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Exploring Potential Novel Waste Management Solutions in Bangkok, Thailand

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ABSTRACT

Bangkok has gone through vast and rapid development, building its infrastructure from its small town into the metropolis it is today. However, with rapid development, Bangkok's waste management system has become obsolete and ineffective. In Bangkok, waste management consists of the basic four methods: landfill, incineration, recycling and composting. The management methods are inaccurate and slow, and have increasingly severe effects on the health of Thai citizens, waste workers, and the environment. This study will explore modern methods of waste management, which can serve as newer, faster, and cleaner alternatives, therefore more efficiently treating and sorting through waste. Overall, modern technologies present the potential to be very useful and effective. In the present day, there are various sorting machines that manipulate the properties of waste in order to separate biowaste, plastic, and metal. More prominently, the increasing accuracy of Artificial Intelligence software, like WasteNet, DETR, and EfficientDet, allow faster, more precise identification of waste. Other mechanical technology, like robotic arms, smart waste bins, and robot swarms can be utilized with Artificial Intelligence in order to improve efficiency in various stages of Thailand's waste management cycle. Overall, while there still are some elements to improve regarding costs and efficiency of modern technology, they present high potential to be implemented in Thai society, keeping waste off the streets.

Introduction

From its humble beginnings as a trading post, Bangkok, the capital of Thailand, has evolved into a bustling metropolis, renowned for its vibrant culture and seamless blend of ancient traditions and modernity. Bangkok has gone through impressive economic and social growth due to successful goods exports and tourism. Over the past four decades, Thailand has moved itself from a lower income country to an upper-middle income country. Between 1960 to 1996, the annual growth rate of Thailand's economy was 7.5%. In 1999 to 2005, the annual growth rate was 5% despite the setback during the Asian Financial Crisis in 1997. Through this economic growth, Thailand was able to create millions of jobs that pulled countless people out of poverty. Thailand was able to reduce its poverty from 58% in 1990 to 6.8% in 2020, due to its high growth rates and rapid structural transformation (The World Bank, 2023). Bangkok has improved in various other perspectives. Rate of education has skyrocketed. Many more people are able to afford health insurance. Additionally, other forms of social security developed quite prominently to support the Thai people. More prominently, Bangkok's population has nearly doubled since 1990, rising from 5,889,000 people to a staggering 11,234,000 people (Macrotrends, 2024).

However, with rapid development of the economy and booming population growth comes its downsides, such as outdated systems that cannot handle the growing population and economy. One of the significant issues, Bangkok's waste management system, has problems rooted deep within the various levels of waste management. On the surface, a number of issues are present within the current waste management system. In

2004, Bangkok generated around 9,400 tons of waste daily. However, the Bangkok Metropolitan Administration's daily waste capacity is only 7,500 tons. As waste generated increases due to the increase in population, the challenge to manage the increasing amount of waste is significant. (Muttamara et al., 2004) For example, in Bangkok, it is difficult finding any street bins, simply because there are no public street bins available for pedestrians to use. The main reason is the general absence of large scale clean-up projects. All large recycling companies make contracts with single condominiums and industries, causing most waste management to be done in the private sector more than the public sector. Public initiatives related to waste management are rare and unsuccessful, making it quite difficult for citizens to recycle if they are not connected to any recycling companies. Additionally, the public and private sector are not integrated properly. While the government is planning to implement more recycling and reduce plastic production, plastic usage still remains quite high. The overuse of plastic and the privatization of recycling and waste management is a significant concern in the present waste management scenario (Mahanakorn Partners Group, 2018).

In 1992, Thailand's government enacted a number of laws to promote sanitation and cleanliness in Bangkok. Each of these acts were enacted to reduce the overall amount of waste produced in Thai society, ranging from municipal solid waste, fecal waste as fertilizer, and hazardous substances in factories. By enacting these laws, the BMA was able to clean up quite a lot of issues regarding incorrect waste disposal, use of harmful or unhygienic material, and maintenance of public properties. The four main acts are in Table 1.

Table 1. Acts Enacted by the Government in 1992

Act	Description
Public Health Act	This act amended laws on governing and monitoring, improving the authority of government officials by enforcing stricter penalties under the current law. To ensure the efficient supervision and protection of environmental health, this act also includes the controlled use of fecal matter as fertilizer. This was done to enforce proper sanitation and disposal of waste. (Public Health Act, 1992)
Public Cleansing Act / Act on the maintenance of the cleanliness and orderliness of the country	This act enforced the maintenance of cleanliness in public places and establishments, lawns and trees in public space. Additionally, the act enforced the prohibition of littering in public places. Similarly to the Public Health Act, the powers and duties of local officials were also enforced. (Act on the Maintenance of the Cleanliness and Orderliness of the Country, 1992)
Factory Act	The purpose of the factory act is to avoid waste generation in factories. This is done by imposing regulations on the operation, factory expansion, and safety requirements of factory establishments. Stricter laws were also imposed on industrial pollution. (The Factory Act, 1992)
Hazardous Substance Act	The hazardous substance act established the committee of hazardous substances. Hazardous substances are classified depending on use, production, import, and export. Regulations are imposed on producers' ability to create certain types of hazardous substances (i.e type 3 hazardous substances cannot be possessed by any producer unless authority has been obtained). Duties and civil liabilities of producers, importers, carriers, etc. of hazardous substances and penalties are enforced in this act. (Hazardous Substance Act, 1992)

Despite this, there are still a number of issues regarding waste management in Bangkok today.

Current Waste Management Scenario in Bangkok

On a deeper level, Bangkok's waste management system has various issues related to waste separation, waste management, and waste disposal. Thailand generates approximately 26,850,000 total tons of waste, with around 76.23% collected by waste management facilities. Proper treatment is applied to 31.06% of this waste, while 26.63% undergoes improper treatment (Funatsu, 2019). In the present day, there are four main methods of waste disposal: Landfills, incineration, compost, and recycling. The pros and cons of each method are described in Table 2.

