in the morning, once during the day, and once in the evening. In general, 16-18 iron cages are full each time.

Figure 2.12: Photo of the disposal room at Hjørring Hospital.

The disposal room currently has one compressor for cardboard changed every third week and one for general waste changed once a week. A small compressor for soft and transparent plastics removes air within the plastic. Hereafter it is collected on half pallets, where they produce about 2-3 half pallets a week, which is collected once a week. They separate this type of plastic because it is worth more than the rest they produce. Any other plastic is collected in 650L multi-purpose containers as described in Subsection 2.4, where 20-25 of these only containing plastic are collected once a week. Non-classified paper waste is also collected in the same type of container. Here two containers are usually collected once a week along with the plastic. The hazardous clinic waste is placed into a "hall" and is collected three times a week. Bio hazardous waste is kept in a separate cold room to prevent fermentation. These are collected when needed along with the other waste. Should any containers containing waste be full before scheduled, they can call the external company, and they usually switch the container rather quickly.

At the end of the visit, the porter stated that the amount of plastic waste generated is increasing each year, so they have requested management for a bigger plastic compressor. According to him, there is space next to the general waste compressor if they expand the disposal room.

Meeting reflections

In contrast to fraction sorting of plastics, they are not at thorough as Aalborg Blood Bank since only soft and transparent plastic was sorted separately from other types of plastic. They desire to sort even more but sometimes encounter problems when new employees are hired and do not sort appropriately according to the porters standard. They know this since they perform random samples and open the bags to see if it is sorted correctly. If not, that department gets reprimanded. They know where it came from because each department and floor have labelled trash bags.

Even though their skyscraper department has a proper logistics waste flow, they still have some practical problems with some flushing rooms being far away from service elevators, which hinders waste collection.

2.5 Existing Solutions

In order to find a suitable solution for this problem, looking into existing products different companies offer can be beneficial to get information and inspiration about how it can be solved most efficiently. Solutions using robots and other mechanical solutions will be looked into for that purpose.

2.5.1 Current Robotic Solutions

For current robotics solution these companies will be described:

- Ishitva Robotics Systems (IRS)
- AMP robotics
- Recycleye

AMP robotics

AMP Robotics, located in Colorado, specializes in artificial intelligence (AI) and robotics technology to recover recyclable materials. Their technology can recover plastics, cardboard, paper, cans, cartons, and many other containers and packaging types. Figure 2.13 shows how their technology function by using CV to identify the waste, which sends the data to their own AI platform, "AMP Neuron", and then utilizes manipulators to pick and place the waste. The platform can identify patterns in specific materials, separate- smashed, folded-, and tattered objects within the same waste stream. It can distinguish different plastic polymers, paper types, metal containers, and multilayered packages. It then characterizes what needs to be sorted during different process stages. It can distinguish more than 50 categories and more than 100 different materials. [14]

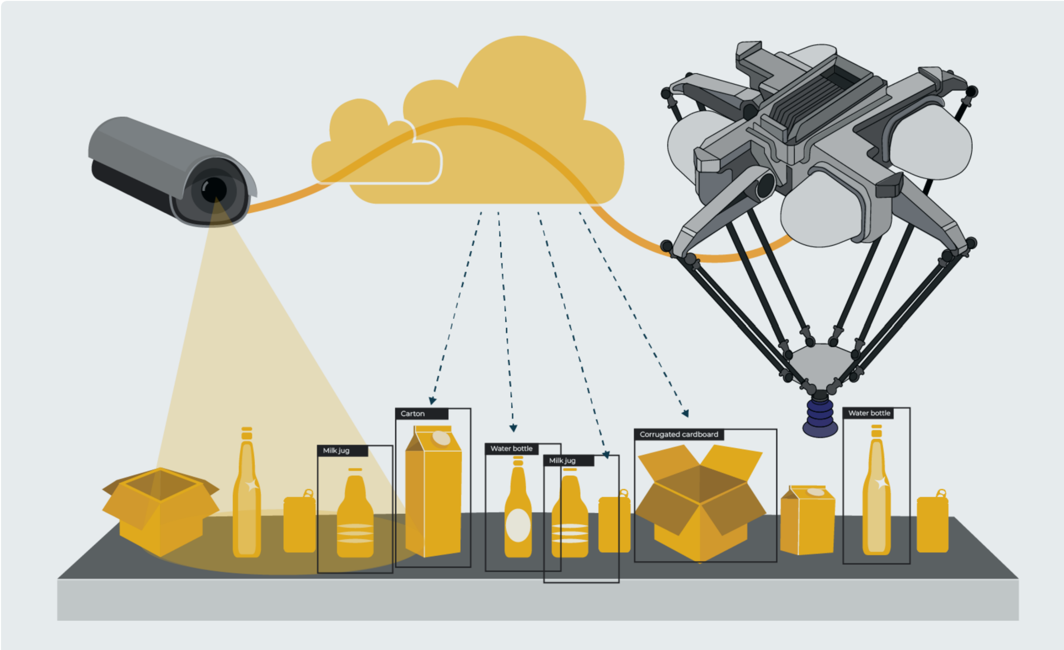

Figure 2.13: Visualization of the AMP technology.[14]

Their AMP Cortex product, seen in Figure 2.14, utilizes the Neuron platform, a single delta robot, and a conveyor. *Forbes* wrote an article about AMP on November 12 2020. According to the article, AMP machines cost up to 300.000 USD and should last five to 10 years, if not longer. A single delta robot can pick up to 80 pieces per minute, with a 99% accuracy, which is twice the amount of an average employee, meaning one unit can replace two workers. They state that the average recycling workers make around 25.000 USD per year, and training two employees costs a facility 70.000 annually. Thus a single AMP Cortex unit should be repaid within three to four years. [2]

Figure 2.14: AMP Cortex. [14]

Recycleye

Recycleye, located in the United Kingdom, solution functions like AMP's solution, with a manipulator above a conveyor and a vision system to scan and tell the manipulator what to pick. The difference is that Recycleye uses a 6-axis manipulator from a company called *FANUC* that can rotate and shoot the trash into bins, saving travelling time to the bin. It is equipped with a suction gripper made from silicone that can grip any shape, with a lifetime of about a week. Should any material be sucked into the gripper, they have applied a filter to prevent blockages. Should blockage still occur, they have a system that warns it is blocked so they can remove the blockage as quickly as possible. In addition, the system is modular and can be fitted into existing MRF [11]

Their vision system consists of an RGB camera along with a database they developed in partnership with academics at leading universities, called *WasteNet*, which leading universities is not specified. The database contains more than 3 million images of waste, which they claim to think is the world's largest data set for waste. The system can identify 28 classes and differentiate between colours, shapes, brands, food and non-food. [12]

In September 2021, they performed a study case with *FCC Environment* and *re3*. In this study it successfully did up to 33,000 picks per 10-hour shift, or 55 picks per minute, with a 99% accuracy with less than 1% contamination. They made their own comparing to other solution that are identical to their own, which can be found in appendix B

Ishitva Robotics Systems

IRS offers both a robotic and a machine solution for their robotic solution they have their "YUTA" and for their machine they have their "SUKA", both are AI powered industrial robot sorting machine, that utilises their "NETRA" machine vision system software, which is their own developed IA vision system. NETRA is connected to their own cloud database and have been trained with more than a million images of with different polymers, brands and color categories. Making it very versatile and its complex computer vision algorithms that can be use to learning, classification, localization and segmentation, which can be integrating with different industrial robots, air sorters or other mechanical unit. Hence fits both machine and robotics solutions [17].

