Improving Waste Collection & Transportation System at Tadweer

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Abstract

Tadweer is the central waste management service provider for the emirate of Abu Dhabi, which sustains a dilemma in handling municipal and commercial waste collection and transport primarily at the emirate's congested districts including, Al Khalidiyah and Al Zaab. The conventional approach pursued by Tadweer during solid waste collection and transport in urban sectors encounters prolonged lead time. Inefficiency in the management of solid waste is exacerbated by desegregation of wastes, overdue waste disposal in bins, non-optimal routing and lack of awareness by the public. To evaluate the efficiency of the system, factors such as collection routes, transport distances, the number of vehicles to be employed will be examined thoroughly to improve the process. Accordingly, methodologies of Six Sigma, Project Management, Design of Experiments and Logistics will be utilized to improve the performance of the processes and maintaining the required standards of health and safety. Furthermore, simulation technology will be employed to enable scenario analyses as well as improvements testing for a proficient and sustainable collection and transportation system.

Keywords

Lead time	The amount of time between process initiation and completion.
Design of experiments	An experimentational practice to determine the cause-and-effect relationship between given factors and a response variable.
Response variable	The effect or outcome in an experiment.
Bottleneck	The constraint that limits or slowdown the overall result of the whole process.
Anomalies	Are unusual cases that do not appear to fit the general patterns present in the dataset.

1. Project Overview

1.1 Problem Statement

Tadweer is the central waste management service provider for the emirate of Abu Dhabi, which sustains a dilemma in handling municipal and commercial waste collection and transport primarily at the emirate's congested districts. The conventional approach pursued by Tadweer during solid waste collection and transport in urban sectors encounters prolonged lead time. Inefficiency in the management of solid waste is exacerbated by desegregation of wastes, overdue waste disposal in bins, nonoptimal routing and lack of awareness by the public. These factors significantly increase operational cost and subsequently reduce revenue generation, as well as result in undesirable environmental pollution.

1.2 Goals and Objectives

In accordance with the meetings conducted with the client, the aim of this project includes the following relevant and measurable objectives:

- Reduce lead time of the waste collection process and transportation system.
- Reduce operational costs associated with collecting and transporting waste.
- Reduce total CO_2 emissions of the waste collection process.

An objective tree is depicted in Figure 1 and was developed to better understand the process of waste collection in the designated sectors.

