Hospital Waste Sorting

A. Saeidylafouraki, H. Balasubramanian

Department of Materials and Production, Aalborg University
Fibigerstraede 16, DK-9220 Aalborg East, Denmark
Email: asaeid21@student.aau.dk,hbalas22@student.aau.dk
Web page: http://www.mechman.mp.aau.dk/

Abstract
This project is concerned with developing and designing an integrated waste sorting system for hospitals, with a focus on plastic waste in particular. In order to start the project, various waste types and sorting processes, including manual and mechanical methods, are analyzed. After evaluating available hospital waste management options, it is decided to give plastic sorting priority. The analysis phase also reviews the most reputable waste sorting businesses, investigates technologies appropriate for both centralized and decentralized setups, and further assesses the validity of human presorting. The ultimate goal of the project is proposed as an ideal long-term solution. Based on these discoveries, a waste sorting system with a central plant and decentralized plants is designed. This well-balanced strategy maximizes waste sorting effectiveness while efficiently using resources. Advanced technologies are incorporated into the design to improve sorting accuracy, reduce contamination, and maximize resource allocation. In conclusion, the goal of this project is to implement an integrated waste sorting system that will revolutionize hospital waste management. The suggested solution provides a sustainable method for managing hospital waste by fusing computer vision and machine learning, taking into account the optimum degree of centralization and decentralization, encouraging environmental responsibility, and contributing to a circular economy.

Keywords: Computer vision, Plastic sorting, Hospital waste, Robotic sorting

1. Introduction

Hospital waste management is a process that assists in maintaining proper hospital hygiene as well as the safety of healthcare workers and communities. The process involves sorting, collection, storage, transport, and disposal. Currently, Region Nord facing issues in implementing waste sorting in local hospitals. The cause for the problem is many like unclear waste standards, it is difficult to sort by the personnel, and so on. Due to these conditions, the potential for exploring and analyzing the solutions is enormous.
The problem is approached by Kolb's learning cycle. The four stages of David A. Kolb's cycle are concrete learning, reflecting observation, abstract conceptualization, and active experiments.
A more effective and extensive sorting of waste in general, 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 in other industries, and hospitals burn waste in most cases.

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.

Fig. 1 Waste sorting categories in Denmark

1.1 Problem Statement

Hospital waste, including plastic and other materials, is a serious problem because it pollutes the environment and endangers the health of patients, staff, and the general public. Hospitals produce a variety of wastes, including hazardous, non-hazardous, and medical waste. If not disposed of appropriately, medical waste, which includes spent needles, syringes, and other disposable medical equipment, can be very dangerous. The fact that hospital waste is frequently improperly sorted is one of the key issues. Many hospitals lack the manpower or resources necessary to effectively manage their waste streams, making garbage sorting a time-consuming and labor-intensive procedure. Inadequate hospital waste sorting can result in contamination and pollution, which puts the health of patients, medical personnel, and the general public at risk.

1.2 Purpose and Scope

This project focuses to compare and combine both centralized solutions and decentralized solutions and solve the problem of plastics not being sorted at hospitals as mentioned above and help the government to achieve its sustainability goals.

- Centralized waste management: Wastes from the hospitals are collected, sorted, and transported to a single location and processed.
- Decentralized waste management: Wastes from the hospitals are sorted in the site and then transferred to a single location and processed.

As additional support, the scope will be focusing on waste to sort efficiently and recycling more. Additionally, maximizing the economic value of the material throughout its lifecycle and reducing waste support the circular economy.

2. Waste generated at the hospitals

To understand what type of solutions would make a difference in sorting the waste produced in the hospital facilities, it makes sense to first know what types of waste are actually produced and in what amounts. Therefore, this section describes the types of waste generated in the hospital industry in Denmark.