Their robot driven solution *YUTA*, function a lot like Recycleye, it have a modular plug and play design, can sort based on colour, brands and can sort plastic based on PET Polymer PET, PP, HDPE. It have above 95% accuracy sorting level and live waste data with prediction and analytic on a cloud platform, unfortunately there is no data on how much it can pick per minute or hour [20].

Their machine solution *SUKA* is only able to sort plastic in mix dry waste, such as PET, PP, HDPE with colors, brands and size sorting. Unfortunately general information about accuracy is not listed on their website but information about amount it can sort is, which is 2 to 8 tons per hour of plastic [19].

2.5.2 Smart Bin

In addition IRS also offers smart bins, seen in 2.15. These bins can automatically segregate paper plastic and cans. The bins are easy to install and should fit into any infrastructure. It is embedded with internet of things (IoT) board enabling it to gather data and transmit wirelessly via the could to electronic devises, such as desktops and mobiles. It is equipped with door sensors informing the system that something is about to be processed. Moreover it has fill level sensors, which it can transmit to waste collectors when it is near full or full, removing unnecessary visits to empty bins. Through the dashboard supervisors can monitor the devices, getting live feed of fullness and see the count of materials. It can collected and analyse data of usage patterns, types and amount of waste collected, how often it is emptied and time spent on collecting the waste. [18] [5]

Figure 2.15: IRS smart bin solution [18]

2.5.3 Current Machine Solutions

WESORT

WESORT is a Chinese company that offers a variety of different color sorting machines. For plastic sorting their 6SXZ series can all functions the same way, the main difference is the size of the machine and the amount they can sort. It can sort ABS, PC, PE, PET, PP, PPS, PPU, PVC, bottle plastic, resin, masterbatch, nylon, acrylic.

It has a smart system consisting of a high resolution CCD color lens, which an AI uses label and identify the material. To reject or accept the material magnetic suspension valves are used either blow or let the material fall through. The 6SXZ-68 model, which is their smallest product, have a capacity of 300-500kg per hour with a 99% sorting accuracy. Specification of different size, capacity and other specification can be seen in Appendix C. [26]

TOMRA

TOMRA, located in Norway, offers different sorting solutions for food, mining, recycling and reverse vending machines. They offer eleven different sorting machines, where ten machine driven and one incorporated with a robot. They have total of ten different technologies, where each one have its own application. All of these technologies can be combined in different ways depending on the task and machine. A lot of their technologies are listed under trademarked names, meaning information about sensors and other properties are minor. The following is a short description of these technologies and their application. More detailed information about how they work can be seen in Appendix D

Their Technologies

Flying Beam, seen in Figure 2.16, uses light and NIR scanners pointed at a rotating polygon mirror. This is placed inside a box to protects the system from contamination affecting the classification system. According to their product manager for recycling *Philipp Knopp*, the flying beam grants a 95-96% purity level. [23] [21]

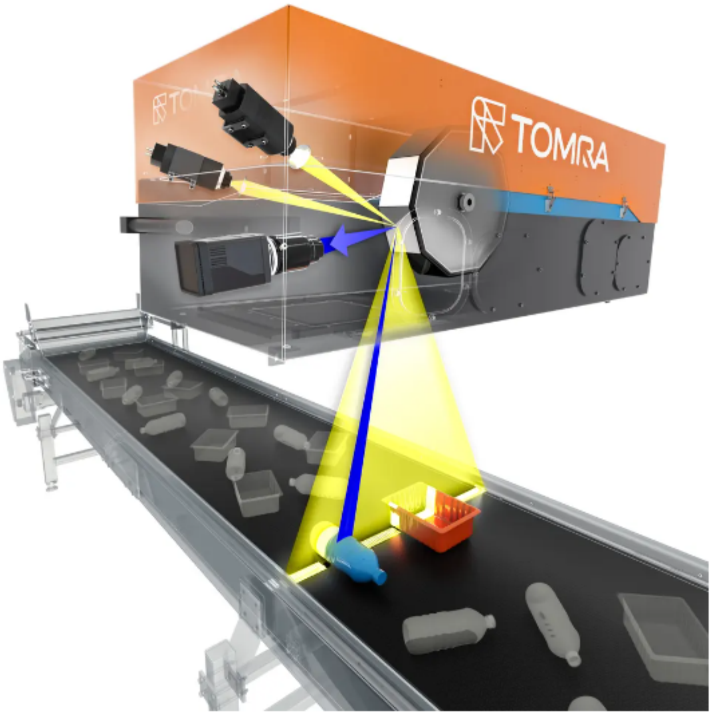

Figure 2.16: TOMRA Flying beam solution. [24]

GAIN is deep learning technology, that is trained on thousands of images. [24]

DEEP LAISER, uses AI and laser line scanning to create digital copy of the objects, even when materials overlap. This can be combined with other sensor data to improve the sorting accuracy level. [24]

SHARP EYE is an optical solution that can identify materials down to their molecular level. [24]

SUPPIXX is software that can scale images up to eight times their size, eliminating mechanical and electrical noise. [24]

Dual Processing Technology combines object and area processing. Where object processing provides identification of compounds and area processing processes the pixels of the material type. Enabling the the system to make data driven decision on methods to use and identify overlapping object. [24]

DUOLINE uses two independent scan lines used in x-ray transmission sorting. This enables sorting of materials with minimal differentiation in density. [24]

FLUID COOL is liquid-based cooling system to extend the lifetime and achieve maximum stability for LED lights. [24]

ELECTROMAGNETIC (EM) SENSOR detects types of metals present in the material stream, regardless of grain size. [24]

COLOR LINE SCAN CAMERA enables materials to be sorted by color, brightness, shape and size. With a sensitivity up to 16k resolution. [24]

Their Machines

According to their website they have five suitable solutions for plastic sorting.
The solution featuring a robot is called *AUTOSORT CYBOT* a part of their Autosort series. It can sort up to five individual fractions and features the deep laiser, flying beam, sharp eye and suppixx is optional.