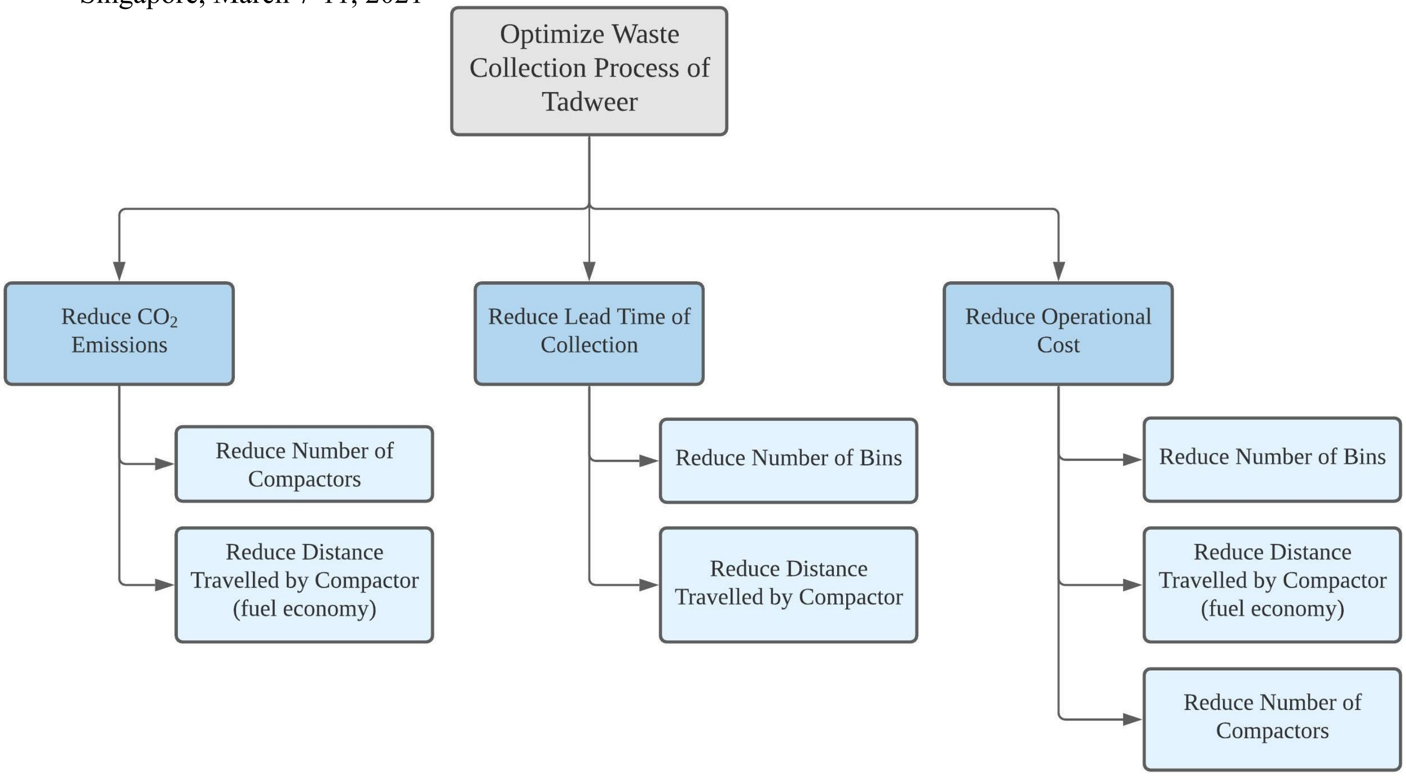

Figure 1: Objective Tree

2. Methods for Developing and Evaluating Concepts

2.1 Process Flow Map

The map generated involves three main roles consisting of the compactor, worker/s and operations. Each step in the sequence is noted with a diagram shape and is linked by connecting lines and directional arrows to other steps. The flowchart uses special symbols to represent different types of actions and steps in a process. For instance, the symbols oval, rectangle, and diamond, represent a terminal where the process starts/ends, an activity or task, and a decision point, respectively. Other symbols such as the ones colored in, pale blue, sea blue and dark blue represent an input/output step, a document, and a database, respectively. Lines and arrows show the sequence of the steps and the relationships among them.

Initially, the operations centre at Averda defines a route for the collection vehicle to follow. The collection shifts differ from one sector to another, once the shift time starts the collection process is initiated. Accordingly, the driver of the designated vehicle follows the planned route, reaches the desired destination, collects the waste and heads back to dispatch the waste at the landfill.

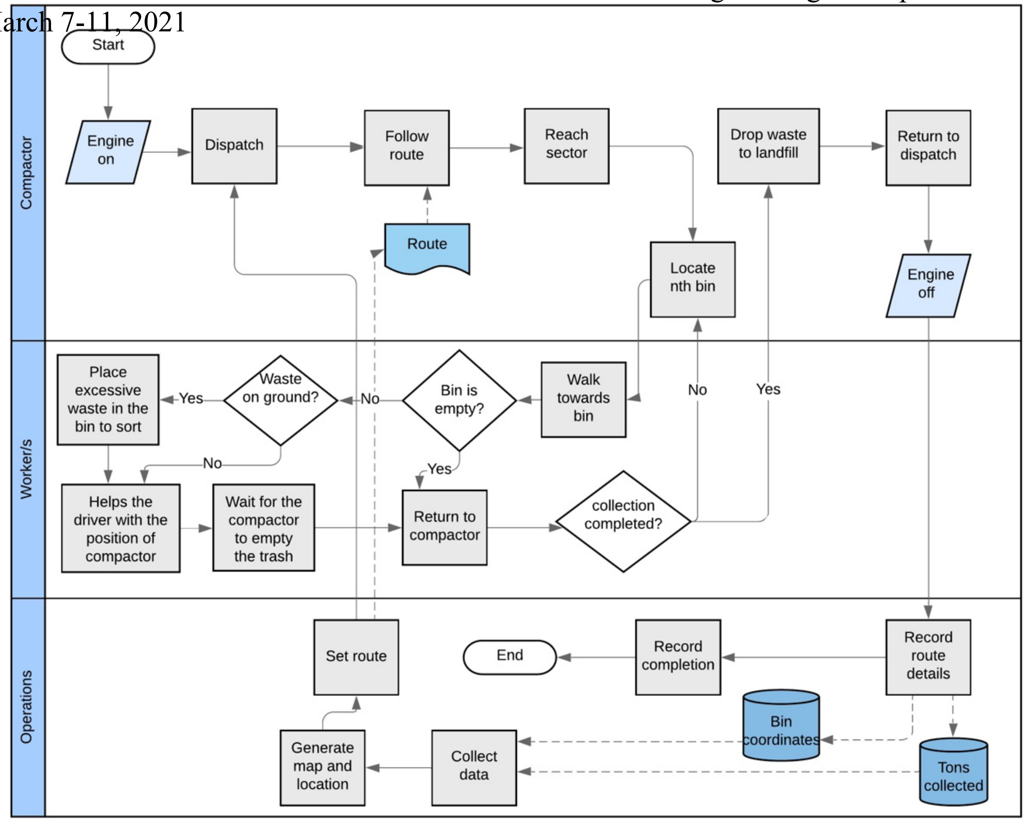

Figure 2: 240 L Bins Collection and Transportation Process

Figure 2 illustrates the flowchart of the waste collection process corresponding to the 240 liters bins collected by a rear loader compactor. The process starts when compactors start the engine to be ready for dispatch and then follow a route set by the operations. Routes are generated by operations through collecting data regarding the bin coordinates and waste generation in accordance to the tonnages collected. Following the route, compactors collect waste as scheduled from the numerous bins located randomly on the map in a given sector. Once the compactor arrives at a sector, it locates a bin then the workers walk towards the bin to check whether the bin is empty or not. If the bin is empty, the workers return the bin and locate another bin if the collection is not completed. On the other hand, if the bin is filled with waste, the workers move it closer to the compactor, fix it in order for the compactor to forklift the bin and wait for the compactor to empty the trash. Later, the worker/s returns the bin and another bin is located to repeat the process. This loop iterates if the waste collection in a given sector is not completed. After completing the waste collection, the compactors transport the waste to drop it in the landfill and return to dispatch. Simultaneously, the operations input the route details in databases of tonnages collected and bin coordinates to finally record completion of the process.

The flowchart of the waste collection process corresponding to the 3.2 cubic meter bins collected by a side loader compactor is identical to the collection process of the 240 liters bins except for the difference in handling overflowing waste. Provided that the bin is filled with waste, the workers check if there is excessive waste on the ground, place it in the bin and help the driver to adjust the compactor in order for it to forklift the bin and wait for the compactor to empty the trash.