Regionens samlede udledning per forbrugsområde 2017-2020

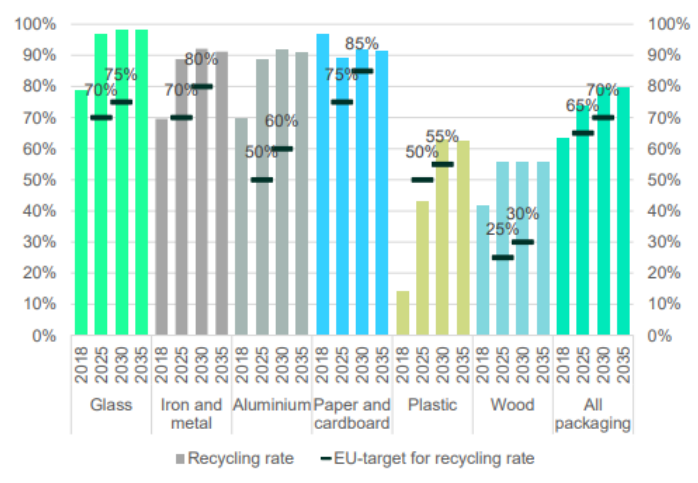
	2017	2018	2019	2020	% udvikling 2019-2020
Patientartikler	83.391	76.343	77.229	80.454	4%
Øvrige indkøb og aktiviteter	29.442	29.545	31.700	31.083	-2%
Bygninger og arealer	30.579	31.233	26.628	23.808	-11%
Udstyr	8.074	7.856	8.097	11.271	39%
Transport	12.188	10.862	9.323	7.565	-19%
Forplejning	8.439	8.156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

Fig. 2 Description of what categories region Nordjylland produces the most CO_2.[?]

Figure 2, 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.

2.1 Focusing on plastics

Figure 3 shows the least recycled material in Denmark which is plastic. Plastic is also the only area in which Denmark could not reach the EU targets yet. This gap makes it more important to focus on.



Source: Eurostat, Danish Environmental Protection Agency.

Fig. 3 Expected developments in the recycling rates of packaging waste in Denmark and EU targets. [?]

The waste generated in hospitals needs proper management, focusing on sorting plastic is more relevant due to the high volume of plastic waste generated, the environmental impact of plastics, their high recycling potential, and their feasibility. Proper sorting and disposal of plastic waste in hospitals can contribute to achieving EU sustainability targets and protecting the environment.

3. Existing solution

3.1 NIR scanners

Identifying and categorizing various forms of waste based on their content, near-infrared (NIR) scanners are frequently employed in waste sorting plants. As the waste moves by on a conveyor belt, these scanners emit a beam of NIR light upon it. After being reflected back to the scanner, the NIR light is used to gauge the amount of light that is absorbed by the waste at various wavelengths. Depending on their chemical makeup, different waste types absorb NIR light in various ways. The NIR scanner can identify and classify various waste kinds into separate streams for recycling, composting, or disposal by examining the pattern of light absorption.

3.2 Vision based sorting

Computer vision (CV) can be used to assist in sorting either at the source or when it is collected at the (recycling place/ internal trash room). Along with a model it can be trained to identify various materials, integrated with smart deceives the CV model can aid users to determine the types of generated waste materials for proper classification. It can also be applied alongside a robotic solution to sort it automatically into bins, furthermore, it can aid unmanned ground vehicles in automatic waste collection in construction sites or manufacturing places.

3.3 Sygehus Sønderjylland in Aabenraa

According to an analysis made by *COWI* of the hospital in Aabenraa [1], 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 than the existing one.
According to the same article [1] part of the problem is that the medical personnel must transport the collected waste to a specific trash room within the hospital and then sort it. *COWI* suggested a solution to the problem by introducing mobile waste trolleys. 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 do waste sorting on the spot, reducing transportation time and eliminating the need for additional time to sort the collected trash in the trash room.

3.4 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. [1] *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*.

3.5 Blood bank Aalborg

Due to the extremely specific waste types in this example as well as the limited space available, more comprehensive waste management solutions cannot be implemented. The regional waste ambassador is in charge of any waste-sorting initiatives. Currently, a system of specific waste buckets located within the department has been implemented, which is similar to the solution used in Region Nordjylland.

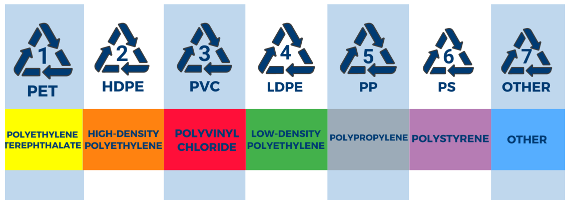


Fig. 4 Seven types of plastic

Due to Bloodbank Aalborg's size, only various types of plastic waste are produced; as a result, a system of waste buckets specifically for plastic and biologically hazardous waste was implemented. In this solution, plastic is sorted into seven different categories. These seven categories of plastic are described in Figure 4.

