MINIMIZING COSTS AND MAXIMIZING COVERAGE: RECYCLING STATION PLACEMENT IN UNIVERSITI UTARA MALAYSIA BY USING SET COVERING APPROACH

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ABSTRAK

Pengurusan kitar semula merupakan cabaran global yang kritikal, memerlukan strategi inovatif untuk meningkatkan kelestarian. Kajian ini menangani pengoptimuman penempatan stesen kitar semula di Universiti Utara Malaysia (UUM) dengan menggunakan pendekatan Masalah Set Penutup (Set Covering Problem, SCP). Dengan memberi keutamaan kepada liputan maksimum dalam jarak berjalan kaki kurang daripada lima minit sambil meminimumkan kos operasi, kajian ini mencadangkan model Pengaturcaraan Integer (Integer Programming, IP) untuk menentukan lokasi stesen kitar semula yang optimum. Pengumpulan data melibatkan pemerhatian dan soal selidik, yang menangkap tingkah laku kitar semula pelajar dan keutamaan aksesibiliti mereka. Model ini dibangunkan dengan pembolehubah keputusan, kekangan, dan fungsi objektif yang jelas, yang bertujuan untuk memaksimumkan liputan. Pelaksanaan model mendedahkan bahawa sebanyak 15 stesen kitar semula diperlukan untuk menyediakan liputan menyeluruh di seluruh universiti. Hasil menunjukkan bahawa penempatan yang dicadangkan meningkatkan aksesibiliti dengan ketara berbanding susunan semasa, sekaligus meningkatkan kadar kitar semula dan mengurangkan ketidakcekapan operasi. Analisis lanjut dilakukan menggunakan Excel Solver, yang mengesahkan keberkesanan model sambil menyediakan penyelesaian alternatif untuk penempatan stesen. Analisis kos menunjukkan implikasi kewangan penubuhan stesen kitar semula, memberikan pandangan yang boleh diambil tindakan kepada pengurusan kampus. Kajian ini menyumbang kepada bidang penyelidikan operasi dengan menerapkan SCP kepada masalah dunia sebenar, serta mempersembahkan metodologi yang boleh direplikasi untuk mengoptimumkan penempatan kemudahan di persekitaran akademik.

Kata kunci: Penempatan stesen kitar semula, Masalah Set Penutup, Pengaturcaraan Integer, pengoptimuman, kelestarian, pengurusan sisa

ABSTRACT

Recycling management is a critical global challenge, requiring innovative strategies to enhance sustainability. This study addresses the optimization of recycling station placement at Universiti Utara Malaysia (UUM) using the Set Covering Problem (SCP) approach. By prioritizing maximum coverage within a walking distance of less than five minutes while minimizing operational costs, this research proposes an Integer Programming (IP) model to determine the optimal locations for recycling stations. Data collection involved observations and questionnaires, capturing students' recycling behaviors and accessibility preferences. The model was developed with clearly defined decision variables, constraints, and an objective function aimed at maximizing coverage. Implementation of the model revealed that a total of 15 recycling stations is required to provide comprehensive coverage across the university. Results indicate that the proposed placement significantly improves accessibility compared to the current setup, enhancing recycling rates and reducing operational inefficiencies. Further analysis was conducted using Excel Solver, which confirmed the model's effectiveness while providing alternative solutions for station placement. Cost analysis revealed the financial implications of establishing recycling stations, offering actionable insights for campus management. This study contributes to the field of operations research by applying SCP to a real-world problem, presenting a replicable methodology for optimizing facility placement in academic settings.

Keywords: Recycling station placement, Set Covering Problem, Integer Programming, optimization, sustainability, waste management

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CHAPTER ONE

INTRODUCTION

Recycle management is a major worldwide issue that calls for creative solutions to reduce its negative effects on the environment and the depletion of its resources. Universities produce a lot of recyclable waste and are vital in promoting sustainable practices since they are microcosms of bigger populations. This review of the literature looks at several research papers to investigate several factors of recycle management, with an emphasis on facility location optimisation strategies that are primarily used for the placement of recycling stations.

1.1 Research Background

Sustainable development requires effective waste management, especially in areas with high population density like universities. Recycle rates may be raised, operating costs can be decreased, and garbage collection efficiency can be greatly improved by carefully placing recycling stations. Researchers have used a variety of optimization strategies to address these issues, with the SCP algorithm emerging as a popular approach because of its capacity to guarantee maximal service coverage at a reasonable cost. Numerous fields, including urban planning, logistics, and facility site optimization, have made extensive use of the SCP algorithm. Many studies highlight the SCP algorithm's ability to resolve intricate facility placement issues, which makes it a viable strategy for maximizing the position of recycling stations in academic settings. Incorporating spatial data and dynamic demand patterns through the integration of Geographic Information Systems (GIS) with SCP, as recommended by multiple researchers, might also improve the precision and flexibility of the solutions.

The present literature review aims to provide an overview of the findings from multiple research that have applied SCP and other optimisation methods to address waste management and facility location problems. This review's analysis of these approaches seeks to identify key strategies and important findings that might direct Universiti Utara Malaysia's careful placement of recycling stations, thereby promoting a more productive and environmentally conscious campus.

1.2 Problem Statement

Recycling is a critical component of sustainable waste management, yet it faces significant challenges in Malaysia. Although many Malaysian wastes could be recycled, less than 5% of the total is separated and recycled (Mohd Nasir Hassan et al., 2000). This low recycling rate can be attributed to several factors, including inadequate infrastructure, lack of public awareness, and insufficient incentives for waste separation. Therefore, a change at university will be made before making a change for this world. The location of the recycling stations at Universiti Utara Malaysia is not ideal for students or staff to recycle, which results in a low recycling rate and ongoing additional operating and recycling costs.

According to Letelier et al. (2021), their waste collection time and cost, environmental pollution and risk of health problems are reduced while at the same time increasing the waste disposal service for neighbors. The implementation of recycling initiatives is essential for promoting sustainability, particularly within educational institutions. Universiti Utara Malaysia (UUM) has launched several 3R (Reduce, Reuse, Recycle) initiatives in recent years, including efforts to reduce plastic usage. Placing recycling stations optimally is crucial as it significantly impacts the university's expenses. Effective placement of these stations can enhance recycling efficiency, reduce operational costs, and support UUM’s commitment to sustainability. Thus, careful planning and strategic implementation of recycling infrastructure are imperative for the university’s environmental and financial goals.

1.3 Research Questions

1. What are the constraints that we need to involve in the set covering model?
2. What are the patterns of recycling behaviour among the university community?
3. What is the best location for recycle station placement in UUM?
4. What is the waste collecting costs and operating costs for current existing recycling station?

1.4 Research Objectives

1. To find the constraints that we need to involve in this set covering model
2. To increase recycle rate in UUM by maximizing coverage of recycle station placement.
3. To find the optimal location for recycle station placement in UUM by adding new stations or remain the same.
4. To minimize cost that will be used in recycling process including waste collecting costs and operating costs.

1.5 Scope of the Study

The scope of this research focuses on optimizing the placement of recycling stations at Universiti Utara Malaysia (UUM) using the Set Covering Problem (SCP) approach. It implies a thorough investigation of the infrastructure currently existing for recycling, including the quantity, location, and consumption habits of recycling stations. In order to maximize coverage and reduce operating costs, the study seeks to determine the best locations for new recycling stations and to suggest necessary upgrades for those that already exist.