The *AUTOSORT* and *AUTOSORT SPEEDAIR*, have identical features the difference is *AUTOSORT SPEEDAIR* works with a closed air loop system, where *AUTOSORT* does not. Both comes in the same four different sizes, equipped with the same size valves and nozzles. However due to closed air loop system, the *AUTOSORT SPEEDAIR*, takes up more space and is heavier than the *AUTOSORT*, an overview can be seen in Appendix D. They both utilize the flying beam and sharp eye technology. The solution catalogue states that the deep laiser is a part of the *AUTOSORT* solution where it is optional on the *AUTOSORT SPEEDAIR*. [22]

The last two are, *AUTOSORT FLAKE* and *INNOSORT FLAKE*. The *AUTOSORT*

FLAKE is more versatile and can be setup to sort various materials, where the *INNOSORT FLAKE* is only suited for sorting plastics. Both are equipped with the flying beam.

2.6 Summery of current solutions

The problem of waste handling can be decomposed into different aspects as; a sorting problem, a data collecting problem, an automatization problem, or as an logistical problem, where whole resource flow of waste from its generation to its disposal can be considered. Although there are various aspects to the same problem, one solution do not exclude other solution, which means that the solution to this project could be improvement of existing solution or a combination of existing solutions.

The problem chart summarizes the different current problems hospitals in Denmark are facing, added with how current solutions works, as seen in Figure 2.17.

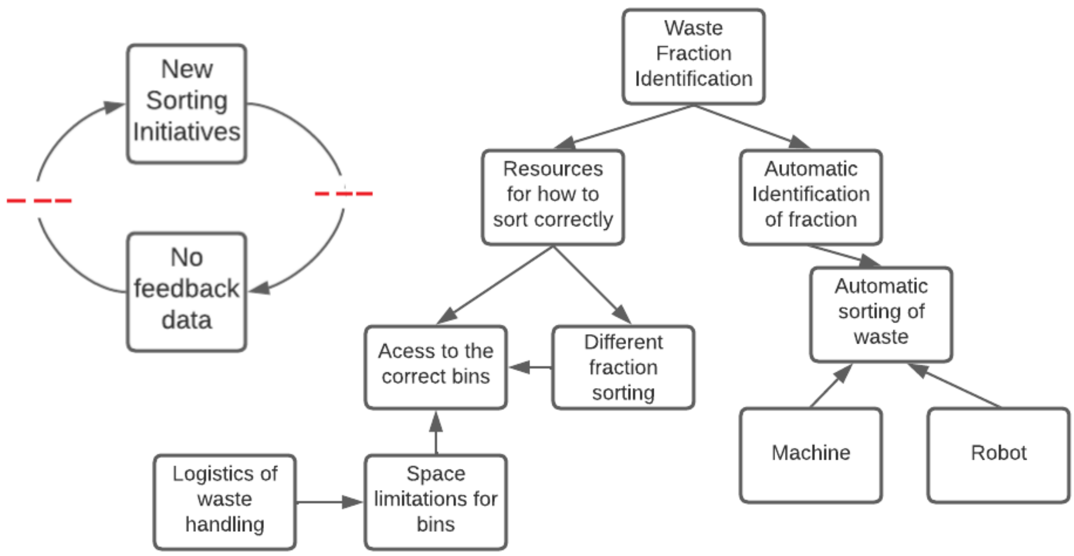

Figure 2.17: Problem chart: Not being able to identify and sort waste automatically.

The different aspects of waste sorting are then:

- Feedback of data collection. Hospitals have limited capacity to track progress and get feedback data regarding waste collection and sorting. Meaning new sorting initiatives cane be difficult to evaluate.

- Waste fraction identification. Personnel finds it challenging to identify which fraction different pieces of waste belongs to. Moreover they do
- Space and access to bins. Some department with limited space for multiple waste bins, the bins are located in different rooms or other unfavorable places, which are bothersome for personnel when sorting.
- no automation of identification or waste handling. They have no automated or efficient way to sort and identify waste fractions. Automating could improve, safety for the personnel and the efficiency and accuracy of sorting.
- Logistics difficulties. The flow of waste from its generation point to its disposal point can be analyzed and improved.
- Different sorting are methods. The hospitals have different ways of sorting waste into fractions, which can require additional sorting for the receiving centralized waste handling stations.

The desired solution should be adaptable to different departments and sizes of Danish hospitals.

Chapter 3

Problem Statement

The purpose of this project was to to investigate and find a feasible solution for waste handling that could fit multiple hospitals in region nord. The meetings with Anita and porter at Hjørring hospital gave insight in where the problems for their departments lies, a meeting with Lisa was also conducted discussing findings and thoughts about what direction the project should go into. It was decided to focus on plastics, with the other waste types in mind, therefore the main focus of this project will be on solution for sorting plastic. This was decided due to making a solution for sorting all waste types would not be possible given the time frame of this project. In order to make a versatile system that can fit and suit multiple departments regardless of its size, a solution catalog will be provided.

3.1 Final problem statement

With the information gathers from the two different hospital department, as well as conversations with Lisa. The focus of this project can be narrowed to a more tangible direction. Giving the problem statement

How can a adaptive automated plastic sorting system be designed for multiple hospitals department.

Chapter 4

Solution Catalog

Due to the characteristics of this project various solutions will be provided to fit centralized and decentralized as well as specific solution for the locations visited, since more information about these location are known.

be specifik about the time and how can i solve it here (hjørring) and if i had time mby i could have looked into more hospitals and made another better solution.

4.1 Product architecture

Solutions for these departments can be formulated based on the observations made during the visits. However, other departments may be unable to fit these into their system. Therefore, multiple solutions will be made as a catalogue to fit into as many departments as possible.

In Section 2.4.1 with the meeting with Lisa, it was mentioned that the previous pilot projects on waste sorting failed. She and the waste ambassador at Aalborg Blood Bank believed this was due to a lack of proper management by the department managers. According to a paper *Cracking the Code of Mass Customization* [3], solutions sometimes fail due to a lack of the three fundamental capabilities. Even though the paper is about mass customization, some of the theory and its principles can be used to aid management when considering applying a solution for a department and to take evaluated decisions.

Three fundamental capabilities

- Solution space development, is about identifying the different need between different hospitals and how they diverge.
- Robust process design. is about to be defining a structural solution, where it should strive to be modular and function with adaptive human capital

- Choice Navigation, is about supporting solution made by the local personal, which minimizes complexity and the burden of choice.

The paper states that solutions should be considered as a process and not a defined destination. Meaning that they should not strive for a state of idealized perfection. Instead they should continually improve how they can sort optimally and improve their different solutions they have applied.

Use this underneath. To provide management a more detailed understanding of what and how each element is or can be affected, the theory and functions of mass customization will be combined along with the method for establishing product architecture. Where the "product" in this case is how waste cane be handled for a given hospital or department. These two combined can thereby be a viable solution approach to improve sorting at hospitals. Til here.

Since hospitals vary in size, type of waste and amount, multiple solutions will be developed and presented as a catalogue in attempt to fit various hospitals and departments. This will be done with with the three fundamental capabilities as a baseline so hospitals can change the functions and develop their own ideal solution for handling their waste. Thus, any relevant solution that fit into the respective facility can be chosen and developed further.

