Enhancing the Facilities that Protect the Planet: Sorting Facility Optimization from Beit Mery to Kfarhazir

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Abstract— **Lebanon has a bad history of waste management systems that depend on dumping trash in landfills; to end this cycle, the use of sorting facilities to recycle our waste is necessary. Due to the importance of these entities, we decided to base our final year project on tackling the inefficiencies that plague these facilities.** ***The main purpose of this paper is to study and understand the process and inefficiencies of sorting facilities, which would enable us to design an optimal one.*** **Our first phase focused on understanding the problems present in the sorting facility. We compared current working conditions to ergonomic standards and suggested solutions to be implemented. We also conducted time studies on tasks to identify problematic ones that could be improved. Our second phase consisted of designing an optimal facility and supply chain by using three industrial engineering tools. First, we enhanced the old layout by using facilities planning techniques. Compared to the old layout, we got an increase of 48.4% in the adjacency score and a decrease of 25.7% in the distance-based objective. Second, we tackled the vehicle routing problem associated with the pick-ups of trash where we created a linear program. We identified the optimal route which resulted in an 8% decrease in time, money, distance, and carbon footprint. Third, we identified the most feasible recycling facilities to collaborate with while optimizing the drop off schedule of recyclables. Finally, to wrap everything up, we simulated the original and the improved systems to show the impact of our proposed modifications.**

Keywords—sorting facility, solid waste management, ergonomics, time studies, facilities planning, lean technologies, routing, inventory control, discrete event simulation.

I. Introduction

The Lebanese garbage crisis began back in 2015 when the Na'ameh landfill was abruptly closed by the government without a contingency plan in place, which resulted in the excessive accumulation of trash (Rsaleh, 2017). Given that 70% of Lebanese waste is organic, it was imperative for the government to shift away from incineration and garbage burial, which is not compatible with the Lebanese type of waste (Galer, 2018). To better manage this waste, a number of municipalities across Lebanon opted for a sustainable waste management system that relies on a liaison between households and recycling facilities: ***municipal sorting facilities***. During this critical period, municipalities and private companies worked together under extreme conditions and in a short period to build sorting facilities; the end results were haphazardly built, unsustainable facilities. The Beit Mery (BM) sorting facility built by Cedar Environmental is a prime example, it was built in the span of three months on the location of the Monteverde former dump site. Upon visiting the facility, we noticed it was plagued with inefficiencies that resulted in wasted time, space, and money, as well as poor working conditions. Given that the BM sorting facility would soon become obsolete due to its unsustainable infrastructure, we searched for alternative accessible villages in Lebanon that were interested in changing their waste management systems. The Mayor of Kfarhazir, which is a small village in Northern Lebanon, was excited about the prospect of better managing their waste. Therefore, we were compelled to study the inefficiencies present in the unsustainable BM facility and to develop optimization strategies to be implemented in Kfarhazir whilst leveraging industrial engineering techniques. We hope our project will encourage the Municipality of Kfarhazir to implement our optimal result to contribute to a cleaner and zero-waste Lebanon. We are ultimately *optimizing the facilities that protect our planet*.

II. Goals and Obejctives

A. Objective 1

Study the process and inefficiencies of Beit Mery sorting facility.

- *Aim 1:* Pinpoint process inefficiencies
- *Aim 2*: Identify areas of improvement in the current working conditions
- *Aim 3:* Determine complex bottlenecks, sources of inefficiencies, and crucial performance measures for the BM sorting facility

B. Objective 2

Design an optimal sorting facility in Kfarhazir based on the Beit Mery sorting facility

- *Aim 1:* Design a new layout with the feasible and relevant lean technologies in place.
- *Aim 2:* Optimize trash pick-up routing and inventory of recyclables to save time, money, and resources.
- *Aim 3:* Compare the performance measures of optimal layout to the previous one to calculate improvements.

III. Background

In order to garner a better understanding of the inefficiencies and formulate strategies to resolve them, we identified five industrial engineering concepts that are necessary to be examined: (A) Ergonomics; (B) Time studies; (C) Lean technologies and facility planning; (D) Routing and inventory control; and (E) Discrete event simulation. This literature review will provide a conceptual base for the aforementioned topics.