Table 2. Pros and Cons of Conventional Methods of Waste Management in Bangkok, Thailand

Waste Disposal method	(%) from properly managed waste	Pros	Cons
Landfill	82.6%	Easy to use	Water pollution through leachates Air pollution caused by decomposition of waste - toxic and flammable Landfill zones are unfavored due to the smell Decreasing land space - landfills not sustainable
Incineration	4.9%	Reduces volume of waste	harmful residuals
Recycling	6.6%	Currently a recycling system, albeit informal, is in place. High profit potential Reduces general waste	The current recycling system is highly ineffective Not a very large portion of the waste can be recycled
Composting	5.9%	Large portion of waste can be recycled Compost waste can be used as fertilizer	Not very useful when contaminated

Landfills are the most common choice of waste management solution in Bangkok. 82.6% of properly managed waste being sent to landfills. A landfill is a designated location to dump waste. This method of waste management is quite harmful for the environment and society, as landfills cause water and air pollution. Water pollution problems experienced at landfill sites occur when rainwater causes 'leachate', which is when water passes through a solid, carrying some of its substance along with it. This affects the quality of nearby surface and groundwater. Air pollution is created due to the process of decomposition. The toxic gasses contained in the air pollution are mainly CO_2 and CH_4, with hints of NH_3, H_2S, and CO. THowever, aside from the toxicity of these gasses, the accumulation of flammable gasses is quite an issue, as explosions or fires may occur. Additionally, the land near the landfills is not very hygienic, making it an undesirable location to live or set up a business. There is also a capacity crisis, because space for landfills is rapidly decreasing due to growth of population, economic development, and utilization of facilities. (Muttamara et al., 2004) As land space for landfills decreases, the Bangkok Metropolitan Administration (BMA) may have to turn towards other measures of waste disposal, like dumping it into the rivers, which is detrimental towards the environment (Sukholthaman & Shirahada, 2015).

Incinerators are another prominent method of waste management. Only about 1.52% of the properly managed is incinerated (Funatsu, 2019). This is when waste materials are converted into carbon dioxide and water by burning. Other residues include HCI and S. While not all waste is combustible, incineration can nearly reduce the volume of waste by 80-90%, which can be seen to be much more land-effective compared to the conventional use of landfills. (Arvanitoyannis, 2013) While incinerators are seen to have less negative effects compared to landfills, it still releases a significant amount of air pollutants, which harm the environment and human health (Sukholthaman & Shirahada, 2015). These air particles can be ingested both directly, breathing, and indirectly, ingestion and dermal contact. In all cases, there is an increased chance of cancer as well as other health risks. (Watchalayann et al., 2021) In addition to air pollutants, incinerators have a risk of contamination, noise, odor, fire and explosion hazards, vegetation damage, and groundwater pollution. (Arvanitoyannis, 2013)

Recycling is the third option for waste disposal. Around 17.65% of all MSW waste is recycled (Funatsu, 2019). This is when plastics, paper, glass, and other recyclable material are remade into new products. Recycling has a lot of potential, because of its ability to reduce waste. In Bangkok, 10.64% of all municipal solid waste can be recycled. (Sukholthaman & Shirahada, 2015) Currently, there is a well-established system in place for recycling in Bangkok. Collection of recyclable material is done throughout the waste management process: at the source, on the route for collection, and by informal waste collectors (More on informal waste collectors later). The waste collected is usually sold to recycling businesses, who treat the waste properly to sell as raw materials to domestic factories. Although this system has been put in place for quite a long time (since 1987), it remains largely informal due to its inadequate technical support, incentives, laws, etc. Workers are often uneducated on how to handle different recyclable materials properly and safely (Muttamara et al., 2004). Proper recycling has very high profit potential. When waste is managed through conventional labor means, valuable waste, like recyclable material, is often lost due to human error, leading to around $200 billion USD worth of valuables worldwide to be lost in the process. (Gong & Maini, 2023) Quite interestingly, despite having low efficiency in the waste recycling sector, Bangkok's system is seen as much more efficient than some other countries' systems.

Composting, the final disposal option, accounts for approximately 1.82% of waste in Thailand (Funatsu, 2019). This method converts organic waste into fertilizer, suitable for agricultural use, yet it remains underutilized in Bangkok. Despite over half of the municipal solid waste being compostable, challenges such as contamination and low popularity hinder its widespread adoption (Sukholthaman & Shirahada, 2015).

Composting and recycling offer considerable environmental and public health benefits compared to landfills and incinerators. However, the prevalent use of landfills and incineration in Thailand is primarily due to the lack of waste separation and sorting, leading to the loss of recyclable materials and exacerbating the waste issue in Bangkok (White et al., 2020).

Concerns on the Effect of the Current Waste Management System on Workers

Apart from the challenge of waste separation and disposal, the current waste management system significantly impacts the health of waste management workers in Bangkok. In 2021, a study by Sarawut Sangkham, Sakesun Thongtip, and Pornpun Sakunkoo investigated the health issues faced by these workers, specifically those involved in curbside waste collection, segregation, and transportation. The study revealed key demographic details: the average age of workers is 46, with the majority being married (57%). About 49.5% have a high school education, 42.1% completed primary school, and the remainder hold diplomas. Workers typically operate individual shifts lasting around 6 hours, though the timing varies widely. While 56% work from 7 am to 4 pm, 14% work between 12 am and 10 am (Sangkham et al., 2021).

The study highlighted numerous health hazards faced by waste management workers. Presently, 72% of workers reported existing health issues, with 59% experiencing musculoskeletal pain and injuries, including back and neck pain. Additionally, 23% reported respiratory symptoms, and 7.8% exhibited symptoms affecting their head, eyes, and ears. Alarmingly, 3.9% of workers suffered from gastrointestinal symptoms like nausea, vomiting, and diarrhea. Those with over 10 years of experience were 13 times more likely to have significant health concerns compared to those with less than 5 years of experience. These findings underscore the inherent dangers of working as a waste management worker in Bangkok (Sangkham et al., 2021).