Mixing this knowledge with principles and elements from *product architecture* will offer a comprehensive understanding of the functional components that each solution will influence. The objective is to encompass the three capabilities and serve as a foundation for future improvements. According to [10], product architecture is done in four steps:

- Create a schematic of the product. In this context is to consider which function the solution is suppose to affect.
- Cluster the elements of the schematic. Cluster the functions with the physical elements in mind to ensure these functions.
- Draft a geometric layout. Make sketch or layout of the product, could be a 2D or 3D model of the product.
- Identify fundamental and incidental interactions. Identify interactions between different clusters in the product, to discover possible conflicts in the product functionality.

Step four is considered to be out of scope since it requires many iterations on specific design of the product, which deemed unnecessary for proposals of ideal solutions. Step three will by made based on Hjørring hospital since this is the only precise, currently known layout. Based on the method for mass customisation and product architecture, solutions will be defined and divided into two main categories. 1^{st} is decentralized solutions and 2^{nd} centralized solutions. Each can provide benefits for the different departments, however as described in Section **??**, a combination of using both categories is believed to provide the most optimal solution for the facilities and help integrate the solution into the departments from a management POV.

The general architecture and how the wastes general disposal walk though is currently can be seen in Figure 4.1. Which will function as the fundamental elements in the "product", which then cannot be changed and the arrows/steps in between is where solutions can be applied. The following sections will describe solutions for Hjørring hospital and Aalborg Blood Bank, since these are the only departments where the infrastructure is known.

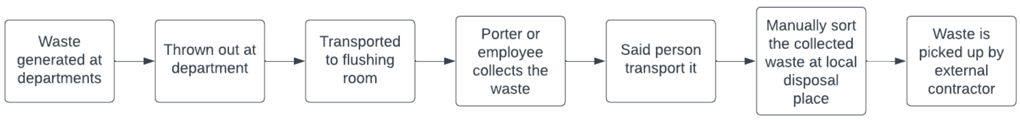

Figure 4.1: The general product architecture.

4.2 Decentralized solutions

Based on the knowledge gain from the visits described in Subsection 2.4.2 and 2.4.3, specific solutions for Aalborg Blood Bank and Hjørring Hospital will be formulated and described.

4.2.1 Mobile Waste Trolleys

The one COWI made A common problem for the blood bank and the old department at Hjørring was placements of the bins and flushing rooms. This sub optimized placement is time consuming for the porters and an annoyance for the rest of the personal, since this forces the porters to walk among them and patients in the halls ways. This was especially a problem for Aalborg Blood Bank, where almost all available space was in use for either medical or technical equipment. Thus, the bins were placed at the first possible convenient spot. Thus for department similar to them it can be impossible to challenging to find space for specialized flushing rooms or even the required amount of wast bins across the whole department.

For smaller departments like the Blood Bank, the Mobile Waste Trolleys solution *COWI* proposed, described in Subsection 2.4, could be utilized due to the amount of waste produced is generally low. This trolley system can be a quick and low cost solution for departments with limited space and is not designed to facilitate waste sorting. For this solution to be viable in various departments, two features must be adaptive in the trolley designs depending on which department it is implemented. Which is the structure and bins dimensions

- The trolley bins need to be modular so that it can hold varying number and type of bins, where the bins can be tailored to contain, the type of waste generated at given department it is used within.
- It must be compact, so that it can be used in rooms with limited space, and be conveniently transported between rooms.

Figure 4.2 shows where this solution affects the general product architecture and what it provides in this step. It consist of three physical elements, a structure, waste containers, and wheels. Where these physical elements provides function such as structural support, storing waste, provide mobility and space reduction

This trolley solution might not be as suitable for larger departments because the amount of waste generated may succeed the amount the trolley system can contain. However, there may be some areas it can be utilized.

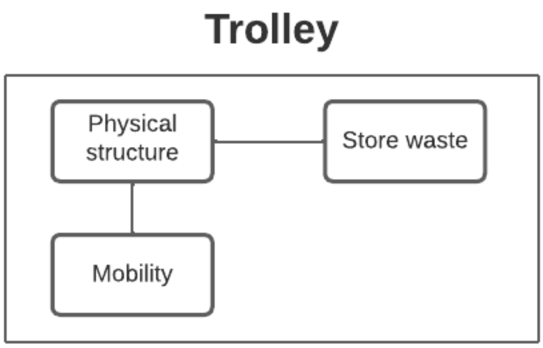

Figure 4.2: The product architecture for the Trolley solution

4.2.2 Smart Bins by IRS

A solution similar to the bucket system by *COWI*, could be to use the smart bins by IRS, described in Subsection 2.5.2. These bins can sort waste automatically which would make it easier for personal to throw waste out, since they do not have to consider which bin it goes into. The upside to this solution is that the bins provide data about how often they are used as well as what type is usually generated the location. Furthermore it can tell porters or personal when it is full. The product architecture for this solution can be seen in Figure 4.3, where it consist of one physical element and provides functions such as flexibility, in respect to sorting, time reduction, in respect to times it takes porter or employee to visit and empty it.

For both the Smart bins and the trolley system, the departments could conduct an analysis of waste generation throughout their facility, which would enable them to figure out which or where they could implement each solution. This would also enable them optimize the location of flushing rooms and waste bins, which would reduce the time personal spends on handling waste of a respective department.