To achieve this, the research will employ the SCP algorithm, known for its efficiency in ensuring maximum service coverage with minimal resources (Syahputra et al., 2022). The integration of Geographic Information Systems (GIS) with the SCP model will enhance the precision of the placement recommendations by incorporating spatial data and dynamic demand patterns. This methodology will allow for a detailed analysis of geographical and demographic factors that influence the optimal placement of recycling facilities.

The study will also explore the use of heuristic algorithms to improve the efficiency of the SCP model. By integrating heuristic approaches, such as the Greedy Heuristic Algorithm, the research aims to balance solution optimality with computational efficiency, making the model more practical for real-world application (Bangun et al., 2022). This methodological approach ensures that the placement strategy is both effective and computationally feasible, addressing the complex nature of facility location optimization in waste management.

1.6 Significance of the Study

The significance of the study are as follows:

- The findings can be used as a guideline for school management to arrange the optimal location of recycle station in Universiti Utara Malaysia (UUM) or any other similar location that having set covering problem.
- To create an optimal solution by using set covering method that assist UUM to have the optimal recycle station placement.
- To help the school management minimize the cost and maximize the coverage of recycle station in UUM by giving an optimal placement.
- To increase the recycle rate within students which results in a sustainable campus.
- To serve as a reference for UUM to locate their recycle station placement by using set covering method.

1.7 Outline of the Study

First, Chapter One briefly describes the introduction of this study, research background, problem statement, research question, research objectives, scope of this study and significance of this study. Moreover, Chapter Two provides an overview of previous research on the set covering problems in several types of location and the solution techniques that had been used to solve it while Chapter Three describes the methodology of the proposed approach which is set covering method to recycle station placement problem in this study. The research design of this study was shown in this chapter. The data collection method, finding the constraint and model development was explained. Next, Chapter Four describes how the data has been analyzed and interpreted in this study. Lastly, Chapter Five summarizes the whole study which also includes the findings, the limitations in this research, research contributions, and recommendations in future research.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter involves five sections of it. The first section provides a review of past studies that related to facilities placement problems. The second section focuses primarily on facilities placement problems that are related to recycling while the third section is related to waste facilities. Section four addresses the placement of other facilities such as bike sharing, temporary landfill facility and relief center for flood victims. Section five presents the three main techniques that are used to solve the facility placement problem. Lastly, the sixth section summaries all the previous studies that discussed in this chapter.

2.2 Review of Facilities Placement Problem

It is very important to determine the location of facilities for planning in various aspects for public and private facilities. This will affect the operational and logistical activities of a facility (Linarti et al., 2020).

In daily life, facilities placement problems happen everytime in different kinds of situation such as household and recycle waste bin location-allocation problem (Letelier et al., 2021), recycling bins location and allocation for sustainable urban municipalities problem (Jamiron et al., 2021) and maximal covering tour problem for locating recycling drop-off stations (Cubillos & Wøhlk, 2020), new waste disposal facilities problem (Syahputra et al., 2022), temporary waste disposal sites location problem (Bahtera et al., 2022), location-allocation problem of bins in urban solid waste management (Rathore et al., 2019), maximal covering bike sharing location problem (Muren et al., 2020), temporary landfill facility covering area problem (Purwani et al., 2021), allocation problem of relief center for flood victims (Mah Hashim et al., 2021).

2.3 Facilities Placement Problem of Recycle Facilities

This section shows that Letelier et al. (2021), Jamiron et al., & Zaharudin, Z. A. (2021) and Cubillos and Wøhlk (2020) have worked on a research of facilities placement problem that related to recycle.

As very useful past research, Letelier et al. (2021) have solved the bin location and allocation problem for household and recycle waste in Chile which due to inefficient collection system and high collecting cost. In this research they have contributed to a more efficient efficient and effective bin-to-tin waste collection process that reduces cost, environmental pollution and the risk of health problems. The constraint in this research is the travel distance between neighbours and recycling bins.

Jamiron et al. (2021) addressed the issue of establishing recycling bin's location and allocation for sustainable urban municipalities problem in Malaysia that due to increase population that results in increase volume of waste. The same problem happens in this study. This research has developed a mathematical model for recycling bins location-allocation problem for urban municipalities and it can be applied for Malaysian urban household's municipality.

According to Cubillos and Wøhlk (2020), it has solved the maximal covering tour problem for locating recycling drop-off stations. By maintaining a low installation and low collection cost, they have solved this problem by having 200 meters of covering distance of a recycling drop-off station. It also addresses the issues of placing stations in rural areas more challenging than placing them in urban areas, because distances are longer, and stations have a bigger impact on collection costs.

2.4 Facilities Placement Problem of Waste Facilities

This section discusses past studies that solved facilities placement problems that related to waste.

Syahputra et al. (2022) have determined the optimal new waste disposal facilities location due to the inadequate location and quantity of temporary disposal facilities in Subulussalam city which has led to arbitrary disposal practices. This research has considered many constraints that will be related to real life problem which is the coverage of service distance from the facility to the demand point and the constraint of ensuring that every demand is covered at least one facility.

Waste problem mostly caused by increasing population in certain country which cause the increasing waste. By having the most optimal waste collecting station, it can solve this problem in the best way. Bahtera et al. (2022) solved the problem of determining the temporary waste disposal sites Palembang. This study implements a model that can lead to cost savings in waste management operations by minimizing the distance and time required for waste collection and transportation.

In addition, Rathore et al. (2019) proposed a proper bin allocation model that reduces the collection points, idling costs and carbon emissions. This research solved the problem of lack of waste bins in appropriate places, resulting in littering and increased waste collection points following by high costs and carbon emissions in the environment. The study effectively demonstrates optimization of waste bin locations, showcasing significant potential for improving urban solid waste management.

2.5 Facilities Placement Problem of Other Facilities

This section reviews the application of facilities placement problem of other types of facilities due to different causes such as bike sharing station, temporary landfill factory and relief center for flood victims.

2.5.1 Facilities Placement Problem of Bike Sharing Station

The sharing economy has received increasing attention due to the rapid growth of large-scale cities and the reinforcement of environmental concepts and sustainability. Muren et al. (2020) has addressed the issue of imbalance in service level at various bike-sharing locations. By optimizing the location of bike sharing stations, this study helps ensure that more people have convenient access to bikes within a reasonable distance. This study also general enough to applied to many sharing economy problems.

2.5.2 Facilities Placement Problem of Temporary Landfill Facility

In the following research, Purwani et al. (2021) has solved the imbalance problem between volume of demand which refers to the amount of waste and the facility's capacity. This study has made decisions to decide whether to open or close the temporary waste disposal facility or change the size of the existing facility and to minimize the number of facilities that can accommodate waste sources. It identified the number of retained facilities, to be closed facilities and new facilities that to be opened.

2.5.3 Facilities Placement Problem of Relief Center for Flood Victims

Natural disasters are something that people cannot ignore since they will put people and country in danger. Hence, to create and advance mathematical location-allocation models in making decisions to locate and allocate flood victims during flood events, Mah Hashim et al. (2021) has improved the evacuation plans and efficient placement of relief centers to ensure better coverage during floods. This study has outperformed the current plan that are unable to allocate all flood victims and proved that the capacity of the current relief center must increase to fulfil the demand.