A. Ergonomics

To ensure that workers perform to the best of their abilities, they require **adequate working conditions** that will amplify their productivity (Fisher, 2017). Some of the risk factors derived from this work environment include lifting heavy objects, lack of proper equipment, and managing multiple jobs. As a matter of fact, recycling employees are often prone to *musculoskeletal disorders* (MSDs), with 33% of all worker injury and illness cases related to MSDs ("United States Department of Labor," 2013). These employees are also susceptible to many other hazards including improperly disposed needles resulting from home medication and laceration risks from sharp objects and broken glass (Graham, et al., 2015). Employees are also subjected to respiratory hazards, extreme temperatures, fatigue and noise. The sorting facility in BM exposes its workers to the majority of the risks previously outlined. Applying ergonomics studies to the facility can not only tremendously reduce the risk factors that the employees are exposed to, but also greatly improve productivity and add value to the entire supply chain.

B. Time Studies

To be able to identify and analyze inefficiencies and irregularities in the sorting facility process, it is crucial to set a standard method and extract the standard time. Waste, specifically unnecessary motion, which is one of Taiichi Ohno's seven different waste categories, can be identified and avoided with the help of a basic scientific management tool: time studies (Jasti & Kodali, 2015). A time study, a main lean tool, is the observation of tasks and the recording of the time taken to complete these tasks (Chauhan & Shah, 2019). By dividing tasks into elements and deriving the standard time, companies can then define the threshold performance level and the fatigue threshold level of an employee (Gusmon & Hutomo, 2019). These studies can be carried out as a starting point to help organizations in reaching necessary decisions regarding improvements towards inefficiencies and wastes. The extracted standard time is also a necessary input into the simulation model that would allow us to identify more complex bottlenecks that are hindering the optimality of the facility as well as key performance measures.

C. Lean Technologies and Facilities Planning

Technology has become an integral component underlying every system. It is imperative that facilities adopt lean tools and technologies to reduce wasteful consumption of resources such as time, money, and human capital whilst ensuring a seamless operation. It is vital for waste sorting plants dealing with municipal solid waste, to utilize a range of separation techniques; like air separators, magnets, eddy currents, advanced sensor technology, and Kanban systems (McKinnon, Fazakerley, & Hultermans, 2017). However, it is not compulsory to use all the technologies at our disposal; the configuration of the sorting line depends on the type of waste as well as the material that is causing the most bottlenecks in our system. Specifically, in emerging economies such as Lebanon, lower tech solutions may be more practical and feasible given the labor costs and the capacity of the facility (Gundupalli, Hait, & Thakur, 2017). After identifying the bottlenecks and deciding on the technology that is to be integrated, the next step is to design the facility in a way that improves the performance of the sorting line and significantly reduces the operational costs (Kovács & Kot, 2017). This is where Facilities Planning comes in; it is concerned with the locations of different departments and the material flow between them to minimize the total distance of goods flow, the material handling cost and the time spent in the sorting system.

D. Routing and Inventory Control

To guarantee a smooth transition between different components of the supply chain, modeling the optimal pickup of waste and drop off of recyclables is necessary. The vehicle routing problem's (VRP) main objective is to ensure that the total pickup amount does not exceed the capacity of the vehicle and to minimize costs by taking operational constraints into consideration (Juliandri, 2018). Another important component of the supply chain is inventory management, which is used to enhance operations related to the effective flow of goods (Aro-Gordon & Gupte, 2016). Inventory management is observing supply (municipal solid waste) and storage (recyclables after sorting) in order to decide on the optimal time to send out the recyclables to their respective recycling facilities. Therefore, creating a linear program that minimizes our cost objective function to model the Kfarhazir pick-up, inventory, and recycling drop-off dilemma would yield the optimal solution.

E. Discrete Event Simulation

To link things together and compare performance measures of the BM facility to the new Kfarhazir facility, a simulation model is needed. Discrete event simulation is used to predict, plan, change, and compare a new system to an already existing one via a virtual model (Gamarra, et al., 2017). A simulation model for a sorting facility in Brazil gave management a better understanding of their operations; ultimately ensuring better resource utilization, layout, and results regarding efficiency in sorting the materials. It also allows managers to see how changing the number of workers on a certain task could affect speed and efficiency which would then help managers make decisions.

IV. Methods

We conducted a root cause analysis using an ishikawa diagram to identify the main issues that plague the BM sorting facility. We found that the **methods**, **machines**, **manpower**, and **materials** categories are the major factors leading to inefficiencies. This study pushed us to focus on the five industrial engineering concepts that were discussed in the background section.