3.6 Hjørring Hospital

Larger hospitals that produce a wide variety of waste with a specific bucket system and established hospital-wide logistics for waste collection, this hospital is further along in its waste management system implementation. The information shown below was gathered on April 27th during a group visit. The specific bucket system in the flushing roomsFigure 5 found within the various hospital departments is the first component of the Hjørring Hospital's solution. Only the necessary buckets are present. In addition, the trash bags have different colors for quicker identification at a later stage of the waste management process.
The second part of this solution is the collection of these waste bags in orange roller cages, which can be seen near the technical staff elevators, where they are collected three times a day: in the morning, in the middle of the day, and in the afternoon. The collection, transportation, and disposal of these roller cages make up the final component of this solution. After being gathered close to the elevators, they are chained up in the cellar and taken through tunnels to the disposal

room. The porter in the disposal room empties the roller cages into the appropriate 650-liter waste containers.

Fig. 5 Flushing rooms at Hjørring Hospital

The process of waste collection consists of the collection of 16-18 roller cages and their disposal by two porters, which can take between 1.5 and 2 hours.

4. Problem formulation

To what extent centralized and decentralized solutions can be combined to sort plastics into seven different fractions efficaciously from the hospital waste?

5. Further analysis

5.1 Improve human sorting reliability

During the literature review, many useful ways were found to improve the willingness of hospital staff to separate waste at source. In research conducted in Malaysia, as a convenience measure, recycling bins were put close to where waste was generated, which resulted in a 28 percent drop in the miss-sorted proportion. Also, quick access to relevant knowledge significantly enhanced recycling behavior in the pilot area.[2]

The findings indicated that lack of "space" was the most common barrier to recycling, and acceptance of legal rules was the most common reason for participation.[3] According to the results of the interviews, providing householders with written material that is clear, understandable, and readily available in an understandable language and supported by word-of-mouth information may increase their involvement in recycling programs.[3]

Another research performed in Borås, Sweden, an area was chosen with a high missorted waste rate.[4] The study assesses home involvement in a source separation program, specifically if the household application of the program improved following two interventions: (a) closer proximity to the drop-off location and (b) simple access to accurate sorting instructions. Following the implementation of a property close collection system (intervention (a)), statistical analyses of the data showed a significant decrease (28%) of packaging and newsprint in the residual waste as well as a significant decrease (70%) of the miss-sorted fraction in bags intended for food waste following the introduction of new information stickers (intervention (b)). [4]

It is believed that feedback regarding one's own recycling effectiveness provided by individuals (such as waste specialists, managers, or coworkers) is even more significant. According to this perspective, autonomy and the quality of recycling-related information are important variables that can be designed to boost recycling motivation and enhance pro-environmental behavior.[5]

Five job characteristics were discovered and modified to support this research based on the work motivation theory:[5]

- People experience autonomy in their work, which means they have freedom in their decisions and receive accurate and thorough information.
- Feedback is supplied, for instance, if waste is disposed of in the incorrect container; this feedback must not be accusatory, but rather instructive and motivating. It's also crucial to provide feedback on what happens to the waste.
- In this research case, people offer the healthcare service from beginning to end, including the disposal of spent materials, so they identify with the task and provide a complete service from beginning to end.
- People believe that their work matters to other people, hence in our example waste separation needs to make sense so that the waste may be recycled or disposed of appropriately.
- The task calls for a variety of abilities; in our example, self-management, organizational, and healthcare abilities.

5.2 Centralized Solutions

In this section, the different ideas for a centralized solution for sorting plastics and also explains the process, methodology, results, evaluation, and so on that is proposed by the various scientific papers and authors around the world to sort plastic into different fractions. These fractions are sorted by various technologies and methods like MFCC, Audio signal, dye fluorescence, and with the help of sensors & artificial intelligence. The mentioned processes are described in depth in the following sections.