The team designed the process flow map by observing the process and collecting information regarding the roles, activities and data flow. The standard used by the team to generate the process flow map effectively is ISO 5807:1985 related to Information Processing—Documentation symbols and conventions for data, program and system flowcharts, program network charts and system resources charts.

2.2 Six Sigma Methodology

To be able to decrease the lead time in order to propose relevant solutions, a brain storming session was carried out to specify the main causes of the problem. The causes are related to six major categories: Residents, Process, Operations, Compactor, Driver and Workers, are projected in Figure 3.

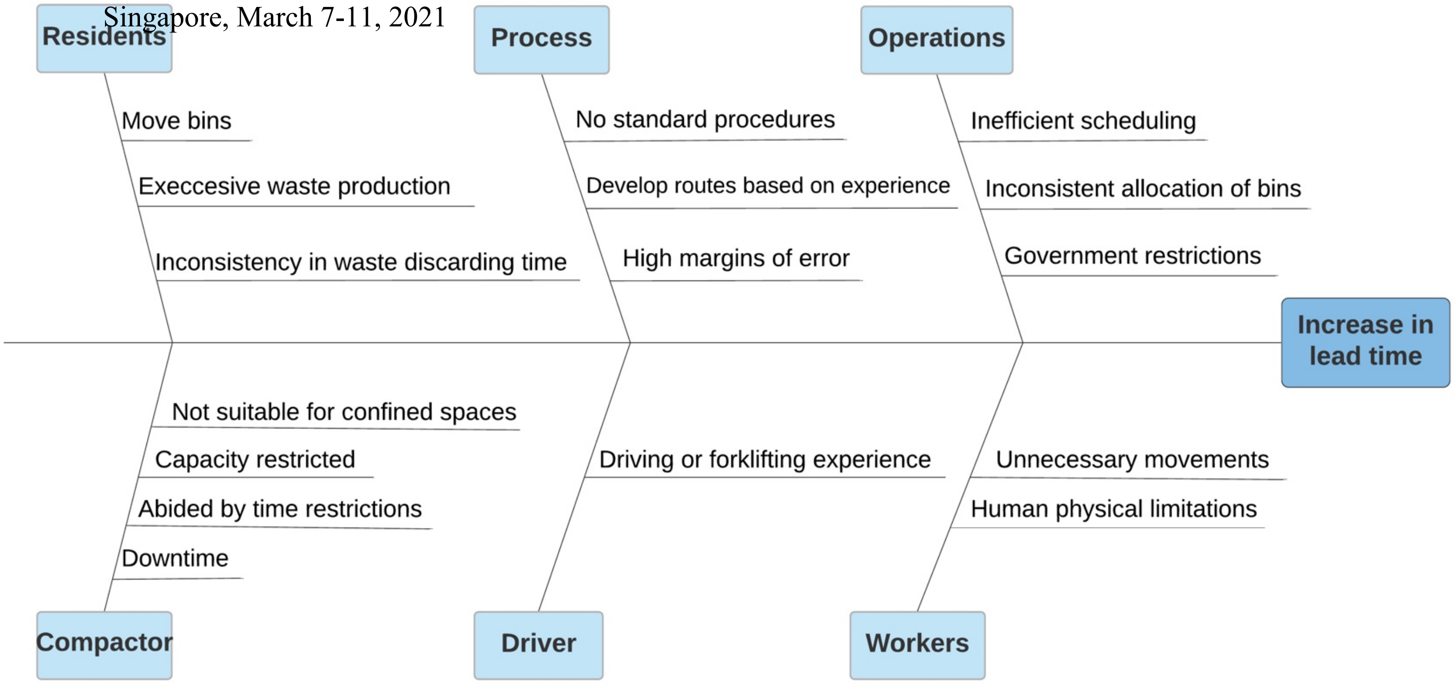

Figure 3: Fishbone Diagram

The first category includes the possible root causes related to the actions or behaviours of the population of people who reside in the designated sectors of the project. Upon collecting data, the team witnessed a massive number of misplaced 240 liters bins. This occurs since the 240 liters wheeled bins are designed to be easily moved, thus, the residents tend to relocate the bins in order to possess more convenience and space in confined areas. As a result, major interruptions of the waste collection process follow since a number of bins defer from the initial location according to the route and schedule. Furthermore, some residents do not abide by the timings of waste collection set by Averda where waste is not discarded on time. This results in encountering a number of empty bins, which ought to be collected by another compactor causing overtime if the quality inspector notifies Averda. Another cause is that some residents tend to produce waste excessively, leaving some bins overflooded and eventually discarding waste outside the bin. This results in increasing the processing time, since workers are obliged to configure the bins in a suitable mode for the compactor to forklift the bins.

The second category outlines the root causes related to the functionality of the compactor. Whilst conducting data collection, the team witnessed a few compactors with downtime. This occurs due to the maintenance strategies set by Averda in which compactors are not subject to strictly follow maintenance activities at specified periods, thereby causing a disturbance in the schedule that leads to an increase in lead time. Another cause is the fact that compactors are abided by time restrictions on heavy vehicles set in Abu Dhabi, which affects the flexibility of operating compactors at specified timings that leads to an increase in lead time. Additionally, compactors are capacity restricted, which limits the amount of waste a compactor is liable to collect. In this case, when compactors encounter excessive waste generation in a

sector, they are entitled to discard the collected waste in landfill. After that, the compactors return to the sector to continue collecting the remaining bins leading to an increase in lead time. Lastly, compactors are not suitable for confined areas (e.g. Al Zaab, S 2-35) included in the routes set by operations because of their massive designs. The layout of some urban areas limits the ability of the compactor to adjust its position, reverse or even come across a number of bins. This results in an increase in lead time since workers tend to grab a number of bins to move them closer to the compactor or unintentionally leave a few bins unaccounted for.