Several factors contribute to these health problems. Lifting heavy loads is a primary cause of musculoskeletal injuries, with repeated work posture and overload exacerbating lower back pain (Palarach & Nunbhakdi, 2023). Approximately 72% of workers lift heavy loads over 150 times per day, and falls from garbage trucks also result in injuries. Moreover, workers face chemical and biological hazards in their environment, including exposure to microdusts, microorganisms, and microbial toxins, leading to respiratory, dermal, and gastrointestinal issues. Bioaerosol exposure often exceeds recommended limits, accompanied by increased mold and fungus spores (Sangkham et al., 2021). The improper separation of waste by consumers poses additional risks, including hypodermic needles and sharp objects like glass, nails, and wood shards, which can cause cuts. Industrial and household chemicals, along with biohazards like rotting food waste, used diapers, animal feces, and pathogens, pose substantial risks to workers (Bergmill Supply, 2017). Exposure to high temperatures, waste odor, and infectious waste contributes to heat exhaustion, skin rashes, burns, fever, odor annoyance, anxiety, and stress (Palarach & Nunbhakdi, 2023). Although workers use torn clothes as protective gear, this can exacerbate issues, whereas face masks have proven effective in preventing illness (Palarach & Nunbhakdi, 2023). Additionally, inadequate training leaves workers vulnerable, highlighting the potential for prevention with improved care and education (Sangkham et al., 2021).

Informal Waste Management Workers, 'Salengs'

A distinctive aspect of Thailand's waste management system are the informal waste management workers known as 'Salengs'. Salengs are workers employed independently from the government or corporations. They collect waste and sell it to junk shops. These workers play an important role in collecting plastic and recyclable waste. They receive an average income of 8092 Thai Baht ($266 USD) per month(Archer & Adelina, 2021). Average daily income is around 270 Thai Baht ($7.54 USD), which is lower than the minimum daily wage in Thailand of 363 Thai baht ($9.98 USD) per day. (WageIndicator, 2024) At first glance, 93 Thai Baht, or $2.56 USD, might not seem quite significant. In actuality, 93 Baht can be used for a day's worth of food, or a significant amount of travel, emphasizing the true wealth disparity of Saleng Workers in Thailand when compared to even minimum wage workers.

Salengs have health risks that are quite similar to those of waste collectors. However, the informal waste collectors have identified a few specific health risks as quite common. For example, knee and back pain is quite prevalent, as well as kidney issues due to exposure to chemicals. Albeit much less common, another symptom prominent among Salengs is throwing up blood. Salengs also have various common pre-existing health issues. Salengs often struggle with disabilities, both physical and mentally, blood pressure, and diabetes. Old age is also quite common, further emphasizing the risk of allowing these people to work in such conditions. Despite working in a dangerous environment, the workers often do not wear much protective equipment. This is mainly because the workers believe that the protective equipment has little benefits and is too uncomfortable.

This is quite an issue especially with old age, as minimum protective equipment increases the chances of infection and illness.(Archer & Adelina, 2021)

In addition to these issues, concerns on the environment's impact on the Salengs are quite prevalent. Sun exposure, especially during the dry season can be quite harmful and quite uncomfortable. Similarly, the rain during the rainy season can be quite uncomfortable. While it might not be as harmful as the UV rays during dry season, the rain can hinder the workers' ability to work, effectively hindering their income. During the time of the case study, COVID-19 was very prevalent and dangerous, especially for workers on the streets. Although COVID-19 is no longer a significant issue in Bangkok society, disease and illness will always be a prevalent concern when working with waste. (Archer & Adelina, 2021)

These informal 'Saleng' workers also face social issues. Salengs have testified that they often face fines and warnings due to blocking traffic and overloading trucks. Homeowners often rush workers to vacate the area after donating waste, as if they are not wanted. Additionally, workers sometimes are restricted from entering condominiums or apartments. This can be linked to the contracts between condominium owners and major recycling companies, as they are obliged to provide the waste to the recycling company. Workers are also often suspected of theft. When accused of theft, they simply accept the accusations due to their lacking social status. In general, they're perceived as dirty, worthless, and unsafe despite their importance in cleaning the streets of Bangkok, highlighting the social issues behind this waste management system (Adelina et al., 2021).

Developing an Effective Waste Management System

According to a study by Garrold and Willis there are six primary functions of waste management: waste generation, storage, collection (consumer side), transfer and collection (government side), processing, and disposal (Sukholthaman & Shirahada, 2015). Each function must operate efficiently to establish an effective municipal solid waste management (MSWM) system. However, achieving this in developing countries presents challenges due to the absence of 'appropriate' technology. 'Appropriate' technology, as defined by Pitchayanin Sukholthaman and Kunio Shirahada, refers to technology that is small-scale, low capital, energy-efficient, meets stakeholder needs, flexible in various situations, and aligns with resource allocation capabilities. The use of 'inappropriate' technology often leads to inefficiency and high costs. Therefore, a better waste management plan should delineate responsibilities for waste management, establish goals and objectives, outline waste types and quantities, specify recycling methods, and detail waste transportation and disposal modes (Branz, n.d.).

In Thailand, there are a few concerns regarding these particular functions of waste management. First, there is minimum source separation done by consumers. This is part of the waste storage function of the waste management system. Consumers should be obliged to conduct source separation in order to improve efficiency of the waste management system. However, most citizens do not separate waste properly, if not at all. Additionally, waste is often mixed when collected by garbage trucks, reverting the efforts of those who do conduct source separation. This is another responsibility that the workers are not exactly adhering to. Secondly, the transfer and collection of waste is inefficient. Bangkok's traffic is quite severe and fluctuates throughout the day, directly impacting the garbage truck's ability to reach certain areas on time. Bangkok's routes and destinations are not taken into account, causing efficiency to vary significantly despite going about the same route. Additionally, waste can be dropped or lost during transportation, contributing to Bangkok's litter. Both of these issues influence the efficiency of Bangkok's waste management system. Efficiency of transportation depends quite heavily on chosen routes, amount of waste gathered, transportation distance, collection methods, number of trips, and weight per trip. Each of these variables vary quite significantly, therefore they cannot guarantee the efficiency that is required to ensure a proper waste management system. Of course, fuel and time are costly. The Bangkok Metropolitan Administration currently is spending valuable time and money without guaranteeing a return of investment. The training of workers is also often insufficient, affecting their ability to use the garbage trucks effectively. More prominently, the workers must spend time sorting and recycling waste in between the transportation route, which can slow down the waste management process even further. Finally, as stated before, the ineffective waste processing and harmful waste disposal methods are also prominent concerns towards the health of workers in the waste management of Bangkok (Sukholthaman & Shirahada, 2015).