Table 2.1 Summary of past research based on type of problem

Authors	**Objective**	**Issues faced**
Letelier et al. (2021)	Find optimal locations for household and recycle waste	Placement Problem of Recycle Facilities
Jamiron et al. (2021)	Find location of recycling bins in household areas	Placement Problem of Recycle Facilities
Cubillos and Wøhlk (2020)	Maximize covering tour for collect recycle waste	Placement Problem of Recycle Facilities
Syahputra et al. (2022)	Find optimal new waste disposal facilities location	Placement Problem of Waste Facilities
Bahtera et al. (2022)	Determine the waste disposal site	Placement Problem of Waste Facilities
Rathore et al. (2019)	Determine the number of bins required and allocate it efficiently	Placement Problem of Waste Facilities
Muren et al. (2019)	Maximize coverage of bike-sharing station	Placement Problem of Bike Sharing Station
Purwani et al. (2021)	Minimize the number of temporary landfill facilities	Placement Problem of Temporary Landfill Facility
Mah Hashim et al. (2021)	Allocate the relief center for flood victims	Placement Problem of Relief Center

2.6 Techniques used for Facilities Placement Problem

This section discusses several approaches that have been used by past researchers in solving the various facilities placement problems to have the optimal solution.

2.6.1 Set Covering Method

According to Syahputra et al. (2022), the optimal location and quantity of Temporary Disposal Facility in Subulussalam city is found using the set covering problem algorithm. The study is to improve waste management, reducing environmental and health issues in the country. They have used Lingo 17.0 software to solve the problem based on the distance between the source of waste and demand point. This study has demonstrated that setting a covering problem algorithm can solve the problem of finding optimal location.

Purwani et al. (2021) proposed a set covering problem model that solved the problem of imbalance between the volume of demand and the facility's capacity. This study is to make decisions whether to open or close the temporary waste disposal facilities or change the size of it to minimize the number of facilities. They also used max-covering method and P-median problem model in this research. They identified the number of facilities to be retained, closed and opened, which proved that set covering method can be used to determine the capacity, type and covering area of the temporary landfill facility in each region.

Mah Hashim et al. (2021) resolved the relief center for flood victims' allocation problem by using Location Set Covering Problem method. The relief center is needed when the victim is affected by flood water, but it experiences congestion due to the large number of flood evacuees. Excel Solver has also been used in this study to create an advance mathematical location and allocation model to locate the flood victims during flood events. This study has outperformed the current plan by using set covering method.

Linarti et al. (2020) has addressed an issue of imbalance between volume of demand and facility capacity problem. It used a set covering model to solve this problem. This study is to develop a set covering model for facility location, capacity optimization and show the concept of capacity expansion in the decision to open or close a facility based on the importance of decision making.

2.6.2 Mixed Integer Linear Programming (MILP)

Muren et al. (2019) created mixed integer linear programming models to address the imbalance in service levels at various bike-sharing locations. This study is to develop a Balanced Maximal Covering Location Problem (BMCLP) model and a Lower Bound Maximal Covering Location Problem mode to ensure balanced service levels. By optimizing the location of the bike-sharing stations, this study ensures that more people have convenient access to bikes within a reasonable distance.

Letelier et al. (2021) have proposed a mixed integer linear programming model to solve the inefficient current household waste collection system in Chile. This problem results in not all citizens being served, having high collecting costs and give the environmental society negative effects. It used two approaches in this study which are mixed integer linear programming model and geographic information system. The proposed mixed integer linear programming model effectively optimizes bin locations and allocations, improving service coverage and operational efficiency.

In addition, Jamiron et al. (2021) has addressed an issue of increase volume of waste due to increased population in Johor Bahru, Malaysia. A mixed integer linear programming model and CPLEX 20.1 is used to solve the location and allocation of recycle bins in household areas problem. By optimizing the bin locations, it has improved the service coverage in the state and encourages recycling behavior.

Rathore et al. (2019) developed a mixed integer linear programming model to solve the problem of location and allocation of bins in urban solid waste management which happens is

Bilaspur city, India. This study also used geographic information systems in the model development process. This study is to determine the total number of bins required and allocate them efficiently considering the type of sources, waste bins and waste types along with safety and rag-picking.

2.6.3 Heuristics Technique

Bahtera et al. (2022) have developed a set covering location problem model and p-median problem model to solve the problem that they met. They also used Lingo 18.0 software and greedy heuristics algorithms in this study. This study determines the temporary waste disposal site in Sako District, Palembang City. As a result, they suggest using greedy heuristics techniques to find the optimal solution which can meet all the requests in Sako District.

Hajipour et al. (2021) proposed a model to determine the optimal fire station location considering dynamic and uncertain conditions following by minimizing uncovered demands and service costs. This study used particle swarm optimization (PSO) algorithm and artificial bee colony (ABC) algorithms to find the optimal solution. As a result, PSO algorithm outperforms ABC algorithm in solution quality and computational efficiency. The model effectively addresses demand variability and dynamic allocation of fire station.

Moreover, Chauhan et al. (2019) has presented a novel model denoted maximum coverage facility location problem with drones by factoring in real-life UAV battery and weigh constraints. This study is to locate a pre-specified number of capacitated facilities and assign drones to these facilities to maximize coverage. The solution is shown by using a mixed integer programming solver, greedy algorithm and three-stage heuristic techniques.

Cubillos and Wøhlk (2020) has proposed a heuristic solution to solve the maximal covering tour problem for real life-sized problem to find a balance between the number of citizens covered and the collection cost. If more drop-off stations are placed, then more citizens will be covered, but the collection cost will increase by following.

Table 2.2 Summary of past research based on type of method used

Authors	**Objective**	**Technique used**
Syahputra et al. (2022)	Find optimal new waste disposal facilities location	Set Covering Method
Linarti et al. (2020)	Determine the open/closed facilities and resizing facilities capacity	Set Covering Method
Purwani et al. (2021)	Minimize the number of temporary landfill facilities	Set Covering Method
Mah Hashim et al. (2021)	Allocate the relief center for flood victims	Set Covering Method
Muren et al. (2019)	Maximize coverage of bike-sharing station	Mixed Integer Linear Programming
Letelier et al. (2021)	Find optimal locations for household and recycle waste	Mixed Integer Linear Programming
Jamiron et al. (2021)	Find location of recycling bins in household areas	Mixed Integer Linear Programming
Rathore et al. (2019)	Determine the number of bins required and allocate it efficiently	Mixed Integer Linear Programming
Bahtera et al. (2022)	Determine the waste disposal site	Greedy Heuristics
Hajipour et al. (2021)	Determine optimal fire station locations	Particle Swarm Optimization Artificial Bee Colony
Chauhan et al. (2019)	Maximize coverage capacitated facility location	Novel Greedy Three-Stage Heuristics

Cubillos and Wøhlk (2020)	Maximize covering tour for collect recycle waste	Heuristics

Table 2.1 and 2.2 have summarized the past studies that have been done by researchers that have been discussed and mentioned in this chapter. The past studies show that a facilities placement problem has been considered in various locations and solved by various techniques. From all the past studies, most of them are about maximizing the coverage of the facilities and minimizing the costs, which is the most important objective in every type of placement problem.

From what has been shown in the table above, set covering method, mixed integer linear programming method and various types of heuristic techniques have been used to solve the facility placement problem. This table shows that these three kinds of methods are appropriate to solve this kind of problem. This study needs to maximize the coverage and minimize the cost which results in finding the optimal solution for recycling station placement in UUM and set covering methods that will be the techniques that suitable to implement in this study.