The third category corresponds to the processes. Due to the inconsistent location of bins and differing environments in each sector, there is a lack of standard procedure in the system. This results in high variations of waste collection existing between the sectors. Another factor is that the routes to be followed by compactors are developed based on experience as mentioned in a meeting with the client. Since no convincing source of evaluation is used, thus, some routes may be subject to further improvement if other techniques are utilized in defining an optimal route. Lastly, as stated by the client, the process encompasses 20% as margins of error leading to an increase in lead time. This means that the process allows for high margins of error including but not limited to, delays in collecting waste, overtime and system interruptions.

The fourth category is related to the driver. In the case where the environment of the sector reflects minor changes on the specified route, the skills of the driver plays a role in increasing the lead time. For instance, while collecting data, the team witnessed a delay in adjusting the position of the compactor when encountering an obstacle or in confined spaces.

The fifth category corresponds to the operations. To start with, the operations tend to schedule the waste collection timings without studying the nature of the people residing in each sector. This leads to inefficiency since the waste collection timings should comply with the time people find convenient to discard their waste. Otherwise, a compactor is expected to encounter empty bins while collecting waste, which imposes the operations to schedule another compactor for the same route leading to increased lead time. Similarly, the allocation of bins should be further studied. According to the maps provided, a number of bins were initially allocated in front of the houses. However, in reality, the team witnessed a number of bins placed in different locations or on the corners of the street rather than in front of the houses because of the confined areas. This inconsistency complicates the waste collection for the driver and increases lead time as the bins locations differ from the maps. Moreover, the operations should abide by the governmental policies imposed, such as time restrictions on the compactors that restrict them to operate in rush hours.

The last category is related to the human physical limitations and unnecessary movements conducted by the worker. There are many human factors to consider in a waste collection process. Workers are obliged to drag bins closer to the compactors when operating. Thus, if the bin is flooded with heavy waste, each worker pertains to his own abilities in dragging the bin. Another factor is the unnecessary movements the workers tend to perform while collecting waste. Such movements increase the lead time, which include having to check on bins, searching for bins, moving bins to the compactor and returning bins to their initial location.

In Quality Management Systems, the fishbone diagram is perceived as a corrective action tool. To construct a fishbone diagram, the main problem statement must be identified, followed by the major categories leading to the problem, which includes methods, equipment, manpower, materials, measurement and environment. After that, further details must be outlined under each category according to the team's observation of the process. The engineering standard related to Quality Management Systems is ISO 9001:2015. It includes several quality management principles, ensuring the consistency of good quality of services in an organization.

Moreover, the team constructed four different pareto charts displaying the processing times of the collection process in each sector. There are two charts concerning the two types of 240 liters bins (i.e. black and green) located in the following sectors; 2-35, 2-37, 2-53, and 2-53. Similarly, another two charts concerning 3.2 cubic meters bins (i.e. black and green) located in the following sectors; 2-56, 2-35, 2-55, 2-75 and 2-76. As shown in Figures 4 and 5, sector 2-35 is the bottleneck of the waste collection process with a processing time of 240 minutes. The chart signifies that sector 2-35 results in a considerable increase in the lead time of the waste collection process. It is followed by sector 2-37 that holds a processing time value of 60 minutes for the green bins, and a value of 90 minutes for the black bins.