Factors that Affect Willingness to Pay for a New Waste Management System

To improve the waste management system, it is vital to consider citizens' willingness to pay for and accept a new waste management system. There are various factors that directly affect their willingness to pay for a new waste management system. The cost and benefits of improving the waste management system. When citizens are more aware of the costs, they will be less willing to accept a new system. On the contrary, when citizens are informed on the benefits, they are more willing to accept a new system. In Thailand, people are more likely to comply when provided money as a benefit. However, it should be noted that costs should not be hidden in order to improve overall willingness, as it may cause citizens to be more cautious and have less trust in the waste management system. More details on this will be covered in a later section. Secondly, past behavior is another factor towards acceptance of a new system. Past experiences directly correlate to habits like, for example, the desire to recycle. If someone does not have a habit of recycling, they are more likely to continue this habit. Similarly, if new drastic changes are established, the general public might not be very comfortable adapting to it, especially if it requires large shifts in behavior. Thirdly, perceived convenience. Convenience is a very important factor that affects the acceptance of a new system. Perceived convenience relies on distance, time consumption, and other factors. For example, in Thailand, if recycling facilities were closer to each household, recycling would nearly triple. Similarly, if a new management system appears to be uncomfortable, citizens are less likely to accept the new management system. As stated previously, trust and transparency is quite important. People will not trust the system if the process is not transparent. Similarly, if the government presents their processes transparently and clearly, people would be more likely to comply. People in Thailand seem to have little trust in the current BMA's (Bangkok Metropolitan Administration) waste management system. Finally, having knowledge on how to use the system greatly increases the chances of people using the service. (Vassanadumrongdee & Kittipongvises, 2017)

Autonomous Sorting Systems: Technology and Functionality

Conventional Sorting Methods

The first category of autonomous sorting systems in this section will not include artificial intelligence or digital technology. Instead, the waste will be sorted by manipulating the properties of different materials. The methods presented are courtesy of a review conducted on automated sorting methods for recycling by Sathish Paulraj Gundupalli and others in 2016.

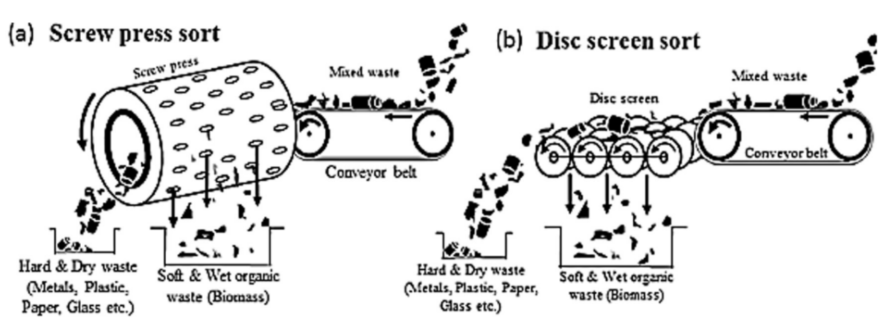

Figure 1. Screw Press sort and Disc Screen sort (Gundupalli et al., 2017)

Figure 1 presents the screw press sort. The screw press sort incorporates a rotating mechanism with small holes. Soft and wet biomass can fit through these holes. As waste is pushed through the screw press sort, the hard and dry waste, like metals, plastic, and glass will pass through the mechanism, while soft biomass will be caught. Figure 1 also presents the Disc screen sort, a mechanism that is quite similar to the screw press sort. Both the screw press and disc screen have the same outcome. However, instead of a large roller, there are multiple discs placed with equal distance between one another. As the waste passes over this disc screen, the biomass will be caught while other waste will pass.

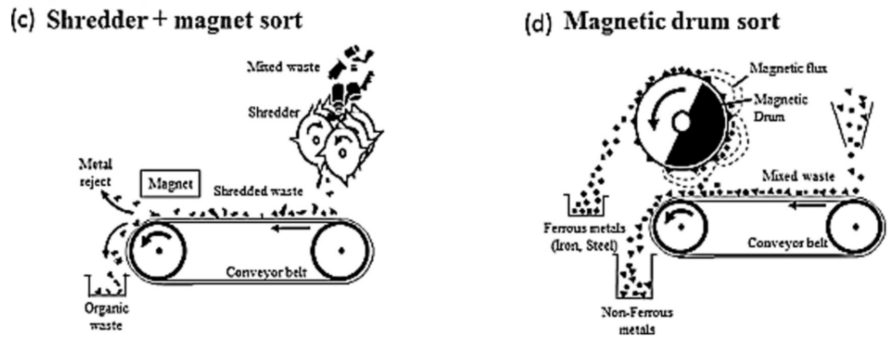

Figure 2. Shredder and Magnet sort and Magnetic Drum sort (Gundupalli et al., 2017)

In the shredder and magnet sort mechanism, as shown in figure 2, the two are utilized on waste that specifically has organic waste and metal. Once the metal-organic waste mixture is shredded, a magnet will pick out metal pieces, leaving the organic waste to be collected. With this technique, 98% of waste is recovered from metallic contaminants. The magnetic drum sort is utilized specifically for ‘ferrous’ metals. According to the Merriam-Webster dictionary, ferrous metals are metals “being or containing divalent iron”. A magnetic drum sort separates ferrous metals from other non-ferrous materials. About half of the circumference of the magnetic drum will be magnetic, attracting ferrous metals to it. The drum will rotate and carry the metals, finally dropping it in a respective container. Other materials will simply pass the magnetic drum.