2.7 Conclusion

According to the discussion on this literature review, there are various techniques to solve the facility placement problem. Set covering method, mixed integer linear programming and heuristics techniques will be the three main techniques that have been found to solve the problem. Since this study is needed to obtain an integer optimal solution of recycle station placement, it is suitable to implement set covering method in this study.

CHAPTER 3
RESEARCH METHODOLOGY

3.1 Introduction

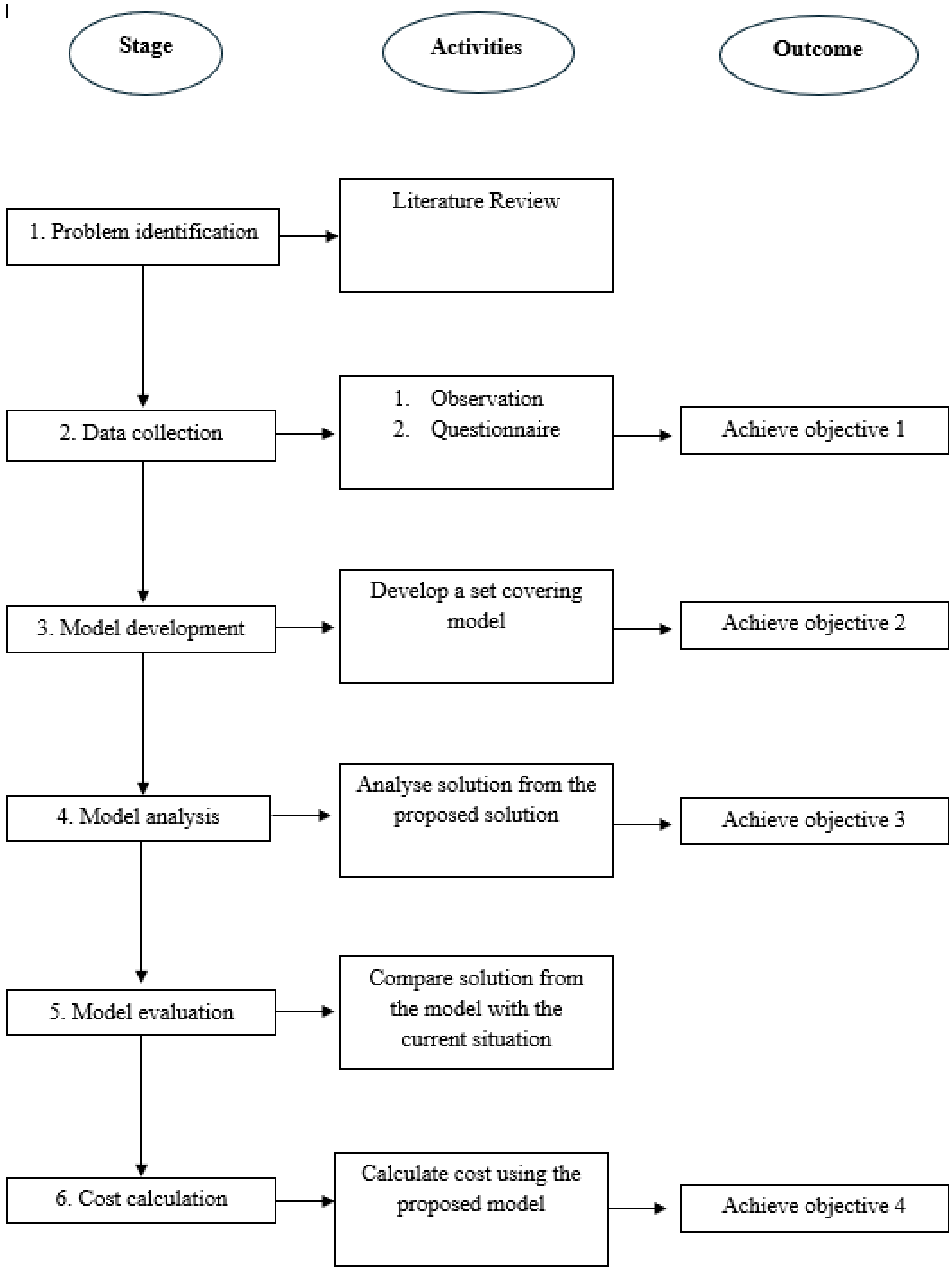
This chapter will focus on the methodology that is implemented to solve a recycle station placement problem in UUM on-campus and off-campus area by maximizing the coverage and minimizing the cost based on students recycling behavior and current recycling bins accessibility. This chapter detailed the data collection method for gathering primary data, the mathematical model development and the approaches which is set covering method that have chosen to solve this problem.

3.2 Research Framework

The research process is categorized into several stages. As shown in Figure 3.2.1 below, the stages, activities and objectives are involved in this study. This study starts with identifying the problems that existed by reviewing past studies and research. Once the problem is identified, similar previous studies that related to recycle station placement problem and its solutions are collected and studied to find the appropriate solution for this study. Hence, set covering methods are chosen as the most suitable solution to solve this recycle station placement problem in UUM. The following steps after problem identify is data collection, primary data are collected in these steps such as interview, observation and from internet source which can achieve the first objective in this study.

Next, the third step in research framework is model development, which is to develop a set covering model to determine the optimal solution for this station placement problem. This step can achieve the objective two in this study. The set covering method is developed in a mathematical algorithm and needs to be tested before it is applied on the identified problem. In the following step which is model analysis. The solution is analyzed from the proposed solution which achieves the objective three. The model is evaluated in the fifth step, the solution will be compared from the model with the current situation. Lastly, the cost that is caused by the recycle station placement set covering method will be calculated and the solution obtained will achieve the fourth objective in this study.

Figure 3.2.1 Research Framework



3.3 Data Collection

This section will discuss the types of data used and explain the data collection process.

3.3.1 Primary data

This research used primary data to collect data that has been used. The primary data that has been collected is two types of data such as observation and questionnaires. This approach to collect data that used to determine the optimal solution to solve the recycle station placement problem in Universiti Utara Malaysia. The observation is the current recycle bins and stations placement in this university which can be used in the model evaluation process that needs to compare solution from the model with the current situation. The questionnaire that collected can show recycling behavior and recycling bins accessibility by students. The hard and soft constraints can be formulated and obtained by analyzing through the responses.

3.3.2 Observation

One of the approaches that has been used in this study is observation. This observation is to ensure that the current situations of recycle station placement 2024 in UUM. The observation obtained has shown that only five locations that recycle station or bins are located such as Pusat Budaya dan Seni, office Inasis SME Bank, office Inasis Sime Darby, office Inasis Yayasan Al-Bukhary and Varsity Mall UUM. There are three kinds of recycle bins which students can recycle paper, plastic or alunimium and paper at Pusat Budaya dan Seni, office Inasis Sime Darby, office School of Quantitative Science (SQS) and office Inasis Yayasan Al-Bukhary. On the other hand, office Inasis SME Bank has recycling bins that can collect plastic bottles and caps in front of their office while a drive-through recycling station is located at the parking lot opposite the Varsity Mall.