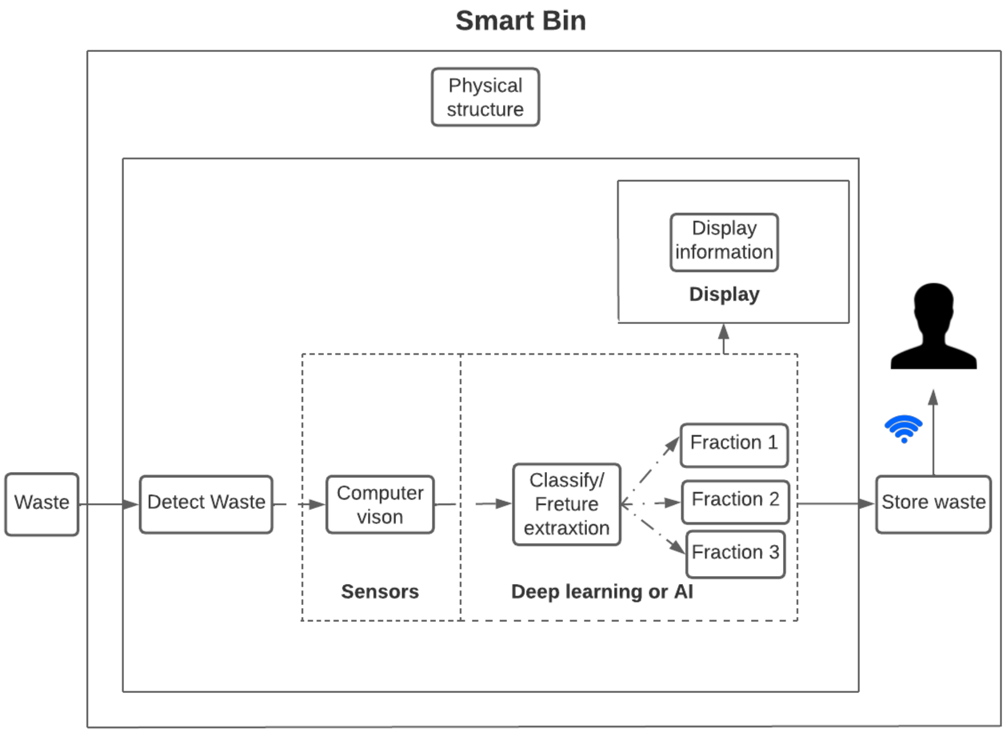

Figure 4.3: The product architecture for the Smart bin solution

4.2.3 Vision categorizer

For departments that wants to incorporate a solution similar to the used one at the blood bank, where they sort the plastic into its different fractions. Could be to implement a vision recognizer system to eliminate misclassification of plastics. At the visit, it was discovered that the main reason for misclassification was due to lack of knowledge of what type it was and which bin it should be thrown into. Not all of the plastic is marked with, with fraction it belongs to, for these types they currently use an external company to analyze it and inform them which fraction that specific plastic belongs to, which are time consuming and inefficient. By having a vision system that can quickly and automatically identify and classify any type of plastic, placed either in the flushing rooms or other places sorting occurs. Will allow personal to quickly and precisely sort it.

The product architecture for this can be seen in Figure 4.4. The most optimal camera type to use is a NIR camera, since this can recognize waste based on its wavelength. However these cameras are expensive. So another approach could be to use RGB cameras, these however needs to be connected to a cloud that contains the images of each type of plastic otherwise it cannot recognize what fraction it belongs to.

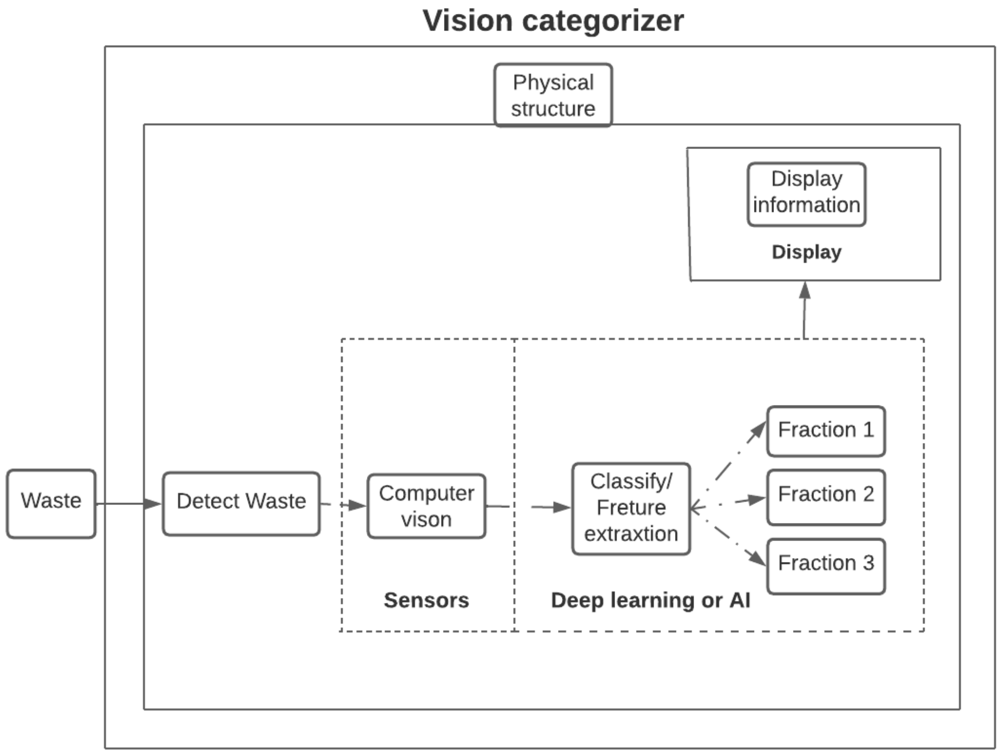

Figure 4.4: The product architecture for the Vision categorizer solution

Decentralized solutions

Hospitals use the solution, or a similar one, Wesort offer described in Section 2.5.3. This can be used to sort general waste or into plastic fraction. The products WESORT offer are feasible for multiple departments since their machines vary in size and capacity. Enabling it to fit into different sizes of department.

Should a department want to use either a machine or robotic solution, and have space and required personnel to use it in their disposal room, the current sorting solutions described in Section 2.5, are all feasible as a solution depending on the requirement needed.

4.2.4 Decentralized - for Hjørring specific

For hospitals with larger disposal rooms like Hjørring, a robot along with a conveyor belt can be implemented to sort the waste instead of the porters.

This can be preformed in two different ways. First, the porters could empty the orange cages onto the conveyor, this however defeats the purpose since they still have to handle it. So, Second, an automatic feeder could be implemented to empty the iron cages onto the conveyor by either machinery or robots. Due to the bags are already color coded an RGB camera can be used to identify what type of waste it is and sort it into the containers. This solution would make it faster for porters to collect waste throughout the facility, since they can leave and collect the rest of the iron cages, throughout the facility. Moreover it would remove the risk of porters getting infected by begin stung by a rouge needle in one of the bags. This solution would work similar to the ones described in Section 2.5.

4.3 Centralized

Hospitals are currently dependent on using a external centralized solution, which station they decide to use generally depends on the expenses they have to pay the company for transporting their waste.

Therefore are centralized solutions in general not relevant for the hospital or the departments since its is outsourced to an external company. A visit to Renonord was attempted, unfortunately they did not have time given the time frame. A few videos was however obtained, however specifications about what sensors or system their machines uses were not provided. Based on the videos it looks like they use a solution similar to the 2.5.3 with a conveyor for transport, a camera light setup, along with CV for identification, and lastly valves to blow the plastic into bins.

Chapter 5

Economics - Cost-benefit analysis

One of groups this project was made in collaboration with contacted Ragn-sells to get information about how much sorted plastic i worth. This will be used to show management how much they can earn from sorting plastics at their hospital. The calculation will be based on the information gathered from Hjørring hospital. The group obtained this information via e-mail and phone call conversations. The following information were obtained the April 26th and are directly copied from their project.