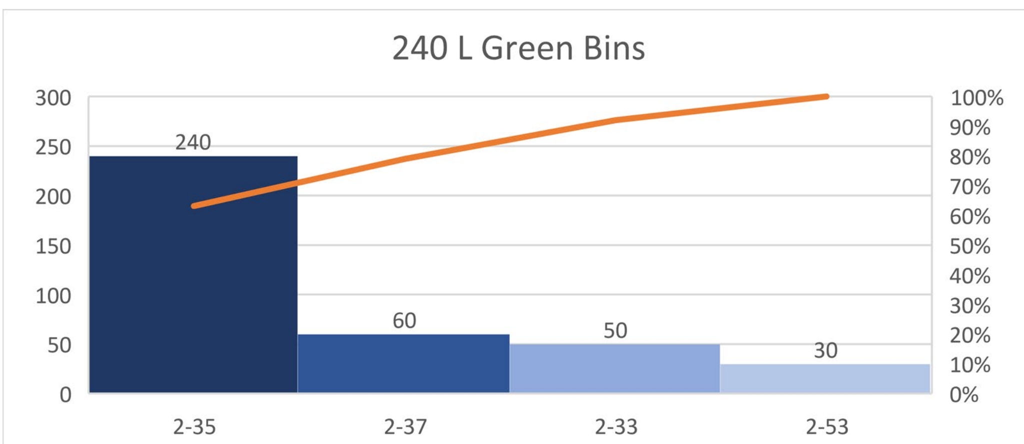

Figure 4: Pareto Chart for the 240 L Green Bins

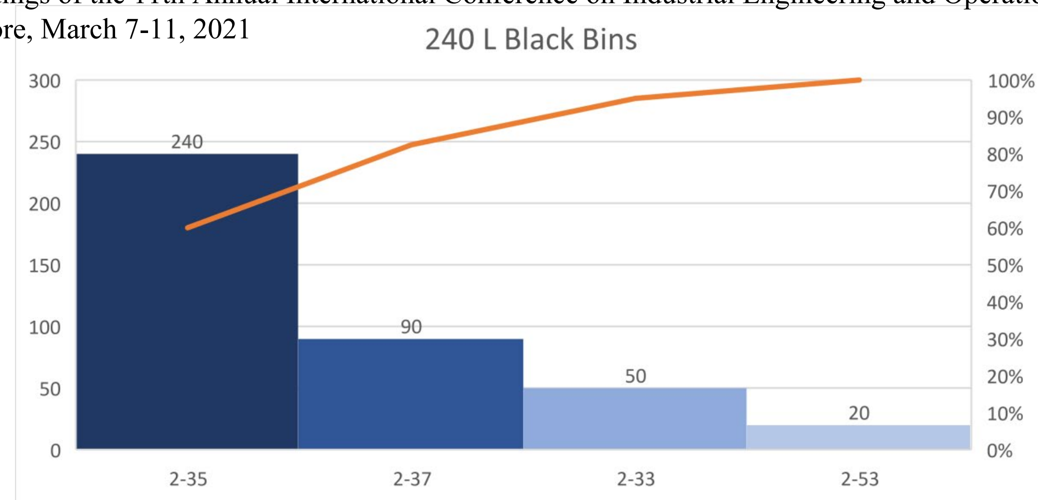

Figure 5: Pareto Chart for the 240 L Black Bins

On the other hand, Figures 7 and 8 clarifies that there are three sectors causing a delay in the waste collection lead time. In figure 6, the three sectors are; 2-56, 2-35, and 2-55 along with processing times of 100 minutes, 60 minutes, and 50 minutes respectively. Nonetheless, figure 7 represents the same mentioned sectors in a different ranking and processing times, where sector 2-56 remains the highest with a value of 130 minutes. This is followed by sector 2-55 and sector 2-35 with processing times of 60 minutes and 50 minutes, respectively.

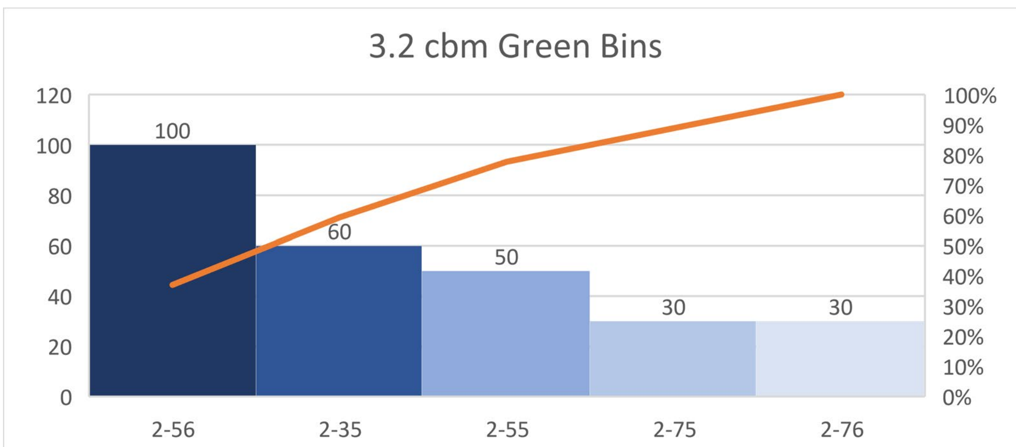

Figure 6: Pareto Chart for the 3.2 cbm Green Bins

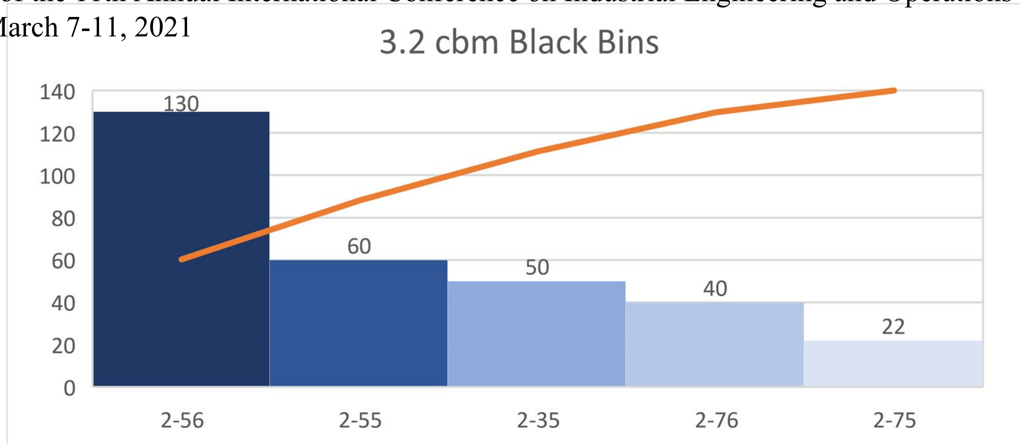

Figure 7: Pareto Chart for the 3.2 cbm Black Bins

To construct the pareto charts shown above, the data required includes the processing times of the various types of bins in eight sectors; 2-35, 2-37, 2-33, 2-53, 2-55, 2-56, 2-75, and 2-76. The international engineering standard used by the team to create the pareto chart is ISO 9001: 2015, Quality Management Systems, the same standard used to construct the fishbone diagram as well as the value stream map.