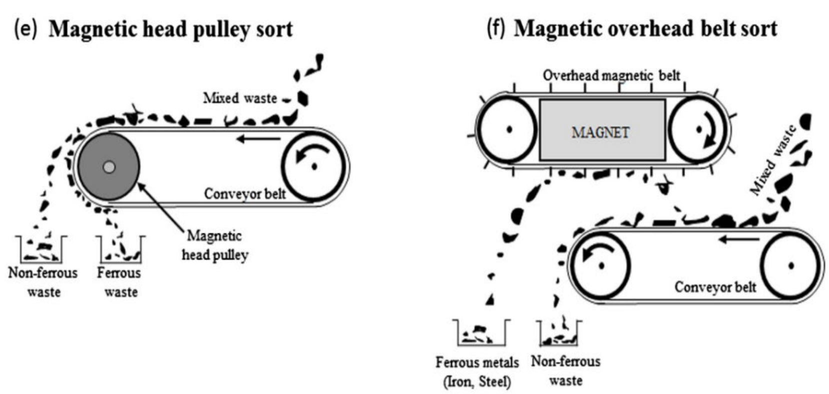

Figure 3. Magnetic Head Pulley sort and Magnetic Overhead Belt sort (Sathish Paulraj Gundupalli et al, 2016)

Both the magnetic head pulley sort and the magnetic overhead belt sort are very similar to the shredder + magnet sort and the magnetic drum sort. As mixed waste is moved via conveyor belt, it is dropped off in two containers. The 'head', or pivot at the end of the conveyor belt, is magnetic, and will attract ferrous waste. Through this technique, magnetic waste and non-magnetic waste will be effectively sorted. The magnetic over-head belt sort is also quite similar. The sole difference is the location of the magnet. The magnet will be placed inside of another conveyor belt separate from the one moving the mixed waste. As the waste passes the magnet, ferrous waste will be attracted towards the new conveyor belt, while other waste will not be moved.

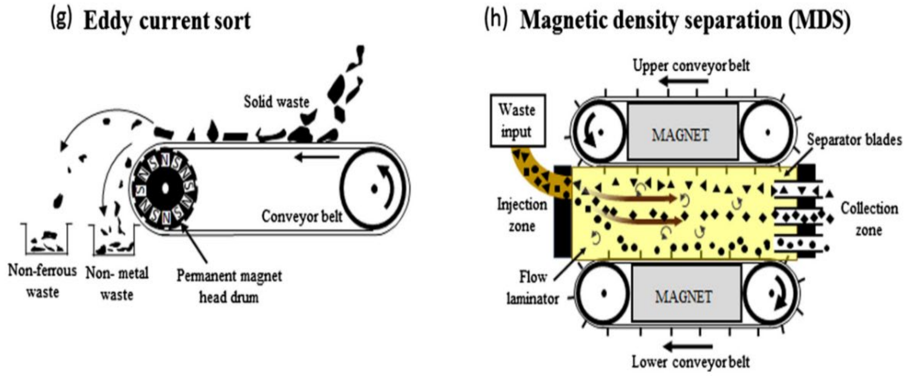

Figure 4. Eddy Current sort and Magnetic Density Separation (MDS) (Gundupalli et al., 2017)

The Eddy current is specialized in separating non-ferrous waste and non-metal waste. Magnetic flux will be created through the use of magnets. This magnetic flux will repel non-magnetic electrically conductive metals from other waste. This technique has a low operation cost and a high degree of purity of recovered metal. However, it's not designed for sorting metals that may become hot in an eddy current field, which may inadvertently damage the separator. The magnetic density separation mechanism has magnetic liquid to separate waste. This mechanism is utilized to separate polymeric materials of different densities. Magnetic liquid, otherwise known as ferrofluid, is a nonmagnetic liquid containing nanoparticles which exhibit magnetic properties (Altmeyer, 2020). This ferrofluid is placed inside of a container. Two powerful magnets will be placed on either side of the container, effectively creating a magnetic field. Magnetic fields reduce exponentially depending on the distance from the magnet. By utilizing this property of magnetic fields, density of the magnetic fluid can vary throughout the liquid. The polymeric materials will float to different levels depending on their density, which is then collected using separator blades seen in figure 4.

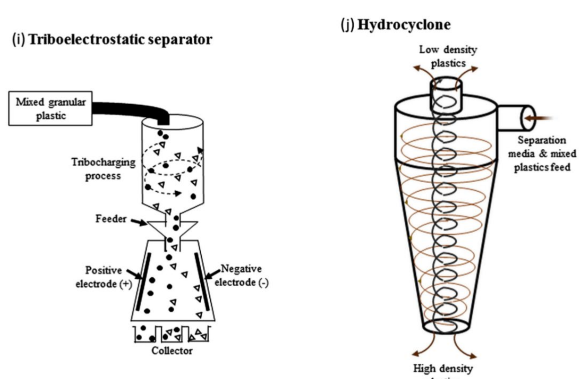

Figure 5. Triboelectrostatic Separator and the Hydrocyclone (Gundupalli et al., 2017)

The Triboelectrostatic separator is used to separate plastics. It uses the phenomenon known as 'contact electrification' or 'frictional electrification'. As plastics pass through a container known as the tribocharging container, contact electrification charges each plastic piece with a certain polarity. After becoming charged, the plastic is put through an electric field. The force acting upon the plastic particle depends on its charge. Hence, the electric field can be tuned to alter the trajectory of each particle to land into its respective bin. A hydrocyclone utilizes the centrifugal force to separate plastics by density. More specifically, Acrylonitrile butadi-ene styrene (ABS), polyethylene (PE), high impact polystyrene (HIPS), and poly vinyl chloride (PVC). plastics with higher density will be released through the bottom, while lower density plastics will exit through the top section of the mechanism.

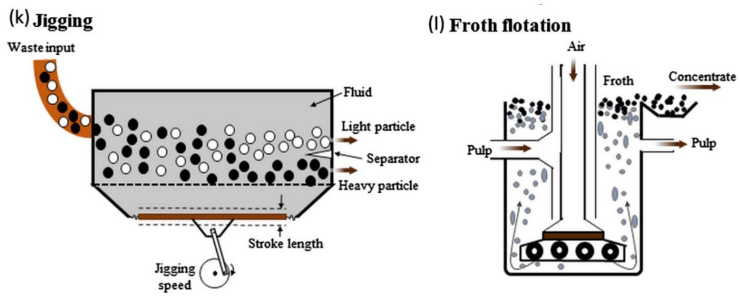

Figure 6. Jigging and Froth flotation mechanism (Gundupalli et al., 2017)

Jigging is another mechanism that separates waste by density. In this case, it works with buoyancy, drag, gravity, and acceleration. A container is filled with liquid. Near the bottom of the container, there is a 'jig' or a mechanism that shakes the waste. When the waste is put into this device, the jigging device will shake, creating a vertical current. Materials with higher density will sit near the bottom, while materials with lower density will rest on top. Froth flotation is a mechanism that separates plastic particles from wastewater. First, fine particles of plastic mixed with water will be placed into the container. Air will be pumped into the container, creating bubbles. The plastic will attach to the bubbles due to the hydrophobic nature of plastic, effectively separating the plastic from the water it was originally in. Finally, an air separator (no diagram attached) is used to recover light, non-metallic material from previous processes. Compressed air is blown onto a collection of mixed waste. Lighter particles will be blown further than heavy particles. This is often used with various bins in a row. When the air is blown onto the waste, the waste will be pushed into its respective bin, depending on its weight.