A. **Objective 1, Aim 1:** *Flow Diagram and Time Studies*

We created a flow diagram to design and document the process within the sorting facility. First, the truck arrives at the facility where it is weighed on a weighing platform. Then, the truck goes inside the facility and dumps the trash in the holding area. A worker moves the trash bags onto the inclined conveyor belt and rips them open. After that, a few workers are also tasked with ripping the bags to ensure that each item of trash stands on its own for when it reaches the plateaued part of the conveyor belt that is specific to sorting. Workers sort the trash in the bins located to the front of them based on PET plastic, aluminum cans, tin metal, green glass, transparent glass, and textiles. Once these bins reach their capacity, they undergo packaging processes to be stored in inventory and then sent to recycling facilities. Biodegradable material remains untouched and moves on the conveyor belt until it enters the composting tube. Non-PET plastics are thrown to the conveyor belt that is located behind the workers that moves in the opposite direction and leads to a separate bin. The non-PET plastics are then sent out to the plastic shredder before being transported to the eco-board factory.

In order to implement time studies in a fruitful way, we decided to tackle two tasks that would make the most out of this scientific management tool. The first task entails sorting trash items into their designated bins. We divided this task into three jobs: sorting normal trash, sorting non-PET based plastics, and sorting compostable materials (Jobs 1, 2, and 3 respectively). All three jobs have the same first element; opening the trash bags until the trash items get to the second belt. The second element starts when the trash item touches the second conveyor belt and ends when it reaches its bin. What differentiates the jobs from one another is the distinct endpoints, which results in different times for element 2. One thing to note is that compostable materials remain untouched after reaching the second conveyor belt, thus the average time depends on the conveyor belt's length (1200 cm) and speed (40 cm/s), making it constant at 30 seconds. The second task includes compressing the sorted PET plastics into a cube, which is also divided into three jobs (Jobs 4, 5 and 6). Job 4 is divided into two elements with the goal of preparing the base of the cube with plastic straps and cardboards. Job 5 is divided into two regular elements and one irregular element, pertaining to filling the machine with bottles and compressing them. Job 6 is comprised of adding cardboard on top of the compressed pile and connecting the base with plastic straps. We performed a pilot study to determine the optimal number of cycles needed for each job using $\alpha = 0.05$ and k = 0.05:

$$n = \left(\frac{\mathrm{T} \times \mathrm{S}}{k \times \bar{X}}\right)^2 \tag{1}$$

After calculating the average elemental times of our six jobs, we rated the performance of the operators using the Westinghouse system. We then applied those ratings to our average elemental times to get the normal times of each job. Finally, we allocated allowances in accordance with the International Labor Organization's standards. Finally, adding the allowances to the normal time, we get the standard times of each job.

B. **Objective 1, Aim 2:** *Ergonomics*

We identified many violations of the Occupational Safety and Health Administration (OSHA) standards when visiting the facility. We listed four major problems, their consequences, the relative OSHA rules, and the solutions proposed to improve the working conditions and ensure the safety of the employees. For example, concerning the workers that are exposed to MSDs we suggested having adjustable conveyor belts so that 90% - 95% of the workers are able to use it while minimizing reach requirements.

C. **Objective 2, Aim 1:** *Facilities Planning*

Using the sorting facility located in BM as our base, we were able to design an optimal layout to be implemented in Kfarhazir. The main goal was comprised of two parts, the first was to maximize the utilization of space and equipment and the second was to minimize the cost, all while providing safety to the employees. Following Murther's Systematic Layout Planning (SLP) procedure, we found that the BM facility follows a process layout in which the machines are grouped together by function. We then created an activity relationship diagram (RD) which allowed us to draw the RD by positioning the activities spatially. The different link types of the diagram were based on the relationship strength between pairs of activities. Based on space availability and requirements, we built the space RD to assign the amount of space to each activity. After modifying considerations and practical limitations, we reached four layout alternatives. To pick the most optimal one, we used two different algorithms:

The distance-based objective that aims to minimize the sum of flows multiplied by the distances:

$$\min z = \sum_{i=1}^{m} \sum_{j=1}^{m} f_{ij} c_{ij} d_{ij} \tag{2}$$

The adjacency-based objective that aims to maximize the adjacency score:

$$\min z = \sum_{i=1}^{m} \sum_{j=1}^{m} f_{ij} x_{ij} \tag{3}$$

Once we found the most optimal layout for Kfarhazir, we followed the same steps to calculate the objectives for the layout in BM and compare the two. We are also looking at adopting technologies that facilitate the compression and separation of non-PET plastics, taking into account the cost-benefit analysis with respect to the size of our facility.