2.3 Design of Experiments

Upon careful inspection of the waste collection process, there were several factors that seemed important at first sight. The factors are the number of speed bumps the truck driver has to go over, the number of bins to be collected throughout the route, the number of traffic lights, and whether the driver is experienced with operating the truck or not, characterized by the average speed of the truck. The levels of each factor can be found in Table 1:

Table 1: Factors and their Corresponding Levels

Factors/ Level	High	Low
No. Speed Bumps	15	5
No. Bins Allocated	10	5
No. Traffic Lights	3	1
Type of Driver (speed)	40 km/hr	20 km/hr

The team decided to set up a simulation using Anylogic to tackle the problem at hand. Upon entering all inputs and parameters, Anylogic calculates the total time the truck takes to go through the complete route and performs the collection process. The following list illustrates the assumed parameters:

- The road length is fixed at 1 km, where the compactor will drive to the end of the road and takes a U-turn back to the starting point (a total of 2 km).
- The average speed of the compactor while driving on the speed bump is 5 km/hr.
- The traffic lights are green for 30 seconds, yellow for 5 seconds, and red for 30 seconds.
- The time it takes for the compactor from the moment it stops at the bin location till it starts moving again follows a triangular distribution with a minimum of 18 seconds, a maximum of 22 seconds, and an average of 20 seconds.
- No bins are expected to be empty in this experiment.

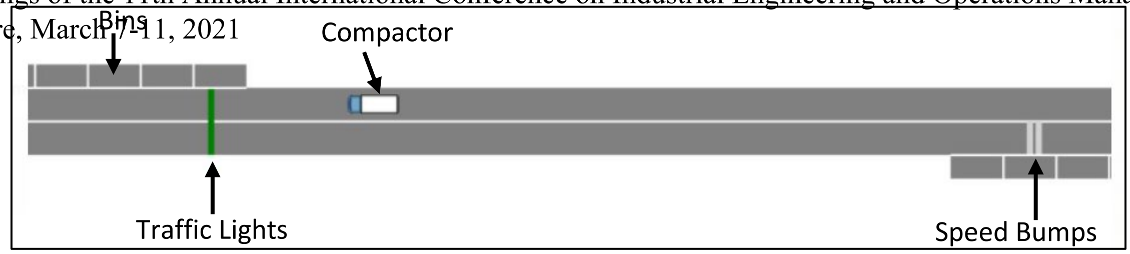

Figure 8: DOE Simulation

The experimental design chosen in this project was a factorial design, in specific, a 2-level full factorial design. All combinations of factor levels (2 levels per factor) were run in order to study the effects of the four factors on the response variable. Moreover, varying the levels of all factors simultaneously allowed the study of interactions between factors. After the assumptions are validated, the design was constructed on Minitab to implement the variations to the simulation.

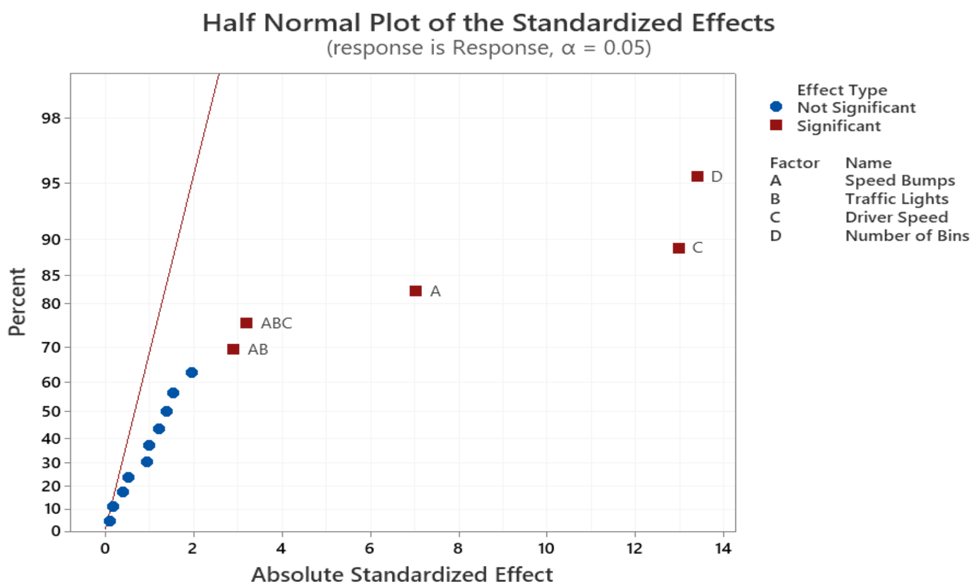

Figure 9: Half Normal Plot

From the half plot shown in Figure 9, the following main factors were plotted: “Speed bumps”, “Driver speed” and “Number of bins” and appear significant. Although the interactions of some of the factors are also significant (i.e. speed bumps and traffic lights are high) they are of no concern. This is backed up with the pareto chart shown below. The factors that were identified as significant in the half plot are also identified as active terms in the chart since they exceed the reference line.