Overall, these are all processes that are quite reliable, because the properties of different materials will never change. Therefore, if set up properly, the waste will be separated properly. However, many of these machines are required to effectively separate waste. For example, the Eddy current sort would be needed to separate metal, a screw press sort is needed to separate organic waste, and froth flotation is needed to separate plastics. Additionally, valuables in the waste can be damaged through this process.

Use of Artificial Intelligence and New Technology

In a study conducted by Sylwia Majchrowska et.al in December 2021, different variations of waste detection software were tested using various datasets containing images of waste in different conditions and environments. The three main object detection tools used were EfficientDet, DETR, and Mask RCNN. EfficientDet is a newer kind of waste detection from EfficientNet, that mainly involves one-stage detection, which is a kind of detection that involves a single step of detecting regions of interest. One-stage detection is quite popular for image detection software due to their simple yet efficient structure (Tan et al., 2020). DETR (Detection Transformer) is a learning model that incorporates transformer architecture, a system made for natural language processing. Although designed for language processing, the transformer is able to understand complex relationships and dependencies in a spatial setting. DETR mainly works by considering all the objects in an image, and attempting to classify them. The transformer function is effectively able to classify and locate objects in an image, which is quite unique compared to conventional object detection that requires sequential processing (Potrimba, 2023). Mask R-CNN is another newer model that extends Faster R-CNN. The extension is quite similar to DETR. The first stage first predicts regions to group objects. Afterwards, it predicts segmentation masks in different areas of the image in parallel to the classification objects. Mask R-CNN has proven to be much more efficient compared to other conventional object detection due to this multitasking capability (He et al., 2018). The datasets used were Wade-AI, UAVVaste, and TrashCan among others. The results of the study present potential: in a wild environment, the waste detection was successful up to 75%. Most predictions were accurate, but there was a significant imbalance. Metals and plastics were predicted accurately. However, other non-metallic or non-plastic waste were often mislabeled as metals and plastics. The precision of unknown and non-recyclable items detection was 52%, which is quite low (Majchrowska et al., 2021). Litter detection has high potential, as the waste detection models were capable at detecting waste in various environments, even underwater. While the results of the study present great potential in waste management, more development needs to be done in order to work effectively at an industrial scale (Majchrowska et al., 2021).

A possible option for waste management in Thailand is smart bins. Smart bins may be particularly useful in Thailand, because of the general lack of waste bins. Simultaneously, implementing this system may prove to be difficult due to the lack of government programs and public waste clean up projects to monitor these bins. The smart bins system usually is fitted with a camera, a sorting mechanism, and a weighing mechanism. The camera would scan the waste, and put the waste into a designated container inside the bin. The weighing mechanism would be used to measure the amount of waste inside the bin. (Fang et al., 2023) In a study conducted at Cornell by Gary White, Christian Cabrera and others in 2020, the use of WasteNet classification in smart bins were compared with other existing waste classification systems. This study used a dataset known as TrashNet, which contains various kinds of waste (paper, plastic, glass, etc) in different positions, to compare the accuracy and precision of different classification models. The sorting mechanism was not tested. Overall, WasteNet was seen to be more accurate compared to the other classification systems at a 97% accuracy, which is 1.7% more accurate compared to the second most accurate classification system - DenseNet169. (Cabrera et al, June 2020) The precision score was also quite similar: WasteNet classification and DenseNet169 classification indicated 0.97% and 0.954%, highlighting the validity of both models in the context of waste identification.

Another option that implements waste classification models are robots. Robots are being strongly recommended as a method of waste management in the present day due to the potential high efficiency in waste classification and sortation. Robots can come in various shapes and forms, ranging from robotic arms to cars to swarms. Each form could be implementable in certain circumstances, depending on its efficiency. (Fang et al., 2023) However, in the present day, visual and operational technology has proven to be inadequate in complex and unpredictable environments. Visual technology refers to cameras, sensors, and artificial intelligence programs, while operational technology refers to other related technology. The efficiency of this technology is inadequate, and will not guarantee higher efficiency compared to conventional manual labor. Utilizing hyperspectral images to locate target locations is being researched, but there have not been any significant results yet. Hyperspectral imaging is a technique that collects and processes information by using information across the entire electromagnetic spectrum. Objects can be identified by analyzing the spectral signature (variation of reflection and emittance of light from a material). (Specim, n.d) According to research done by Bing Bing Fang and others, Robots are able to cope in complex situations when provided simultaneous localization, mapping technology, and instantaneous segmentation technology. (Fang et al., 2023) Robots have been implemented in collecting construction and demolition waste. The complexity and amount of waste in construction sites can be quite dangerous. Therefore, automated functions have been researched. When deep learning technology like instantaneous segmentation is used, the robots are able to accurately detect demolition waste. (Fang et al., 2023)

Swarms are a specific kind of robot that presents high potential in waste management. Currently, swarms are being researched for foraging. Foraging is the action of exploring and collecting objects or information in an environment. (Alfeo et al., 2018) There are many applications of this, ranging from material delivery to farming. The most relevant application is in waste collection and transportation. Currently, There are two main types of foraging: Multiplace Foraging (MPF) and central place foraging (CPF). MPF has multiple 'nests' or places, unlike CPF's centralized base. While CPF has shown some results in performing simple missions, MPF is much more viable in a dynamic city environment. In a study done in 2019, MPF was compared to the conventional truck system in a simulated city environment. The two main performance metrics were amount of uncollected trash (AUT) and number of full trash bins (FTB). The conventional truck system had a score of 0.212 and 0.202 for AUT and FTB respectively. The MPF system had an AUT and FTB score of 0.061 and 0.0007, which was 71% and 99% lower when compared to the conventional truck system. Hence, the MPF system is much more efficient. (Alfeo et al., 2018) However, research done on MPF is rather simplistic, hence more research must be conducted in order to properly evaluate the validity of a MPF model in our cities. Furthermore, this research is very theoretical, and current technology cannot support a swarm robotics system effectively (Sroka, 2023).