D. **Objective 2, Aim 2:** *Vehicle Routing Problem and Inventory Control*

The municipality of Kfarhazir collects trash from dumpsters three times per week, resulting in 15 tons of trash collected per week. The truck driver and two other part-time workers take a random route to collect the trash, it takes them two rounds to transport all of the trash to the designated landfill due to the 4.5 ton capacity of the truck. It takes workers 2.5 hours to collect three tons of trash without the time spent driving, we simplified this to three sec/kg of trash collected. Since inefficiencies resulted in increased cost, time, and carbon footprint, we solved the VRP to get the most optimal route for the collection of trash.

Our interview with the Mayor of Kfarhazir, Mr. Fawzi El Maalouf, provided us with all the parameters needed to input into the VRP. The village consists of 403 households and seven dumpsters. One of the basic requirements that a sorting facility needs to have is *fresh trash*: the trash's value decreases the longer it is left unsorted. That is why we decided that trash should be collected on a daily basis to the extent feasible (workers do not work on Sundays). Tuesdays through Saturdays are considered regular days and Mondays are considered irregular days because Saturdays' and Sundays' trash are picked up on Mondays.

To optimize the entire supply chain of the waste management system in Kfarhazir, we must also focus on the inventory control and drop-off of packaged recyclables to the respective recycling facilities. We will perform a cost analysis to evaluate the alternatives of recycling facilities; which will be accomplished using a linear program. We will also set up an inventory control model to help us identify the optimal schedule to send out recyclables; the holding cost will be determined by factoring in rent of the land and the opportunity cost.

E. Discrete Event Simulation, ***Objectives 1&2, Aim 3***

In order to link all of our findings of the BM facility, we created a simulation model using the program Arena. We first tackled the arrival process, in which we noticed that there was not **one** underlying distribution for truck arrivals, this pushed us to look at each driver separately. Looking at peak days and at individual drivers, we were able to prove that each driver arrives based on a Poisson process; this led us to the conclusion that arrivals follow a ***non-homogeneous*** poisson, wherein each driver has his/her own schedule. After identifying the arrival process, we were able to build the entire system and introduce trash as an entity, where we were able to assign a distribution for the amount of trash on each truck. We proceeded to add the processes such us weighing the trash, emptying the trash in the designated area, and dragging the trash to the conveyor belt to be opened. We added a decide module that would differentiate between the types of trash (we got the percentages from the output of trash given that 70% of Lebanese trash is organic). We built the remainder of the process making sure to incorporate the threshold of the bins, which when at capacity would shift towards the processes of compression or packaging. At the end we added a record module in order to measure the output of recyclables. To compare the BM facility to the Kfarhazir facility, we must also build a simulation model for the latter. It will be built in a similar way but utilizing the new and improved generated layout and process. The comparison's purpose is to show how the modified aspects of the new system will impact the system as a whole.

V. Results

A. Time Studies

Based on the formulas and techniques mentioned in the Methods section, we were able to calculate the average elemental, normal, and standard times for our two tasks that are presented in Table 1.

Table 1: Time Studies Results

	Tasks					
	Trash Sorting			***Plastic Bottle Compression***		
Jobs	1	2	3	4	5	6
Cycles needed | Cycles collected	198 | 62	158 | 62	49 | 62	17 | 4	16 | 28	10 | 4
Average Elemental Time (sec)	27.51	36.5	18.93	84.25	155.03	257.25
Normal Time (sec)	28.61	37.96	19.69	85.93	158.13	262.39
Standard Time (sec)	34.91	46.31	54.02	100.5	185.01	307.01

B. Ergonomics

Upon monitoring the workers, we noticed a plethora of problems that violate the health and safety standards and put workers at risk. During their 12-hour work shift, workers perform repetitive tasks such as opening and sorting the trash. They also bend, reach far, twist, and push heavy bins. These activities may result with MSDs and stiffness in the neck and shoulders. The permissible noise exposure for an eight-hour shift is 90 dB which is equivalent to an acceptable level of 87 dB for a 12-hour shift based on a five-dB exchange rate (OSHA, 2006). In our case, workers are exposed to 107.7 dB during their 12-hour shifts. This high intensity level could result in hearing loss, headaches, and poor performance due to stress. Workers do not wear face masks and safety glasses, which puts them at risk of the flu, asthma, lung cancer, and having small particles come in contact with their eyes. We also noticed that trucks frequently come into the facility and workers are standing all day, which puts their feet at risk; especially when they are not wearing safety shoes. All of the major problems listed could be substantially reduced by applying ergonomic principles (OSHA, n.d.). We came up with several solutions such as using adjustable conveyor belts, avoiding below knuckle height reaches, eliminating awkward postures, designing the job to reduce hand forces and repetition, and providing seats if necessary. Workers should wear masks, gloves, and hearing protectors, and employers should invest in less noisy equipment. Since we are building a new facility, these solutions are feasible and will increase productivity and maintain worker health.