Picture 3.3.2.1 Recycle bins office Inasis Yayasan Al-Bukhary

Picture 3.3.2.2 Recycle bin office Inasis SME Bank

Picture 3.3.2.3 Recycle bins Pusat Budaya dan Seni

Picture 3.3.2.4 Recycle bins office Inasis Sime Darby

Picture 3.3.2.5 Drive-through recycling station Varsity Mall

Picture 3.3.2.6 Recycle bins office School of Quantitative Science (SQS)

3.3.3 Questionnaire

A questionnaire was developed for the data collection process. The questionnaire is filled in by 45 respondents and consists of three sections, which are Section A, Section B and Section C. In Section A, demographic information of respondents is collected while Section B records the recycling behavior of students. Lastly, the accessibility of students to the recycling bins and stations in university are collected in Section C.

Chart 3.3.3.1 Recycling Behavior Question One

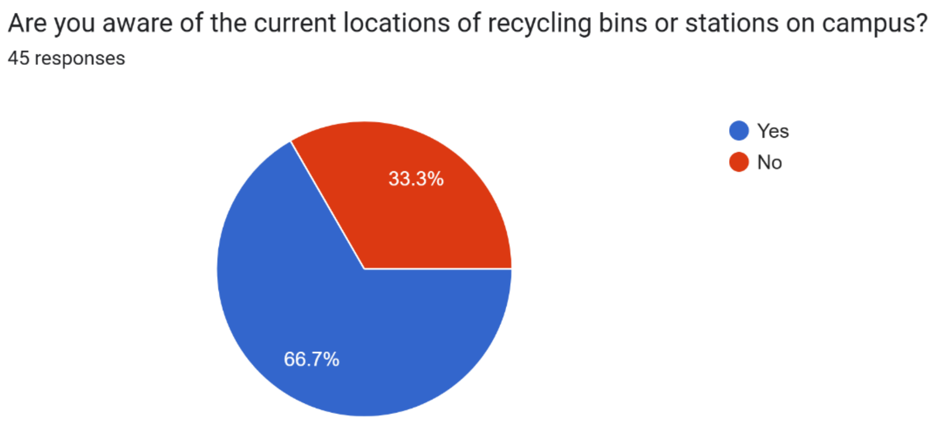


Chart 3.3.3.2 Recycling Behavior Question Two

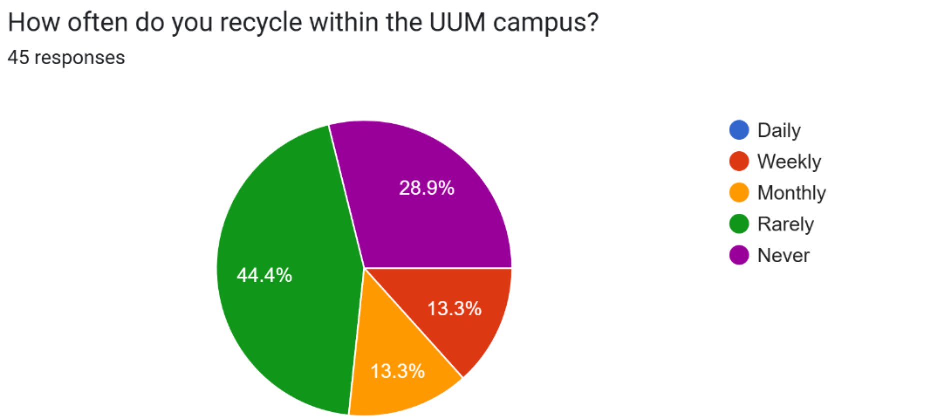


Chart 3.3.3.3 Recycling Behavior Question Three

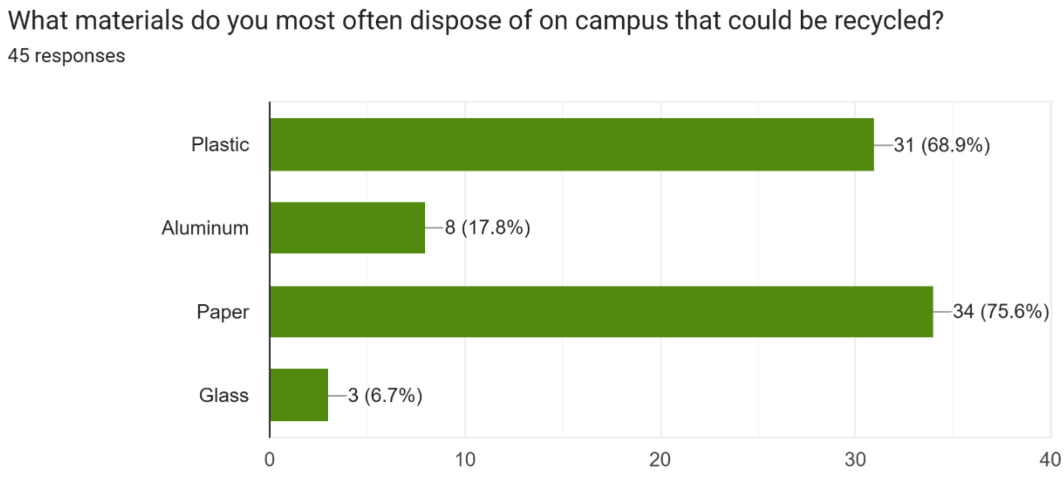


Chart 3.3.3.4 Recycling Bins Accessibility Question One

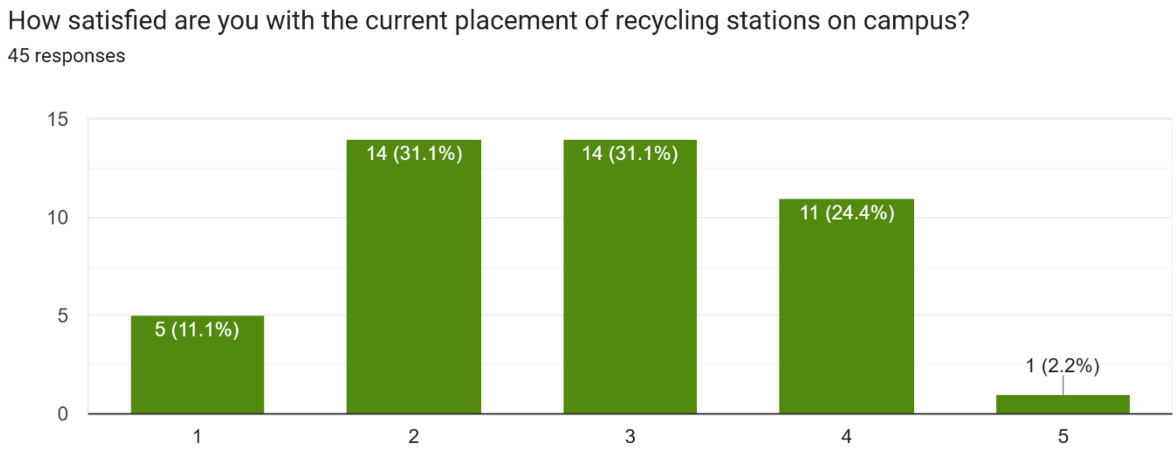


Chart 3.3.3.5 Recycling Bins Accessibility Question Two