There are some advantages and disadvantages of implementing robots into the current municipal solid waste management system. The main advantages are the increased management effectiveness, increased precision in classification, and reduced labor costs. Robots generally are much more efficient and precise compared to laborers due to the lack of human error. Additionally, labor costs are effectively reduced by using robots (Fang, et al., 2023). However, the use of robots currently is impractical due to its high cost but lacking efficiency. Current technology is not developed enough to guarantee significantly improved efficiency compared to conventional human labor methods (Fang, et al., 2023). In certain situations, our technology is not developed enough to begin prototyping, like swarms. While robotics has shown significant potential in the implementation of demolition waste, more research and development is necessary in order for robots to function properly in a complex city environment.

Predicting waste generation has also become an interesting topic in the field of waste management. Various models have been made to attempt predicting the generation of waste. Models include statistical, machine learning, deep learning, and fuzzy models. Artificial intelligence algorithms are currently considered most advanced and reliable for waste generation prediction due to its unique capabilities, like data inputs, learning capabilities, and predictions. They are quite robust and fault tolerant, allowing the system to run even in times of failure. Additionally, neural networks are capable of understanding complex relationships between various variables, which is quite ideal in a busy city environment like Bangkok (Fang et al., 2023). These prediction models can be quite beneficial. By understanding traffic and waste generation patterns, it is possible to optimize the route for waste transportation, which will cut down time taken and fuel usage, effectively making the waste management system more cost-effective. Reducing fuel usage will effectively reduce carbon emissions (Sroka, 2023). Aside from the general lack of development of neural network models, using these models require high levels of technical ability in order to manage and interpret the AI itself (Sroka, 2023). Hence, while artificial intelligence presents high potential, it is not plausible to implement this method of waste management in the present day.

A Theoretical Model of an Autonomous Waste Management System

A paper by Adil Bashir, Shoaib Amin Banday, Ab. Rouf Khan, and Mohammed Shafi present a conceptual design of an autonomous sorting system. Figure 7 presents a general diagram of their waste management system.

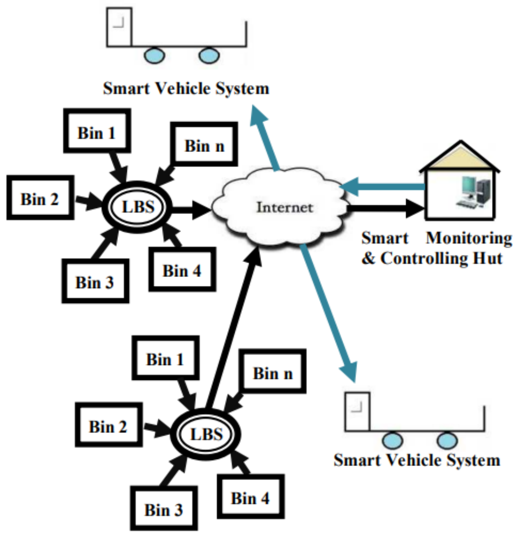

Figure 7. Automated Waste Management Concept (Bashir et al., 2013)

As seen in figure 7, there are four main components of the waste management system. On the consumer side, the main disposal method is specialized smart bins. The bins incorporate similar technology to the designs presented above, but without the artificial intelligence recognition capability. In the bin, load sensors are used to detect the amount of waste. When the waste reaches a certain limit, a RF transmitter will send a signal to the local base station (LBS). The local base station is a RF receiver placed near a group of smart bins that it monitors. When it receives a signal from a particular bin, it sends a signal to the main monitoring/control hub. The control hub or 'hut' will then send a smart vehicle to collect the waste from the smart bin. Tasks and relevant details are stored on the vehicle and presented on a display. A robotic arm attached to the vehicle will place the waste inside a container. After completion, the vehicle alerts the control hub about its status and will move onto its next task (Bashir et al., 2013).

While the concept is highly idealized and not particularly robust, there is potential, as improving the efficiency of waste retrieval is necessary to create a proper waste management system.

Current Services Regarding Resource and Waste Management

Dematics is a materials handling service provider based in the US. They provide technology and software regarding sorting and handling products. Diverter systems control the flow of the items in low to mid-rate conditions. This is done using steerable wheels, right angle transfers, and horizontal belt diverters. Dematics linear sort is another sorting system that uses sliding shoe sorters and steerable wheel sorters. The subsystem of this system is merging (managing incoming goods), induction (minimizing gaps between goods to maximize efficiency), scanning (identifying destination), sorter (sorting mechanism), takeaway (moving items away from the sorter), and the controls (track the items to ensure accuracy). Dematics circular sorters are a split-tray and a cross belt. Its sections include the in-feed (assigning by characteristics), preparation (separating by characteristics), identification (determine destination), distribution (onloading), and discharge (sending to the designated location). The Dematics pouch system is quite different, as goods are stored in pouches before transporting them to the designated location. This is not quite useful in the waste management scene. (Dematic, n.d.)

The Dematics website presents various benefits of their service. Overall, productivity, efficiency, and accuracy increases. This is due to the automation of sorting, reducing human error to the minimum. Product flow can be controlled, and processing time is reduced. The system is scalable and can integrate storage, enhancing customizability of the mechanism. Furthermore, Dematics is presented to have easy reconfiguration capabilities, which allows easy customization for the user (Dematic, n.d.).