5.3 Plastic segregation machine using audio signal

An automatic plastic system is essential because plastic consumption is increasing rapidly. Based on the acoustic features, a mechanical arrangement as in Figure 6, uses microcontrollers to distinguish plastic from other waste materials. It is used to identify and automatically sort plastic when debris that includes metal, wood, paper, and plastic passes through a sensing unit.

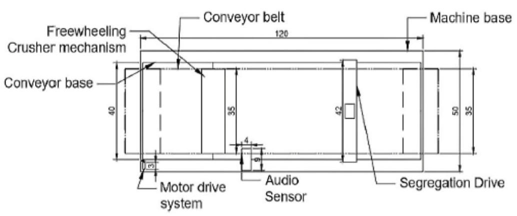


Fig. 6 Top view of the Mechanical system

By using an autonomous plastic segregation system, the traditional waste management system can be upgraded to a smart system. In order to distinguish recyclable plastics from other types of waste, automated sorting systems use a variety of sensing systems. These detection systems sort plastics automatically using the latest technologies. Combining detection systems in digital plastic separating systems allows for the identification of various recyclable plastic types. MFCC(Mel-Frequency Cepstral Coefficients) feature extraction is used to extract the audio signal where each audio stream is initially divided into short segments of 15ms to 20ms time frame, and the spectral distortion is eliminated by using windows to taper the signal to zero.] An inexpensive plastic separation machine is created with the help of the MFCC extraction of features method and ANN classification, which can be used to detect plastic in audio signals. The machine prototype can extract features from audio signals and identify objects based on the extracted features. The accuracy of the plastic identification system with vector quantized MFCC features and the mechanical system was discovered to be 85%[6].

5.4 Automatic identification and sorting of plastics

A novel approach for the automatic classifying of plastics is disclosed, which is based on optical recognition[7] of dye fluorescence signatures inserted in such materials in trace amounts prior to product manufacturing. Three commercial tracers were chosen for their high absorbency in the 310-370 nm spectral range and their distinguishable narrow-band fluorescence fingerprints in the visible portion of the spectrum when found in binary combinations.

The plastics used for tracing and recognition are HDPE, LDPE, PP, EVA, PVC, and PET, and the tracers were compatible and inert chemically with the host matrices, with no effect on the plastics' transparency[7].

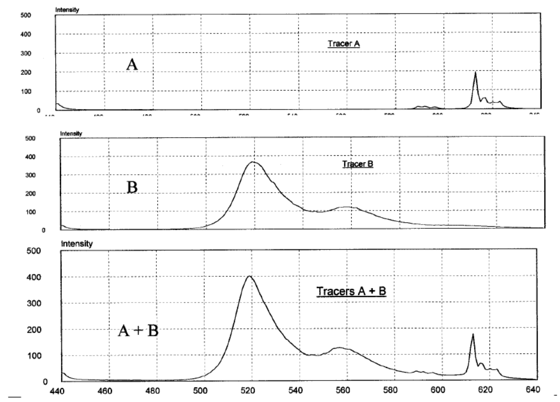


Fig. 7 Fluorescence spectra of two traces

The design of a monochromatic and collimated excitation source, as well as the sensor system, are detailed and its performance in recognizing and sorting tracer-doped plastics at a few parts per million concentration levels is evaluated. This method is inapplicable to colored engineering. Tracers exhibit their plastics, such as automotive parts, when excited by ultraviolet light cannot be employed if distinctive fluorescence signatures are present. Tracers reveal their distinctive fluorescence characteristics when excited by ultraviolet light. Commercially available tracers can be chosen so that their spectrum emission characteristics have no overlap and their spectral signatures are detectable even when combined in a host plastic material, as demonstrated in Figure 7 here high-density polyethylene is taken as an example.

More research is required to develop more efficient tracer dyes or modify existing ones for higher fluorescence quantum yields for specific applications, as well as to improve detection methods such as efficient filters and detectors, fast data processing electronics, and so on. The technology, which is based on fluorescent tracers, could be used for process/quality control in a variety of other industries, including pharmaceuticals.

5.5 Multi-Sensor based plastic waste segregation

This section will highlight the Radical Innovations Group's continuing work in tool development using blockchain and multi-sensor-driven AI systems[8]. This study will talk about a multi-sensor AI system for sorting plastics, in this systemFigure 8 various types of sensors are backed by AI throughout the segregation stage. Multi-sensor data fusion has proven to be quite effective in training smart robots for a variety of activities.