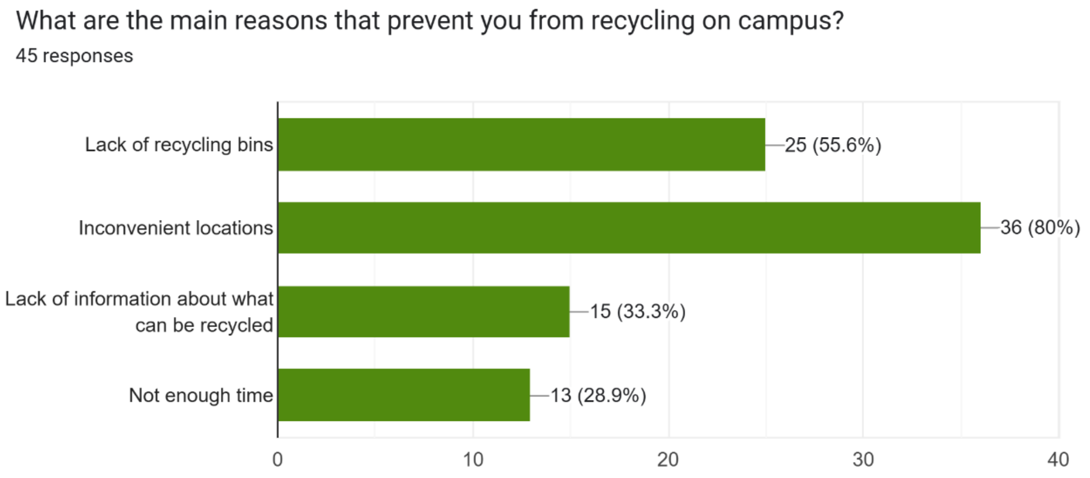


Chart 3.3.3.6 Recycling Bins Accessibility Question Three

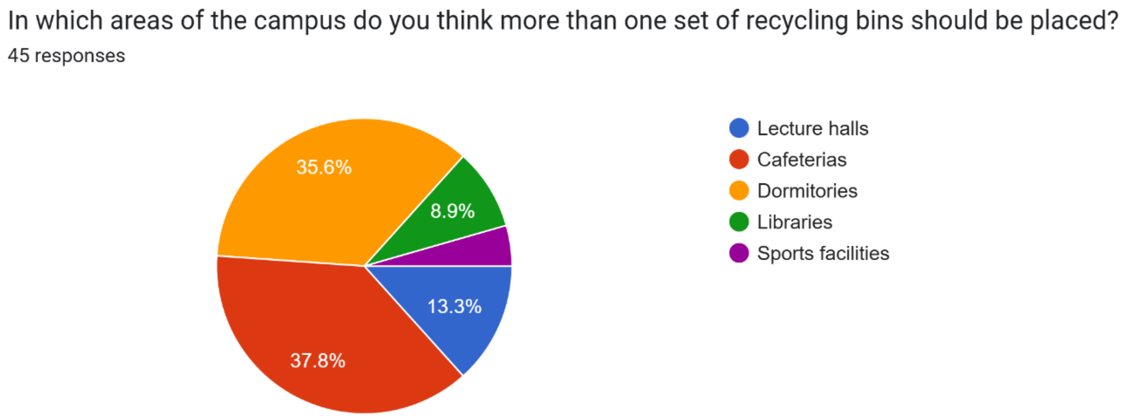


Chart 3.3.3.7 Recycling Bins Accessibility Question Four

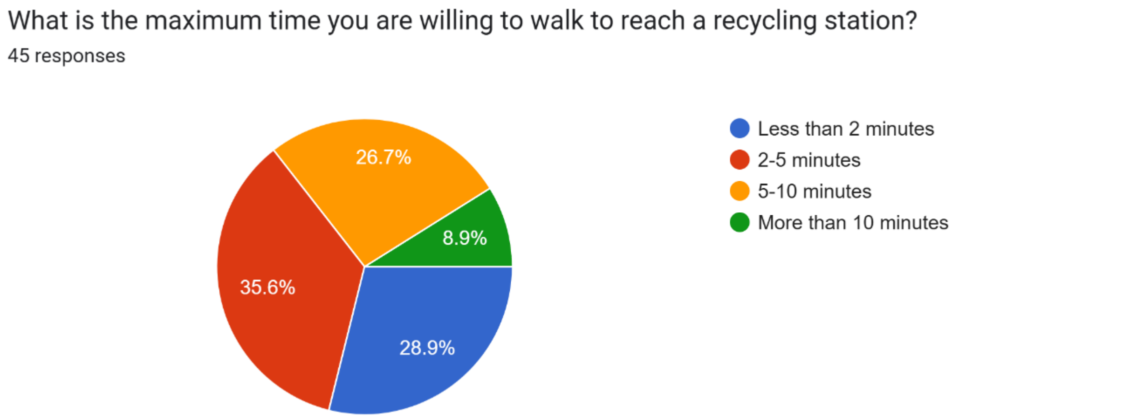


Chart 3.3.3.8 Recycling Bins Accessibility Question Five

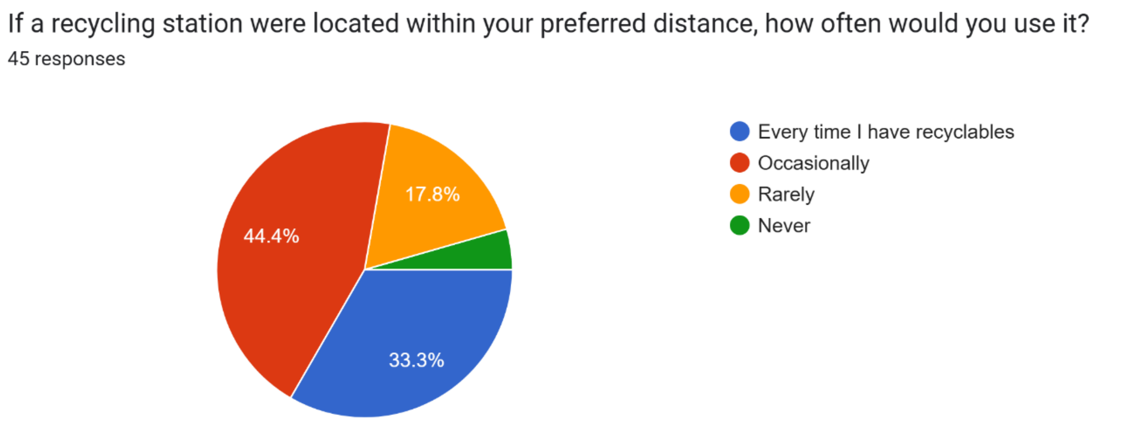
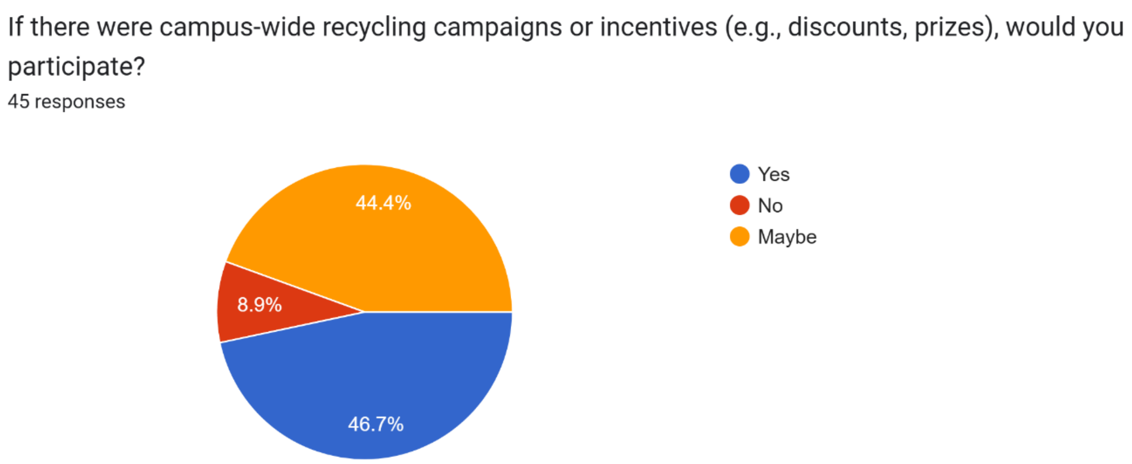


Chart 3.3.3.9 Recycling Bins Accessibility Question Six



According to the questionnaire, most of the students are aware of the current location of recycling bins or stations on campus but they rarely recycle within the UUM. They most often dispose of paper and plastic materials on campus. Most of the students are dissatisfied with the current placement of recycling stations on campus due to the inconvenient recycling bins and station locations. Most of them think that Cafeterias need more than one set of recycling bins to be placed at and the maximum time that they are willing to walk to reach the recycling station is 2-5 minutes, which they will occasionally use the recycling station if it were located within their preferred distance. Lastly, most of the respondents are willing to participate in the campus-wide recycling campaign or incentives.