The main benefit of Dematics in the waste management scene is its customizability, scalability, and effectiveness. Although Dematics is not made for managing waste, some of its features can be utilized. Sliding shoe sorters can be used to adjust separate larger portions of waste, while a split tray sorter could be used to place sorted waste into its respective bins. (Dematic, n.d.-a)

AMP is a private company that works with automated waste management. Their main focus is to recover recyclable waste through the use of modern technology. Their technology is advertised to be customizable, durable, and efficient even with the roughest loads of waste. They have five main mechanisms. (Dematic, n.d.-a)

The vision mechanism is their main AI vision software. An RGB camera is paired with the AI software, which can identify waste my type, form factor, color, and brand. It is quite effective, as it can easily identify waste moving up to 600 feet/minute. AMP's vision is then implemented with a few different mechanisms. The 'Jet' sortation uses air jets to sort waste. AMP's AI vision first identifies categories of waste. Air nozzles push the material to the target destination depending on its category. Furthermore, the AI vision software is able to track the trajectory of waste and adjust the air nozzles accordingly, effectively achieving a 90+% capture rate of target materials. AMP's microjet mechanism is very similar to the Jet mechanism. The only difference is its compact but effective sortation capabilities, as the microjet can be attached to most conveyor belts, unlike the jet mechanism which requires a specialized setup. The Delta mechanism is also paired with AI vision. Instead of air however, it is a robotic arm with a suction cup that can effectively pick out certain waste. AMP's VAC mechanism does not use AI vision, but it solves the issue of flexible film causing entanglement and clogs in automated waste management. The VAC mechanism is a row of air pipes that are constantly intaking air. The plastic film is meant to be sucked up, while other, heavier waste remains on the conveyor belt. This mechanism can be mounted onto most existing conveyor belts, and can collect up to 120 pieces of plastic film per minute, which is nearly 5 times as effective as conventional human workers (AMP, (n.d)).

Each robot from AMP is estimated to be around 300k USD, which is much cheaper in comparison to the standard price of robots in 2020 (Gong & Maini, 2023). AMP robotics presents the potential of implementing robotics into waste management. However, although AMP's robots present high accuracy, more research could be done in order to improve its efficiency.

Case Studies of Potential Waste Management Solutions

Smart Bins in Sutton

Smart bins were tested in Sutton, UK, in 2019. 21 standard litter bins were replaced with 10 smart bins. The bins do not implement a waste scanner. Instead, there is a fill-level sensor which tracks fill level, temperature, location, and orientation of the bin. In some bins, solar power panels were implemented to power a crushing mechanism. This mechanism would compress waste, allowing the bin to hold 10 times more waste than in a normal situation. The bins with crushing mechanisms were used in high footfall areas. All of the smart bins would include a fill-level sensor that would send updates about the smart bin to a centralized hub. A garbage truck would only pick up the waste when the bin indicated that it was full. After four weeks, there was a 90% reduction in collections (number of times a garbage truck went to collect waste) and over 43,000 liters of waste collected (Sutton Government, n.d.).

The government of Sutton noticed a few advantages and disadvantages of the smart bins.

First, the use of solar powered compact bins were able to effectively maximize the capacity of bins. Waste bins that are full were immediately emptied, reducing the number of overflowing bins on the streets significantly, which improved public hygiene. Furthermore, waste is only collected when the bin is full, optimizing waste routes, reducing fuel usage, and reducing greenhouse gas emissions (Pryce, 2023). Due to the smart bins' effectiveness, the required number of bins were also reduced, improving the streets visuals and hygiene (Sutton Government, n.d).

However, smart bins still have disadvantages. Due to the heavy reliance on technology, the waste management system could easily be disrupted if a component fails. Additionally, the cost of implementation is very high, judged to be around £250,000 on only 51 bins in Manchester city. Traditional bins are much cheaper in comparison. Smart bins reduce the need for human labor, which leads to unemployment. People may be unhappy with using smart bins due to this fact. Smart bins are also only practical in areas with high footfall and waste production, which may lead to a lack of waste disposal methods in certain areas of the city. This may effectively cause more littering (Pryce, 2023).

Automation of Waste Management in Waste Treatment Facilities in Japan

In Japan, JFE Engineering announced the full automation of operation at an incineration plant through the use of AI. Previously, waste management through incineration in Japan was widely automatic, but due to the complexity of the waste being managed, they required an operator to monitor and intervene with the waste management process when necessary. However in 2018, JFE was able to reduce the need for a manual operator by 100% (JFE Engineering Corporation, 2019). They used combustion images accumulated from the workers' operation data to train the AI. With this data, the AI's precision improved signifcantly, allowing the incineration plant to achieve full automation. Life cycle costs were effectively reduced (Onoda, 2020). Additionally, combustion was more stable, steam generated became more stable, which improved the amount of energy generated using this steam (JFE Engineering Corporation, 2019).

Application of Dematics in a Variétés Pierre Prud'homme Inc. company

Variétés Pierre Prud'homme Inc is a family owned distributor for various retailers across Canada. They manage the inventories of a variety of products, and are known to distribute products in a timely manner and exceptional service. Variétés Pierre Prud'homme Inc's success allowed them to increase size of operations to a larger facility. Although the facility size allows them to manage more products simultaneously, it would be a challenge to work at this scale. Variétés Pierre Prud'homme Inc decided to use Dematic Voice-Directed Piece Picking workflows, a workflow that uses voice and RF-scanning verification. This system improves productivity without the need for extra training or space, which can be quite useful. The workers would have a headset, which would receive verbal instructions. The warehouse of Variétés Pierre Prud'homme Inc is designed to have single orders fulfill multiple orders. Through the use of Dematics, worker productivity increased by 40%, and operators of the sortation system are able to pick 20% more orders a day. The high productivity and low error of Dematics workflow allows Variétés Pierre Prud'homme Inc to work at much larger scales effectively (Dematic, n.d.-b).

Conclusion

Bangkok has gone through various social and economic development, which has benefited Thai citizens in a variety of ways. However, with these improvements come downsides such as outdated waste management solutions that can only effectively sort and properly treat about 30% of the waste collected, this leaves about 70% of the waste collected not effectively sorted therefore causing harm to the environment and people working. In addition to sorting collected waste, due to the lack of publicly available waste bins to accommodate the growing population, around 23% of the waste is littered and not collected. Of course, no single solution will provide benefits in all angles. However, the Bangkok Metropolitan Administration should work towards implementing automated waste management throughout the entire process therefore increasing the amount of waste sorted. Autonomous waste management solutions provide a safer environment for workers as well has efficiently sorts and processes waste. This study provides numerous solutions ranging from sorting systems, AI-driven technologies as well as case studies of other waste management options. Just like in Sutton, smart bins could be placed in high-density regions to ensure waste stays off the streets. Different robots and mechanisms like AMP can improve the efficiency of waste collection and separation, while the development of artificial intelligence can support the accuracy of waste identification. While other legal changes should be made to support the clean up of modern waste problems more effectively, utilizing the proper and novel technology is essential towards creating a robust and efficient waste management system.

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