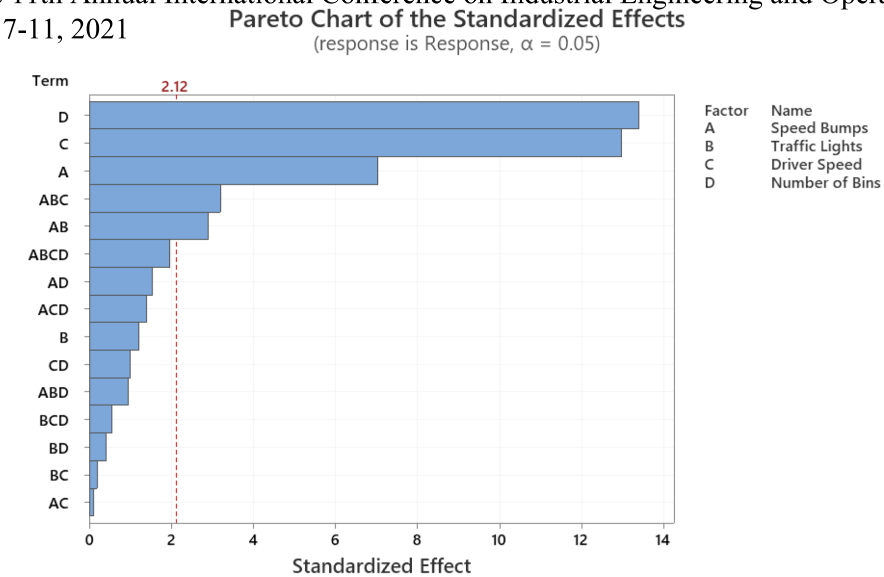

Figure 10: Pareto Chart of the Standardized Effects

Based on the results of the experiment shown in Figure 10, the most significant factor turned out to be the number of bins, followed by the driver speed and the speed bumps. The result of this experiment indicates that the number of bins should be the top priority when finding a way to shorten the lead time. While that is true, the experience of the driver and the number of speed bumps should also be an aspect for the proposed solution.

2.4 Lean Methodology

The identification of the eight types of waste is done after observing the workers, movements, compactors, and materials involved in the waste collection process. Table 2 represents the identified wastes by the team.

Table 2: The Eight Mudas

Type of operation waste	Waste collection applications
Defects	• Leaving bins uncollected
Waiting	• Time acquired in high traffic areas • Time for compactor to adjust position
Motion	• Workers walk to the bins, grab them and fix them for the compactor • Movement between bins
Overproduction	• Checking whether the bins are empty while collecting
Overprocessing	• Collecting overflooded bins
Human Potential	• Lack of team training • Lack of work standards
Inventory	• Waste in bins that are not yet collected • Unutilized number of bins
Transportation	• Delay in waste collection when reaching excess capacity • Unoptimized route

The international standard ISO 9001 used for the lean methodology, is a standard for quality management systems. By integrating lean methodology into the ISO 9001 Quality Management System, the process will be further improved by eliminating waste.

2.5 Simulation

In this project, the team built a model to represent the current state of the waste collection process. The purpose of the model is to identify and demonstrate the causes of the increase in lead time in order to develop relevant solutions to the identified problem. After running the model, the generated simulation model is illustrated in Figure 11:

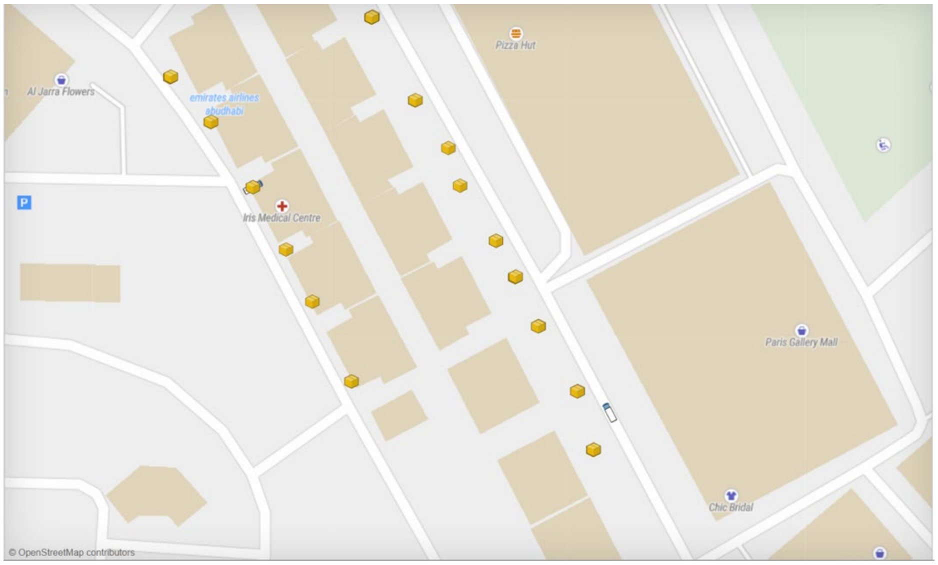

Figure 11: Waste Collection Simulation Model

The team used System and Software engineering -- Systems Life Cycle Processes as a standard for the simulation modeling. This standard concerns systems that are created by humans and may be configured with many system elements such as software. It defines the process from an engineering point of view with the associated terminology for managing and performing the stages of a system's life cycle.