- **How much can you pay per tonne of sorted plastics?**

  It highly depends on the type of plastic and its quantity, but also on which plastic item it is. The prices for plastic waste right now are on their all time lowest. [27]

- **How does the price differ between sorting plastic into the 7 fractions comparted to sorting into specific items?**

  An estimate would be that plastic waste sorted into different plastic fractions would approximately be rewarded by 400 DKK, while additional sorting with regards to item type would double the price to approximately 800 DKK. [27]

The calculations made will be for PP and PET plastics, since they according to [**empty citation**] have the lowest and highest density among the seven main types of plastic used. The calculations will estimate how many kilos of plastic each blue 650L container can contain.

The worst-, middle- and best-case scenario be calculated to provide better estimation for how much the plastic produced at Hjørring is worth.

PP have a density of 0.905 g/cm^3, where PET density is 1.38 g/cm^3. This means that the total amount of plastic assuming they are in a vacuum are 585.25kg for PP and 897kg for PET.

$$0.905 \cdot 650 = 585.25 \tag{5.1}$$

$$1.38 \cdot 650 = 897 \tag{5.2}$$

However since the plastic in these containers are not drained from air and are just thrown in, this have to be taken into account. How much air they contain are unknown so the following percentages of air present in the containers are assumptions made by the author. For the worst case it is assumed that 90% is air, the middle case are 80% are air and for the best case it is assumed 70 % are air. The amount of kg this is equivalent to for one container, can be seen in Table 5.1.

	PP plastic	PET plastic
Worst case 90%	58,53kg	89,7kg
Middle case 80%	117,05kg	179,4kg
Best case 70%	175,58kg	269,1 kg

Table 5.1: The amount of PP and PET amount for one container's, worst-, middle- and best-case scenario

As mentioned in Section 2.4.3, the porter states that they produce 20-25 of these containers each week, which would be ≈ 90 containers a month the total amount each month can be calculated and seen in Table 5.2.

	PP plastic	PET plastic
Worst case 90%	5.267,7kg	8.073kg
Middle case 80%	10.534,5kg	16.146kg
Best case 70%	15.802,2kg	24.219kg

Table 5.2: Total amount of PP and PET amount for 90 container's, worst-, middle- and best-case scenario

With the information from *Ragn-sells*, it can be estimated how much Hjørring can earn from the plastic the produce each month. Even though the plastic prices are at an all time low, the numbers provided by *Ragn-sells* will still be used as the middle- and best case scenario prices, where the worst case will be set to 200DDK, assuming the prices are still falling and the plastic or not sorted correctly. The results can be seen in Table 5.3.

	PP plastic	PET plastic
Worst case 200DDK per ton	1.053,540 DDK	1.614,600 DDK
Middle case 400DDK per ton	4.213,800 DDK	6.458,400 DDK
Best case 800DDK per ton	12.641,760 DDK	19.375,200 DDK

Table 5.3: Worth in DDK for 90 container containing PP and PET, worst-, middle- and best-case scenario

As seen in Table 5.3, the Hjørring department can earn between 1.053 to 19.375 DDK monthly, if they sort their sort their plastic properly. These numbers does not take into account the plastic they already drain air from, since measurement of the pallets was not taken. However these numbers are estimations, made by the author of the total weight of plastic in each container. Thus the actual value can differ.

Chapter 6

Dissussion

This chapter will discuss the findings found in throughout the project.

The project aimed to find sorting solutions for hospitals in Region Nord. It was decided to focus on plastic sorting during meetings and hospital visits. Current ways and solutions for sorting plastics were analyzed to set up a solution catalogue. A structural approach was developed to aid managers and management in handling the waste problem within hospitals. Because of this, multiple viable solutions and ideas on how waste can be handled, the quality of each individual solution might have decreased. A project only focusing on a solution for one department or a single hospital could have provided a more prominent solution for one of the visited hospitals.

6.1 New hospitals design

When new hospitals are to be built or renovated, they could be done using the same logistics as Hjørring, with the service elevator next to the flushing rooms. However, this could be further improved by implementing a chute instead of the elevator and having a waste identifier in the chute, which could then sort it into the correct orange iron cage. To further automate this process, mobile robots could transport the cages to the disposal room, where in combination with the previous solution mentioned in Section **??**, they could feed a conveyor belt with an attached robot to sort it into the correct compressor.

Hjørring has the space to add a plastic compressor, which the porter desired. This could also be implemented in the sorting system if this were to happen. The chute principle and the current layout of Hjørring can be seen in Figure 6.1

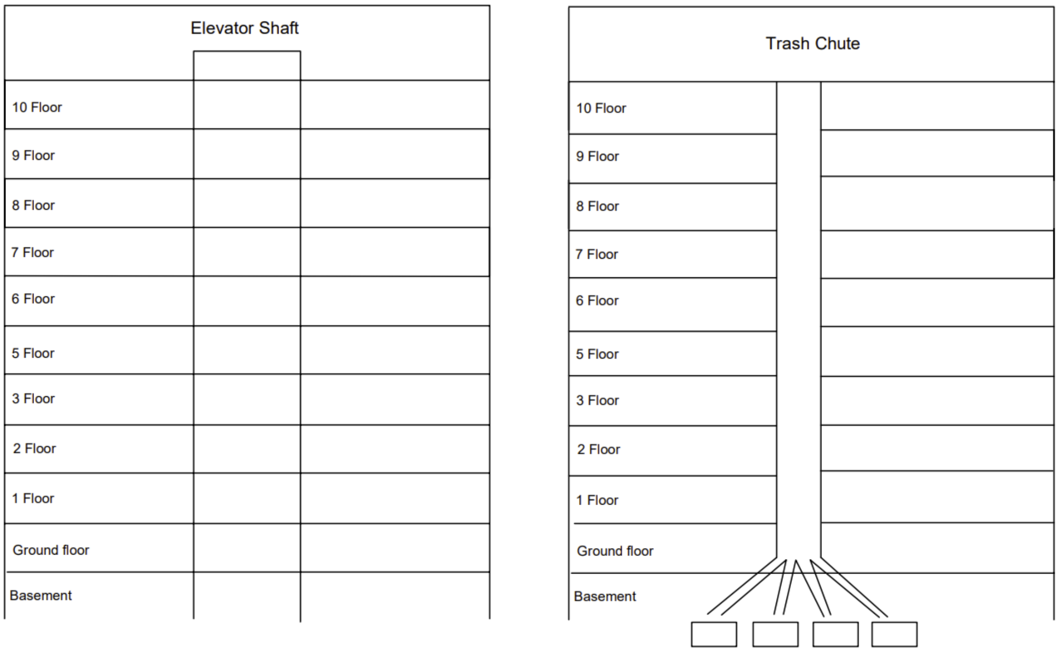

Figure 6.1: Drawing of Hjørring hospital ????? change caption

6.2 Cost-benefit analysis

The stated amount Hjørring Hospital could earn in Table 5.3 in Section 5. The table assumes that all the plastic in the 90 produced 650L containers are the same fraction and that 90% to 70% of these containers are air. These are assumptions made by the author, therefore, not reliable. However, they provide insight into how much a department like Hjørring could earn if they started sorting their plastics. If they weighed and counted how much plastic they produced of each fraction. Could provide them with information on how long a given sorting solution would have to be implemented to pay back the investment used on the solution

Chapter 7

Future work

se om det er en subsection eller section det ref. tilbage til ved jeg har en fejl med mødet med lisa

Chapter 8

Conclusion

During this project knowledge on how Danish hospitals can sort properly and their current state was gained. Actions to improve or aid managers and management were made in the form of a solution catalogue and product architecture for steps where they could implement solutions or preform analysis to improve infrastructure and logistic flow of waste.