3.4 Model Development

In the stage of model development, a mathematical model that consists of decision variable, objective function and constraints is formulated for the recycling station placement set covering problem in UUM, Sintok. The mathematical model is known as Integer Programming (IP) model. The main objective is to maximize the coverage of all students' recycling needs in university while ensuring minimum total cost of placing the recycling stations. The modelling components such as decision variables, objective function, constraints, model evaluation and expected findings.

The indices in the model are defined as follows:

i : Index of demand points.

j : Index of potential recycling station locations.

The parameters of each variable are:

I : Set of demand points.

J : Set of potential recycling station locations, J = 53, including cafeterias, dormitories, lecture halls, libraries, and sports facilities.

d_{ij} : Walking time between demand point i and potential location j.

C_{ij} : Binary parameter indicating whether the potential location has walking time less than 5 minutes.

3.4.1 Decision Variables

Other than the indices and parameters of the model, the first step in formulation of this integer programming is to define the decision variables of the problem and it is denoted as follows:

$$X_j \begin{cases} 1 \text{ if a recycling station is placed at potential location j} \\ 0 \text{ otherwise} \end{cases}$$

for j = 1,2,3,4, . . ., 53

3.4.2 Objective Function

The objective function in this research is to maximize the total coverage of demand points within 2-5 minutes walking time range:

$$\text{Minimize Z} = \sum_{j \in \mathrm{J}} X_j$$

where C_{ij} is a binary parameter that equals to 1 if the distance between demand point and potential recycling station location, $d_{ij} \leq 5$ minutes and C_{ij} equals to 0 otherwise.

3.4.3 Constraints

There are two constraints in this research, and both of it are hard constraints which have strict requirements that must be satisfied in the solution. The constraints that have been considered in this model are:

a) Each demand point must be covered at least one recycling station within the range of less than 5 minutes walking time.

$$\sum_{j \in \mathrm{J}:\, d_{ij} \leq 5} C_{ij} \,.\, x_j \geq 1, \forall_i \in \mathrm{I}$$

b) Each location must be record 0 or 1 which represents the location of recycling bins placed:

$$x_j \in \{0,1\}, \forall_j \in \mathrm{J}$$

c) Five current locations must be recorded as 1:

$$x_j = 1$$

Where j = node of current recycles station placement

3.4.4 Model Evaluation

The proposed model, including its objective function and constraints, is developed and assessed during the evaluation stage. This evaluation assists management in making decisions to create an optimal schedule. Comparing the actual data with the model's output is crucial for identifying potential improvements and finding better solutions. To ensure the correctness of the calculations by manual, Microsoft Excel is used to check it as an automated result checking,

3.4.5 Cost Calculation

By minimizing the cost that will be used in recycling process including waste collecting costs and operating costs, the total cost will be calculated by using information from online websites and the result that will be shown in Chapter 4. The cost calculation is conducted to examine how much the cost of the recycling station is according to the number of recycling stations that are placed in this university.

3.4.6 Expected Findings

The expected findings of this study are:

i. An integer programming model that helps to produce the optimal solution of recycle station placement in UUM.

ii. An excel calculation that helps to ensure the reliability of the manual calculation.

iii. A cost calculation that helps to determine the total cost of the recycle station placement.

CHAPTER 4

IMPLEMENTATION AND RESULTS

4.1 Introduction

The previous chapter discussed the proposed methodology which is Integer Programming (IP) model used to solve the recycle station placement problem in Chapter Two. This chapter will more focus on the implementation of the model that has proposed and result interpretation. First of all, the implementation of the proposed model for solving the problem that we mentioned before is examined and then followed by the interpretation of the results that were obtained from the integer programming model. The model is shown by using nodes and branches which are done manually and a version of automated results by using Microsoft Excel will be done to ensure the reliability of the manual results.

The evaluation such as a comparison between the proposed model and the current situation is presented to identify whether the proposed model does improve and better than the current situation that achieve the objectives.

4.2 Information Gathered

As stated in Chapter Two, the current situation of recycle station placement in Universiti Utara Malaysia are office Inasis Yayasan Al-Bukhary, office Inasis SME Bank, Pusat Budaya dan Seni, office Inasis Sime Darby, office School of Quantitative Science (SQS) and Varsity Mall. All the placement is collected through observation. A questionnaire was also distributed to students UUM to collect data regarding their demographic information, recycling behaviors and the recycling bins accessibility in university.

4.2.1 Information Related to Recycling Behavior and Recycling Bins Accessibility

The data of students' recycling behaviors and the recycling bins accessibility in UUM were collected through a questionnaire survey Section B by using Google Form. The sample questionnaire is attached to Appendices. The charts are all shown in Chapter Three. Through the questionnaire, the materials that students often dispose in university will be plastic and paper. Hence, the recycling bins that will be used to collect these two materials must be placed in every single recycling station. This research is proposed due to the inconvenient locations that have the highest vote of the main reasons that prevent students from recycling from campus.

Moreover, cafeterias are places where students think more than one set of recycling bins should be placed and the maximum time for students willing to walk to reach a recycling station is 2 to 5 minutes. This information is used as a constraint that every point must not be more than 5 minutes and students will use it occasionally if the recycling station is located within their preferred distance.

4.3 Implementation and Result of the Proposed Model

The objective function is to minimize the number of recycling station placements and maximize the coverage in university. Its demand points also act as potential locations for the placement since the objective of the function is to cover every cafeteria, lecture halls, dormitories, libraries and sport facilities (not including Sisiran Sintok).

The variables involved in this model are:

I : Set of demand points, I =53.

J : Set of potential recycling station locations, J = 53, including cafeterias, dormitories, lecture halls, libraries, and sports facilities.