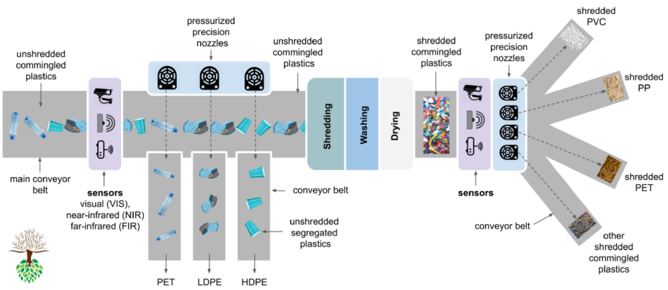


Fig. 8 Segregation of Plastic waste using multi-sensors

The light absorption spectroscopy of plastics, notably in the wavelength range of 300 to 3000 nanometres[nm].Near-infrared laser diodes are also rapidly being utilized to investigate the resonance frequencies of various polymers. These laser sensors can distinguish six distinct kinds of detectable plastics: PET, PE, PVC, PP, PS, and ABS[8].

Figure 8 depicts one of the flow models comprises of three data-fusion modes (cooperative, complementary, and competitive)that use three different types of sensors, in which all three sensors-VIS, NIR, and FIR-are used in tandem to obtain distinct information about the same object.

A multi-sensor data fusion tool powered by artificial intelligence aid by Radical Innovations Groups is explained in the segregation of commingled plastics based on physicochemical parameters such as color, polymer type, density, and so on. When both speed and accuracy are considered for industrial-scale setups, these approaches can achieve almost 99 percent efficiency for color-based segregation and 95-98 percent precision for plastic-type-based segregation.

5.6 Decentralized solution

5.6.1 One-Shot learning-based segregation of plastic waste

The decentralized option is explained for sorting plastics into different categories locally within the hospitals or departments depending on the availability. The classification is segregated by one-shot classification using a neural network. This study describes a method for classifying plastic waste based on images employing one-shot learning techniques[9]. The suggested method uses discriminative features generated by Siamese and triplet loss convolutional neural networks to distinguish between types of plastic trash based on resin codes as in Figure 4.In this paper, we suggest using siamese and triplet loss networks on plastic waste photos from the WaDaBa(Waste Database)[10].

5.6.2 Siamese Network

Two images are used as input, with the label set to 0 if they are from the identical class and 1 contrary. As illustrated inFigure 9, the pictures are sent through two similar CNN networks with common weights. Each image receives a 4096 feature vector as a result. The Euclidean distance between the two feature vectors is then calculated and processed through a sigmoid layer, and the resulting cross-entropy loss is fed back to both identical networks.

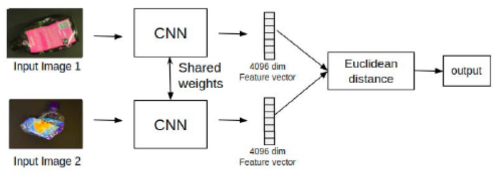


Fig. 9 Structure of Siamese Network

5.6.3 Triplet Loss

$$||f(x^a) - f(x^p)||_2^2 - ||f(x^a) - f(x^n)||_2^2 + 0.4 \quad (1)$$

Three similar networks with shared weights comprise the structure as inFigure 10. One image is chosen at random and is referred to be the anchor image. The other two images are known as positive (images of the identical class) and negative (images of a different class). All three images are sent to three identical CNN networks.

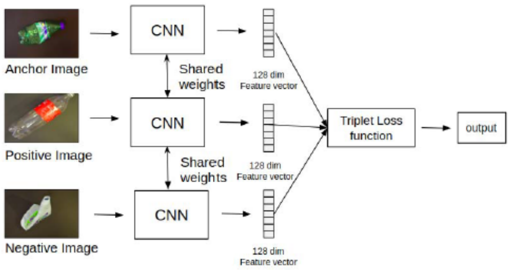


Fig. 10 Structure of Triplet Loss

The CNN network utilized is identical to the Siamese network, but an additional fully-connected layer of 128-dim is added after the Siamese network's penultimate fully-connected layer. In Equation 1, the loss is computed and propagated backward into each of the three identical networks, where $f(x^a)$, $f(x^p)$, and $f(x^n)$ denote the anchor, positive, and negative embeddings generated after passing the relevant pictures through the CNN, respectively.The accuracy is measured using the K-nearest Neighbour algorithm. From the evaluation, the accuracy of siamese and triplet loss are obtained at 99.50% and 99% respectively.[9]