Hospitals and a small department was visited, which contributed understanding of how these actions differs from paper to actual implementations. It was discovered that hospitals despite, them being part of the same industry, solves their waste handling problems with different methods.

A problem charts and theory from a paper on mass customization [3] was used to treat the hospital industry, that produces plastic waste as a product. To set up a product architecture that can guide mangers and management to see where they can affect and implement a solution for either the logistic flow of waste or a solution for handling waste.

Based on the problem charts, mass customization theory and product architecture. A solution catalogue with solutions on how to handle the waste or its flow was made.

Lastly a cost benefit analysis was conducted to see how much the Hjørring department could earn monthly on sorting and selling their sorted plastics which could potentially be between 1.053 to 19.375 DDK. Based on assumption made by the author of this project.

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Part I

Appendix

Appendix A

Appendix - First Interview With 2 Nurses

A.1 Interview with Nurse about Waste Produced

The following appendix describes interviews with two different nurses about waste in their respective departments of rheumatology and neonatal intensive care unit. It is acknowledged that two interviews with different nurses only provide qualitative data on the problem of waste sorting, and can not on its own be used as argumentation to implement changes. The interviews have been translated from Danish into English.

A.1.1 Rheumatology department

Question: What types of waste do you most commonly see in your department?

Answer: We throw out a lot of plastics, especially for packaging. Some products have their packaging as a combination of plastic and paper. On the syringes, we have some metal, but they are thrown out into dangerous waste, so they are not sorted with plastic or metal anyways. Additionally, we mostly throw out band-aids, cotton, and disinfectant wipes.

Question: If you had to pick one or a few types of waste that are generated the most of, and aren't sorted properly, what would that be?
Answer: It seems, that the most significant amount of waste that we throw out is plastics, mostly from the packaging of medicine.

Question: Are there any problems that are especially clear to you/annoy you about sorting in your department?

Answer: Just that we seem to especially seem to throw out a lot of plastic into general waste that could be recycled

A.1.2 Neonatal intensive care unit

Question: What types of waste do you most commonly see in your department?
Answer: We most commonly see plastics and paper. One type of plastic we actually sort correctly is plastic bedding for patient beds, but a lot of materials that could be sorted go into general waste instead.

Question: If you had to pick one or a few types of waste that are generated the most of, and aren't sorted properly, what would that be?
Answer: We throw out a lot of plastics for packaging, for equipment, and accessories for equipment. We also use a lot of single-use plates and cutlery even though we have proper cutlery and plates plus a dishwasher. The personnel just don't want to spend the time to fill up the dishwasher and empty it.

Question: Are there any problems that are especially clear to you/annoy you about sorting in your department?

Answer: There are actually three problems that I've noticed. **First**, we have two types of equipment for collecting milk from mothers, one type was one-use, the other was reuse. Patients and personnel do not care/know about the difference, and thus even the reuse equipment will sometimes be thrown out wil the one-use equipment. **Second**, even though we have a dishwasher and dishes, people still use one-time equipment to save time. **Lastly**, we receive equipment from a supplier that delivers equipment to many hospitals across Europe. Because facilities in Europe differ, their equipment has to be usable everywhere they ship it. They don't customize it to the different facilities however, instead, they include all the plastic parts that the different hospitals need. As a result, we have been instructed to throw all redundant plastic equipment that comes with the packaging that is not meant for our department, this plastic doesn't even go into a plastic waste bin, it goes directly into general waste. When we confronted the salesperson from the company about this problem, they said that it is cheaper to just deliver a general package, rather than customizing the packaging for every single facility.

Based on two interviews with different nurses working in rheumatology and neonatal intensive care unit respectively. When questioned about what types of things they threw out, their answers were almost solely focused on patient articles, hereunder:

- Medication

- Packaging
- Band aids
- Cotton
- Disinfectant fabrics
- Plastic covers for beds

Reporting that the vast majority of waste materials that were produced belonged to the category of plastics. One of the main issues reported was that there was no access to designated sorting bins in the hospital rooms. Instead, all waste had to be thrown into the same container for general waste.

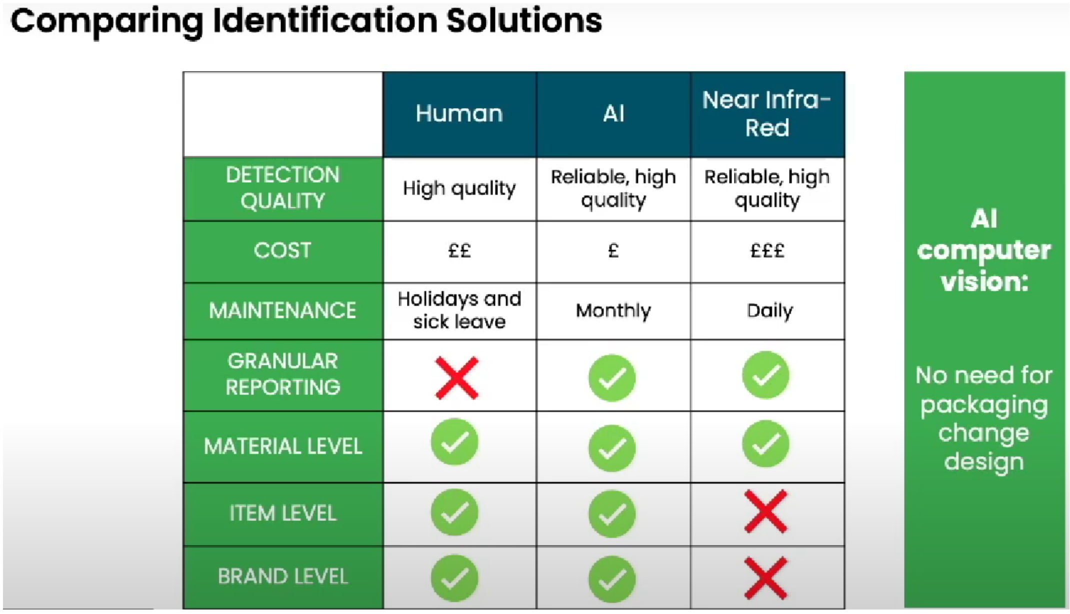
When asked whether the nurses had experienced any faults in the sorting of materials, one problem that was highlighted was that some products came prepackaged with a lot of plastic that was not even meant for their specific facility, as a consequence, they had to unpack plastic directly from the shipment and were made to throw it out into the general waste bins. When the supplier that provided the equipment was confronted with this problem, they answered that it would be too expensive to pack the product differently, and they, therefore, delivered it this way. Two problems were identified from this.