2.6 Linear Programming Formulation

Linear Programming was used to help the team in decision making and planning. This mathematical method involves determining the optimal number of bins and shifts to serve the appointed population. The objective function, the expression to be minimized, seeks to reduce the total cost associated with the collection activity by simultaneously satisfying certain constraints. The total cost comprises of the labor cost and the bin purchase cost that are assessed for trade-offs. It is subject to constraints that include waste generation limitations, capacity constraints, non-negativity and integer constraints. The formulation model is presented in Figure 12:

Minimize:

$$Z = C_1 (x_1 + x_2 + N) + C_2 (x_3 + x_4 + M) + L_1 y_1 + L_2 y_2$$

Subject to:

Sector Waste Generation Constraint

$$B_1 x_1 + B_2 x_3 \geq T_1$$

$$B_1 x_2 \geq T_2$$

$$B_2 x_4 \geq T_3$$

Compactor Capacity Constraint

$$B_1(N) + B_1(x_1 + x_2) \leq y_1 Q_1$$

$$B_2 (M) + B_2(x_3 + x_4) \leq y_2 Q_2$$

Working Hours Constraint

$$(x_1 + x_2 + N)(P_1) + (x_1 + x_2 + N - 1)(K_1) + D_1 \leq S * y_1$$

$$(x_3 + x_4 + M)(P_2) + (x_3 + x_4 + M - 1)(K_2) + D_2 \leq S * y_2$$

Non-negativity Constraint

$$x_i \geq 0, i \in \{1, 2, 3, 4\}$$

Integer Constraint

$$x_1, x_2, x_3, x_4, y_1, y_2 \quad \textit{are integers}$$

Legend:

Costs:

C_i	Cost of bin
L_i	Labor cost of bin

Capacities:

B_i	Bin capacity
Q_i	Compactor Capacity

Constants:

N	Quantity of 240 L bins in remaining sectors
M	Quantity of 3.2 cbm bins in remaining sectors
T_i	Tons of waste produced daily per sector
P_i	Processing time by bin type
K_i	Traveling time between bins
D_i	Traveling time from finish to dumping, and back to discharge.
S	Shift hours

Decision Variables:

Z	Total cost
x_1	Number of 240 L bins sector 2-35
x_2	Number of 240 L bins sector 2-37
x_3	Number of 3.2 cbm bins sector 2-35
x_4	Number of 3.2 cbm bins sector 2-56
y_1	Number of shifts for 240 L bin route
y_2	Number of shifts for 3.2 cbm bin route

Figure 12: Linear Programming Formulation

3. Proposed Solution

The mathematical formulation involves determining the optimal number of bins and shifts to serve the appointed population. The objective function, the expression to be minimized, seeks to reduce the total cost associated with the collection activity by simultaneously satisfying certain constraints. The total cost comprises of the labor cost and the bin purchase cost that are assessed for trade-offs. It is subject to constraints that include waste generation limitations, capacity constraints, non-negativity and integer constraints.

References

ISO. 2021. *ISO 5807:1985*. Available: https://www.iso.org/standard/11955.html, 2019.

M. Hammar, "How to use root cause analysis to support corrective actions in your QMS," *9001academy*, Available: https://advisera.com/9001academy/blog/2016/03/01/how-to-use-root-cause-analysis-to-support-corrective-actions-in-your-qms/, March 2016.

"FISHBONE DIAGRAM," *ASQ*, Available: https://asq.org/quality-resources/fishbone.

“What is ISO 9001:2015 Quality Management Systems,” *Certification Europe*, Available: https://www.certificationeurope.com/certification/iso-9001-quality-management-systems-certification/.

"ISO 9001 vs. Lean: The similarities and differences", *9001Academy*, Available: https://advisera.com/9001academy/blog/2014/07/22/iso-9001-vs-lean-compare-different-2/, 2014.

"ISO/IEC/IEEE 15288:2015," *ISO*, Available: https://www.iso.org/standard/63711.html, May 2015.

Biographies

Khadija Alhmoudi is an Industrial and Systems Engineering Student at Khalifa University, Abu Dhabi, UAE. She has developed an interest in Six Sigma Methodology and Applications, Advanced Simulation, and Project Management. Khadija has conducted a Six Sigma project at a 5-stars hotel located in Abu Dhabi to reduce the cost of gasoline consumed by transportation busses. She conducted a time-motion study and analyzed the data using lean and six sigma tools including process maps, SIPOC diagrams, and Control Charts. She is a board member in the Industrial and Systems Engineering Student Chapter.

Khalid Alhosani is an Industrial and Systems Engineering Student at Khalifa University, Abu Dhabi, UAE. He has developed an interest in Supply Chain & Logistics, Project Management, Production & operations Management, and Design of Experiments. Khalid has conducted a Production & Operations Management project to improve the customers' experience at a local restaurant in Khalifa University. The number of potential customers and the arrival rates were analyzed using lean tools including spaghetti diagrams, fish and bone diagrams, and flow diagrams. Finally, recommendations were proposed to the managers of the restaurant to be considered. He is the president of the Industrial and Systems Engineering Student Chapter.

Shamma Alali is an Industrial and Systems Engineering Student at Khalifa University, Abu Dhabi, UAE. She has developed an interest in Six Sigma methodologies, Project Management, Data and Information Engineering. Shamma has conducted a Data and Information Engineering project where a real-life bicycle renting database was created using Microsoft Access to help organize information and make it more accessible and user-friendly by constructing tables, queries, reports, and forms. She is a board member in the Industrial and Systems Engineering Student Chapter.

Roudha Alattar is an Industrial and Systems Engineering student at Khalifa University, Abudhabi, UAE. She has developed an interest in Advanced Simulation, Project Management as well as Engineering Economic Analysis. Roudha conducted a project involving a real-life case study to maximize profit in real estate investment, using tools and techniques related to Engineering Economic Analysis such as present and future worth analysis, benefit-cost ratio, internal rate of return and sensitivity analysis. She is an active board member in the Industrial and Systems Engineering Student Chapter.