5.7 Leading companies

After further analysis of the leading companies in the plastic sorting industry, AMP Robotics was chosen for the robotic solution to be used in the decentralized part of the solution and Binder+co was chosen for the central part of the solution.

5.7.1 AMP Robotics

AMP Robotics is modernizing and scaling the world's recycling infrastructure by applying AI and automation to increase recycling rates and economically recover recyclables reclaimed as raw materials for the global supply chain. In addition to developing AI-enabled solutions to retrofit existing recycling facilities, AMP also designs and builds new facilities powered by its application of AI for material identification and advanced automation. The AMP Cortex DRS machine uses two high-performance delta robots to quickly sort, pick, and place materials at the speed of 160 pieces per minute. It builds on its current product line of high-speed recycling robotics that is controlled by the AMP Neuron AI platform. In order to distinguish between different colors, textures, shapes, sizes, and patterns, AMP Neuron uses computer vision and machine learning. It then instructs the robots to select and position the desired material.

Fig. 11 AMP Coretex DRS machine

5.7.2 Binder+co

An Austrian business called BINDER+CO specializes in offering solutions for sorting and processing a variety of commodities, including plastic waste. Their plastic sorting systems are made to work more effectively, generate less trash, and produce recycled plastic of higher quality. A modern sorting system created to effectively sort plastic waste is the Binder+Co Clarity plastic machine. It is made especially for recycling post-consumer plastic waste like plastic bottles, packaging, and other plastic items. Utilizing cutting-edge sensor technologies, such as near-infrared (NIR) and color cameras, the Clarity plastic machine can recognize and classify various types of plastic based on their spectral and visual characteristics. Including PET, HDPE, PP, PVC, PS, and LDPE, the system is able to sort a variety of plastic materials. The machine uses precise micro fans to blow every item out of the flow accurately.

Fig. 12 Binder+co CLARITY plastic machine

6. Solution

6.1 National solution

From a more comprehensive point of view, a system can be implemented to cover the requirements of the whole hospitals of Denmark. This solution has to be applicable to all major hospitals. This solution will be implemented in two phases.

6.1.1 First phase

In the first phase of the solution, a centralized setup is designed to sort the most common type of plastic. The most common type of plastic is not always the same. However, based on the research, the most common type of plastic in household waste is PET[11]. The data from household waste is used since there is no available data about hospital waste. To detect this specific type of plastic, computer vision technology supported by a neuronal network machine learning can be implemented. In order to separate this specific kind of plastic, a delta robot system can be implemented. This machine should be able to detect one specific type of plastic at this phase. AMP Cortex DRS was chosen in this solution in order to cover the requirements.

6.1.2 Second phase

The second phase of the solution implementation consists of two parts. The first part is done in decentralized plants all over the country which is implemented in the first phase and the second part is in the centralized plant.
In the second phase, decentral plants which are basically AMP Cortex DRS machines, change their rule to just take out impurities like paper, metal, etc. from the flow. This operation is needed due to errors in human presorting. This central plant uses a Binder+co Clarity plastic machine as the main sorting machine. The plant also needs a storage area to store the purified waste transported from all over the country and a forklift to transport sorted plastics inside the plant.