C. Facilities Planning

After performing the SLP procedure, we were able to calculate the distance and adjacency-based objectives for all the alternative layouts; results are presented in Table 2.

Table 2: Facilities Planning Results

Layout	Distance-based objective	Adjacency-based objective
1	195.5	46
2	208.75	46
3	222.25	32
4	227.5	42

Based on the results, the maximum adjacency-based objective as well as the minimum distance-based objective corresponds to layout 1 making it our chosen optimal layout design. Compared to the BM layout for which we got a distance-based objective of 263 and an adjacency score of 31, we can conclude that the chosen Kfarhazir layout is optimal.

To enhance the layout even further, we referred back to our time studies and we found that the compressing and wrapping procedures had the lengthiest standard time. Hence, we decided to incorporate automated compressing packaging machines. As for the safety of the workers, we will also be integrating a ventilation system.

D. Vehicle Routing Problem

The average weight of trash collected from each household on a regular day is 5.32 kg and on an irregular day is 10.64 kg. We also deduced the weight of trash that is present in every dumpster on regular and irregular days based on the number of households in areas with close proximity to the dumpsters (while remaining mutually exclusive). Using AMPL, we obtained the following optimal route for the collection of trash from the dumpsters: Municipality → 1 → 3 → 4 → 6 → 5 → 7 → 2 → Sorting Facility. The only variable from one route to another is the distance driven (time spent driving assuming constant driving speed of 30 km/hour meaning 0.12 sec/m). This specific route takes 770 seconds to be completed without the pickup time on regular and irregular days, leading up to a total of 77 minutes per week. Taking a random route, with the old routing system (three days per week), Municipality → 6 → 7 → 3 → 5 → 1 → Sorting Facility → 2 → 4 → Sorting Facility, takes 28 minutes leading up to a total of 84.55 minutes per week leading to an 8% time decrease.

E. Work in Progress

The inventory control section is still a work in progress, we are in the process of writing the Linear Program and building the inventory system.

VI. Discussion

The proper research that commenced at the preliminary stages of our FYP and proceeded till the very end, enabled us to derive the maximum amount of value from our findings.We tackled the first objective which focused on studying the process and inefficiencies pertaining to the BM sorting facility by using the methods of time studies and ergonomics. Using time studies, we were able to extract the standard times for the sorting and packaging processes. We noticed that the packaging processes were lengthy and labor intensive; this pushed us to look for feasible technologies to implement that would facilitate this process. Not to mention that, all of the extracted standard times will be inputs to our simulation which would allow us to derive even more value. Regarding ergonomics, once management implements our proposed suggestions, MSDs resulting from physical overexertion, other safety hazards, and their associated costs, can be substantially reduced (OSHA, n.d.). In order to design the optimal sorting facility in Kfarhazir we needed to use facilities planning and VRP approaches. In terms of facilities planning, when comparing the existing BM facility to the chosen Kfarhazir layout, we got a 48.4% increase in the adjacency score and a 25.7% decrease in distance-based objective which are both major improvements because we want the different departments to be as adjacent and as close as possible. Our new routing system resulted in an 8% decrease in cost, time, and carbon emission. It may seem like a small percentage of improvement, but when scaled up to the entirety of Lebanon, then an 8% decrease in cost is quite significant. It will result in 404 grams of carbon dioxide emitted per mile driven, which is equivalent to saving 43 kg of carbon dioxide per year in Kfarhazir (United States Environmental, 2018). It is important to note that in the design of the new and improved facility in Kfarhazir, we will perform a full-fledged economic feasibility study that would ensure a positive return on investment. We faced numerous limitations mainly due to the current situation in Lebanon, which hindered our access to AUB labs, the facility, and meetings with different mentors and industry partners. If we were to expand our work even further, we would delve deeper into the technicalities of the sorting process and look at it from a quality control point of view. We would also look into designing more facilities in Lebanon and study the impact of it on a nation-wide scale.

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