- Even waste that is obviously plastic, is sometimes thrown into general waste, simply because there are no designated buckets for that type of waste.
- Waste that could be eliminated before even going into circulation was pushed into the market by the suppliers. When consulting the waste hierarchy[7], this type of waste is the most influential to eliminate.

Appendix B

Appendix - Recycleye Self comparing to other identical solutions

Recycleye own comparing to other identical solutions, where they compare human labour and NIR to AI systems in general. According to B.1 they claim that AI out preform both human labour as well as NIR, especially with respect to expenses to both other solutions and will replace NIR which is according to them the most used solution at the moment.



Comparing Identification Solutions

	Human	AI	Near Infra-Red
DETECTION QUALITY	High quality	Reliable, high quality	Reliable, high quality
COST	££	£	£££
MAINTENANCE	Holidays and sick leave	Monthly	Daily
GRANULAR REPORTING	✗	✓	✓
MATERIAL LEVEL	✓	✓	✓
ITEM LEVEL	✓	✓	✗
BRAND LEVEL	✓	✓	✗

Figure B.1: Recycleye own comparing to other identical solutions [12]

Appendix C

Appendix - WESORT

Specification of WESORT's, models, capacity, sorting accuracy, air pressure, air and power consumption.

Product parameters

Product Category	MODEL	Capacity (kg/h)	Sorting Accuracy (%)	Power (kw)	Air Pressure (Mpa)	Air Consumption (L/min)
Single channel plastic color sorter	6SXZ-68	300-500	⩾99	0.6-0.8	0.4-0.6	＜500
90 type plastic color sorter	6SXZ-90	500-750	⩾99	0.7-0.8	0.6-0.8	＜750
Two-channel plastic color sorter	6SXZ-136	600-1000	⩾99	1.1-1.4	0.5-0.7	＜1000
Three-channel plastic color sorter	6SXZ-204	900-1500	⩾99	1.6-2	0.5-0.7	＜1500
Four-channel plastic color sorter	6SXZ-272	1200-2000	⩾99	4.2-4.6	0.6-0.8	＜2000
Five-channel plastic color sorter	6SXZ-340	1500-2500	⩾99	5.3-6.2	0.6-0.8	＜2500
Seven-channel plastic color sorter	6SXZ-476	2100-3500	⩾99	7.5-8.7	0.6-0.8	＜3500
Ten-channel plastic color sorter	6SXZ-680	3000-5000	⩾99	11-13	0.6-0.8	＜5500

NOTE: The above processing capacity is calculated with reference to the ABS plastic with an impurity content of 5% in the raw material.

Figure C.1: WESORT different machines specifications. [26]

Appendix D

Appendix - TOMRA different technologies they use in their machines

Due to most of their technologies are trademarked, a lot of the information are not available, therefore the following are mostly copied from their web page with the sales aspect removed.

Their flying beam technology, see 2.16, features an integrated light source and a NIR/visible spectrum laser system, that is focused on a rotating polygon mirror, which enables a stable and homogenous light distribution across the conveyor belt. Its setup is placed inside a box used to protects the system from any contamination that could negatively affect system classification, improving its performance and durability. It can work within numerous applications and waste streams, including paper, plastics and municipal solid waste. According to their product manager for recycling *Philipp Knopp*, the flying beam grants a 95-96% purity level.[23] [21]

Their *GAIN* is a deep learning technology that extracts numerous material characteristics of individual objects to classify them for sorting. It is trained with thousands of images to create a pool of information that drives performance. Delivering high purity and user defined fractions, this innovation can upgrade material output and create new revenue streams. [24]

DEEP LAISER, uses AI and laser line scanning to create digital copy of the objects. With this 3D digital replica it can enhance the image sharpness, improving recognition and material classification, combined with other sensor data it can further improve the sorting accuracy level. This works even when materials overlap. Along with their sorting algorithms, operators can prioritize specific materials allowing them to flexible adapt to sorting tasks as needed. [24]

SHARP EYE is an optical solution that grants efficient, high density light to enhancing image sharpness, which is then analyses. It can identify materials down to their molecular level enabling high detection rate and sorting accuracy. Its advanced multi-point scanning system can detect individual objects based on their chemical properties making it able to accurately classify the object according to the assigned task. [24]

Their *SUPPIXX* software can scale images up to eight times their size, eliminating mechanical and electrical noise. This enables it to detect even small and thin objects, which then can be separated and sorted with great precision. [24]

Their *Dual Processing Technology* combines object and area processing. The object processing analyzing provides identification of compounds where the area processing processes the pixels of the material type. This enables the system to take a data driven decision on which method to use and identify overlapping object, thus achieving a constant result even at high throughput rates and with complex compounds. Furthermore the software optimizes ejection efficiency to reduce air consumption, lowering operational costs. [24]

Their *DUOLINE* uses two independent scan lines used in x-ray transmission (XRT) sorting. The dual line scan offers advancements in separating low from high density objects across multiple applications, regardless of the relative thickness of materials. The technology enables sorting of materials with minimal differentiation in density. Operators achieve even greater results thanks to the choice of high resolution or high sensitivity sensor units, depending on the targeted sorting task. [24]

Their *FLUID COOL* is an advanced liquid-based cooling system to extend the lifetime and achieve maximum stability in LED lighting systems. The technology utilizes liquid silicone to remove heat from LEDs through a highly efficient convection process. It is an ideal solution for sorting in harsh operating environments with extreme temperatures. This technology features an illumination unit to deliver a constant and stable light source for maximized quality and output. Coupled with a dual technology sensor system, provides unsurpassed color detection and recovery of materials with high purity levels - even with very fine material grains. [24]

Their *ELECTROMAGNETIC (EM) SENSOR* detects all types of metals present in the material stream, regardless of grain size. By generating electromagnetic fields that induce currents, the high sensitivity EM sensor detects both pure metal objects and metal-based composite materials and classifies these objects for the sorting system. Their EM sensor technology is instrumental in producing recoverable metal concentrates and maximum purity fractions of non-metal materials. Their state-of-the-art electromagnetic sensor detects metals with maximum precision without compromising throughput or efficiency. [24]

Their *COLOR LINE SCAN CAMERA* color line scan camera technology enables materials to be sorted by color, brightness, shape and size. With sensitivity up to 16k resolution, the imaging technology delivers color fidelity for high throughput sorting of complex material streams. The high-speed machine vision technology detects entire spectrum of CRGB colors, giving operators more flexibility in creating high purity products that can even be sorted by color. [24]