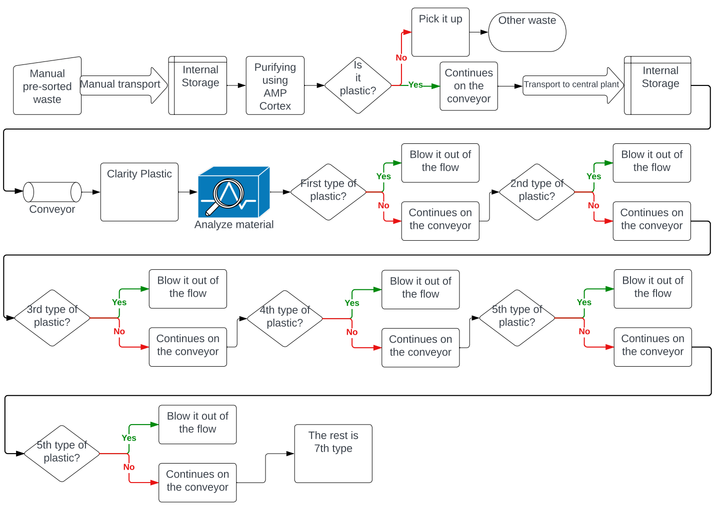


Fig. 13 Material flow diagram of the national solution

It was calculated that the whole setup will cost 954 800 Euro per year to operate. In May 2023, 954 800 Euros is equal to 7.1 millionDKK. We know from the cost-benefit analysis, hospitals can make 1.3 millionDKK by selling sorted plastic and save 9.5 millionDKK waste handling costs. In total, excluding transportation costs, this setup can make 3.7 millionDKK a year. It means that if the transportation costs less than 3.7 millionDKK, The proposed solution can be profitable. It is impossible to calculate the transportation cost because the location of the plants is not set. Also, it needs to be kept in mind that the environmental benefits are way more important.

6.2 Decentralized Implementation

A decentralized Solution, allows more flexible and distributed decision-making, can be suitable in cases where the availability of space is less, where the hospital might be located in a remote area and hard to reach, and finally limited resources. In such cases, a decentralized solution is ideal for sorting plastics. This can result in improved efficiency, scalability, and robustness.

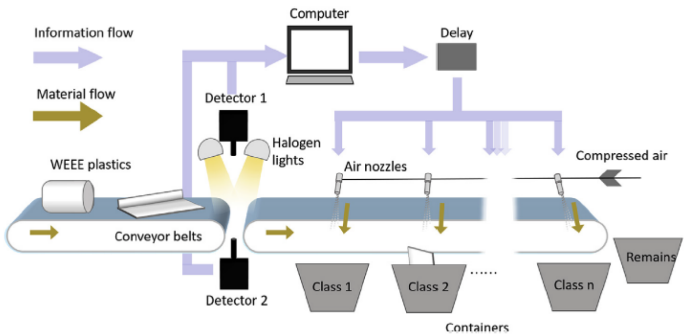


Fig. 14 Automatic line to sort plastic from hospital waste

Figure 14 shows the automatic line to sort plastics, the hospital wastes along with plastics from the different departments. The wastes can be fed into the conveyor, if the plastics come under the detection range, it records the type of plastics and gives the information to the computer. The air nozzles are placed perpendicular to the conveyor and it receives output from the delay. For example, If the plastic is PET it pushes to the respective storage bin. The information will be given by the computer and the delay system. It applies the same to all types of plastics depending upon the data it pushes to the respective bins.

Finally, for dispersed plastic sorting in hospitals, this system can be an effective and efficient solution. Because of the capacity to train a model with a modest amount of labeled data, hospitals can accurately sort their plastics without incurring large labeling costs. Furthermore, decentralized plastic sorting allows various divisions to sort their plastics autonomously, minimizing the time and effort required for plastic sorting. Overall, using one-shot learning as a solution for hospitals to separate plastics has the potential to improve plastic sorting efficiency while reducing the environmental impact of plastic waste.

7. Conclusion

The Previous Chapters provided an overview of the sorting of plastics from the hospital waste. The circular economy is essential when it comes to plastics. Building the circular economy for plastics tries to break the linear model by boosting plastic reuse, recycling, and regeneration. It highlights the concept of closing the loop, which means keeping plastics in the economic system for as long as possible to reduce the need for fresh production and waste generation. Plastic sorting efficiency is critical to developing an economy that is circular for plastics. Here are some of the reasons why effective sorting is critical:

- To facilitate recycling
- To promote resource recovery
- To Enhance waste management
- To Enable closed-loop systems
- To drive innovation and investments

Decentralized systems at localized levels, such as those seen in hospitals, allow for the quick separation of various waste fractions. Implementing technology-driven solutions such as one-shot learning and machine vision, as well as smart bins and employee training can help to streamline waste sorting and reduce cross-contamination. At the regional level, the establishment of centralized sorting centers outfitted with cutting-edge technologies such as robots and machine intelligence provides scalability and efficiency. These facilities can handle complex waste streams while adhering to rules and best practices. Although the expense of implementing a regional-level solution may be prohibitively expensive, it is critical to think of it as an investment in the circular economy and a sustainable future. Recovering and recycling valuable resources reduces the requirement for raw materials while also minimizing environmental effects. Collaboration with stakeholders, exploration of funding sources, and cost-benefit assessments can all aid in the financial management of implementation. Hospitals can optimize waste sorting, increase recycling rates, and contribute to a cleaner, healthier future through the integration of decentralized and centralized systems. These solutions support resource conservation, employment creation, growth in the economy, and sustainable development.

8. Future work

After making the solution, a number of recommendations for further future work on this project are needed. There are always a lot of great ideas among people working in an industry. Obviously, better ideas come to mind when people are in an environment and doing a job every day. Talking with the hospital personnel and letting them propose their ideas can provide a huge source of creativity. These people are also familiar with the challenges and limitations in the workspace. It can also be beneficial to let hospital personnel test their ideas and give them the freedom to help in their own way, even if it takes a small amount of their time.

It is also possible to invest on educate hospital personnel and make an easier sorting solution and a feedback system to increase human sorting reliability. The Danish government can save a lot of money this way.

In the end, after the analysis and compare different solutions, it is concluded that new governmental or even EU regulations for plastic production methods are required to make reuse and sorting easier. These regulations can consist of a wide range of rules from implementing fluorescent indicators to produce each item form one type of plastic.

Acknowledgement

The authors of this work gratefully acknowledge Grundfos for sponsoring the 11th MechMan symposium.

References

[1] G. Sygehusbyggeri, “Fra affald til resurse: Systematisk affaldshåndtering på hovedstadens hospitaler.” N/A, Not Applicable. Online; accessed 3rd March 2023.

[2] F. W. I. N. I. S. et al., “Household solid waste management practices and perceptions among residents in the East Coast of Malaysia. BMC Public Health.” https://rdcu.be/da6L2, 2022. Online;2022.

[3] N. B. Sviatlana Miafodzyeva and M. Andersson, “Recycling behaviour of householders living in multicultural urban area: a case study of Järva, Stockholm, Sweden.” https://journals.sagepub.com/doi/pdf/10.1177/0734242X13476746, 2013. Online;2013.

[4] K. Rousta, “Quantitative assessment of distance to collection point and improved sorting

information on source separation of household waste." https://www.sciencedirect.com/science/article/pii/S0956053X15001452, 2015. Online;2015.

[5] J. V. . K. R. Nunes, "Recycling behaviour in healthcare: waste handling at work." https://doi.org/10.1080/00140139.2014.887786, 2014. Online;2014.

[6] Dharmana, M. Madhu, U. M. L. N., I. Abhinav, and M. R. B. Hari, "(plastic segregation machine using audio signal)." https://ieeexplore.ieee.org/document/8821842, 2019. Online; accessed 28 April 2023.

[7] S. R. Ahmad, "A new technology for automatic identification and sorting of plastics for recycling." https://pubmed.ncbi.nlm.nih.gov/15551828/, 2004.

[8] A. C. P. B. D. K. M. Q. M. Kshirsagar and K. Sankaran, "From Trash to Cash: How Blockchain and Multi-Sensor-Driven Artificial Intelligence Can Transform Circular Economy of Plastic Waste?." https://www.mdpi.com/2076-3387/10/2/23, 2020. Radical Innovations Group.

[9] A. Shivaank, G. Ravindra, and P. Saxena, "One-Shot learning based classification for segregation of plastic waste." https://ieeexplore.ieee.org/document/9363374, 2020.

[10] B. Janusz. and J. Piatkowski, "Pet waste classification method and plastic waste database-wadaba." https://link.springer.com/chapter/10.1007/978-3-319-68720-9_8, 2017.

[11] K. L. L. N. S. T. R. S. J. R. J. N. J. M. G. H. Leonard, "The United States' contribution of plastic waste to land and ocean." https://www.science.org/doi/pdf/10.1126/sciadv.abd0288, 2020. Online;2020.