The objective function of this research is to minimize the number of recycling stations:

$$\text{Minimize } Z = \sum_{j \in J} X_j$$

where

$$X_j \begin{cases} 1 \text{ if a recycling station is placed at potential location j} \\ 0 \text{ otherwise} \end{cases}$$

for j = 1,2,3,4, . . ., 53

The constraints that have been considered in this model are:

1. Each demand point must be covered at least one recycling station within the range of 2-5 minutes walking time.

$$\sum_{j \in J:\, d_{ij} \leq 5} C_{ij} \,.\, x_j \geq 1, \forall_i \in I$$

Constraint 1: $x_1 = 1$

Constraint 2: $x_2 + x_3 + x_4 + x_{44} \geq 1$

Constraint 3, 4: $x_2 + x_3 + x_4 + x_5 + x_6 + x_{44} + x_{45} \geq 1$

Constraint 5, 6: $x_3 + x_4 + x_5 + x_6 \geq 1$

Constraint 7: $x_7 + x_8 + x_{11} + x_{14} \geq 1$

Constraint 8, 14: $x_7 + x_8 + x_9 + x_{10} + x_{11} + x_{12} + x_{13} + x_{14} + x_{15} + x_{16} + x_{17} \geq 1$

Constraint 9, 10, 15, 16, 17:

$$x_8 + x_9 + x_{10} + x_{11} + x_{12} + x_{13} + x_{14} + x_{15} + x_{16} + x_{17} + x_{18} \geq 1$$

Constraint 11: $x_8 + x_9 + x_{10} + x_{11} + x_{12} + x_{14} + x_{15} + x_{16} + x_{17} \geq 1$

Constraint 12: $x_7 + x_8 + x_9 + x_{10} + x_{11} + x_{12} + x_{13} + x_{14} + x_{15} + x_{16} + x_{17} + x_{18} \geq 1$

Constraint 13: $x_8 + x_9 + x_{10} + x_{12} + x_{13} + x_{14} + x_{15} + x_{16} + x_{17} + x_{18} \geq 1$

Constraint 18: $x_9 + x_{10} + x_{12} + x_{13} + x_{15} + x_{16} + x_{17} + x_{18} \geq 1$

Constraint 19: $x_{19} = 1$

Constraint 20, 21, 22, 23: $x_{20} + x_{21} + x_{22} + x_{23} \geq 1$

Constraint 24： $x_{24} = 1$

Constraint 25： $x_{25} + x_{26} + x_{27} + x_{28} + x_{29} + x_{30} \geq 1$

Constraint 26： $x_{25} + x_{26} + x_{27} + x_{28} + x_{29} + x_{30} + x_{32} \geq 1$

Constraint 27： $x_{25} + x_{26} + x_{27} + x_{28} + x_{30} + x_{31} + x_{32} \geq 1$

Constraint 28： $x_{25} + x_{26} + x_{27} + x_{28} + x_{29} + x_{30} + x_{31} + x_{32} + x_{33} \geq 1$

Constraint 29： $x_{25} + x_{26} + x_{28} + x_{29} + x_{30} + x_{31} \geq 1$

Constraint 30： $x_{25} + x_{26} + x_{27} + x_{28} + x_{29} + x_{30} + x_{31} + x_{32} \geq 1$

Constraint 31： $x_{27} + x_{28} + x_{29} + x_{30} + x_{31} + x_{32} + x_{33} + x_{34} + x_{35} + x_{46} \geq 1$

Constraint 32： $x_{26} + x_{27} + x_{28} + x_{30} + x_{31} + x_{32} + x_{33} + x_{34} + x_{35} \geq 1$

Constraint 33： $x_{28} + x_{31} + x_{32} + x_{33} + x_{34} + x_{35} + x_{36} \geq 1$

Constraint 34, 35： $x_{31} + x_{32} + x_{33} + x_{34} + x_{35} + x_{36} + x_{37} \geq 1$

Constraint 36： $x_{33} + x_{34} + x_{35} + x_{36} + x_{37} + x_{39} \geq 1$

Constraint 37： $x_{34} + x_{35} + x_{36} + x_{37} + x_{38} + x_{39} + x_{41} \geq 1$

Constraint 38： $x_{37} + x_{38} + x_{39} + x_{40} \geq 1$

Constraint 39： $x_{36} + x_{37} + x_{38} + x_{39} + x_{40} + x_{41} + x_{42} + x_{43} \geq 1$

Constraint 40: $x_{38} + x_{39} + x_{40} + x_{41} + x_{42} + x_{43} \geq 1$

Constraint 41： $x_{37} + x_{39} + x_{40} + x_{41} + x_{42} + x_{43} + x_{45} \geq 1$

Constraint 42： $x_{39} + x_{40} + x_{41} + x_{42} + x_{43} + x_{45} \geq 1$

Constraint 43： $x_{39} + x_{40} + x_{41} + x_{42} + x_{43} + x_{44} + x_{45} \geq 1$

Constraint 44： $x_{2} + x_{3} + x_{4} + x_{43} + x_{44} + x_{45} \geq 1$

Constraint 45： $x_{3} + x_{4} + x_{41} + x_{42} + x_{43} + x_{44} + x_{45} \geq 1$

Constraint 46： $x_{31} + x_{46} \geq 1$

Constraint 47, 48： $x_{47} + x_{48} \geq 1$

Constraint 49： $x_{49} + x_{50} + x_{51} \geq 1$

Constraint 50, 51： $x_{49} + x_{50} + x_{51} + x_{52} + x_{53} \geq 1$

Constraint 52, 53： $x_{50} + x_{51} + x_{52} + x_{53} \geq 1$

2. Each location must be record 0 or 1 which represents the location of recycling bins placed:

$$x_j \in \{0,1\}, \forall_j \in \mathrm{J}$$

3. Five current locations must be recorded as 1:

$$x_j = 1$$

Where j = 4, 23, 32, 37, 52

4.3.1 Output of the Model

There are a total of 53 demand points and potential locations points which all are in categories of cafeteria, lecture halls, dormitories, sport facilities and library. The table shows all the node numbers following by the location name and the type of location. As information, the locations that are in the same buildings we counted as one node.

4.3.1 Potential Recycling Station Locations and Demand Points

Node	Location	Type of location
1	Cafe Campus Brew	Cafeteria
2	Cafe DKG 6	Cafeteria
3	Dewan Kuliah Gugusan 6 (DKG 6)	Lecture Hall
4	School of Technology Management and Logistics (STML), School of Quantitative Sciences (SQS), School of Creative Industry Management and Performing Arts (SCIMPA), School of Multimedia Technology and Communication (SMMTC)	Lecture Hall
5	School of Government (SOG), School of Law (SOL), Cafe DKG 5	Lecture Hall, Cafeteria
6	Dewan Kuliah Gugusan 5 (DKG 5)	Lecture Hall
7	Manager's Coffee, Perpustakaan Sultanah Bahiyah	Cafeteria, Library

8	Cafe Hijau Kuning	Cafeteria
9	School of Economics, Finance and Banking (SEFB), Islamic Business School (IBS)	Lecture Hall
10	Dewan Kuliah Gugusan 3 (DKG 3)	Lecture Hall
11	School of Business Management (SBM)	Lecture Hall
12	Tunku Puteri Intan Safinaz School of Accountancy (TISSA)	Lecture Hall
13	School of Education (SOE), School of Language, Civilisation and Philosophy (SLCP), Cafe Pusat Bahasa	Lecture Hall, Cafeteria
14	Dewan Kuliah Gugusan 2 (DKG 2)	Lecture Hall
15	Dewan Kuliah Gugusan 1 (DKG 1)	Lecture Hall
16	School of Applied Psychology, Social Work and Policy (SAPSP)	Lecture Hall
17	Cafe Alumni Junction	Cafeteria
18	School of Computing (SOC), Dewan Kuliah Gugusan 4 (DKG 4)	Lecture Hall
19	Sport Complex Universiti Utara Malaysia	Sport Facility
20	Cafe Bank Muamalat	Cafeteria
21	Inasis Bank Muamalat	Dormitory
22	Cafe YAB	Cafeteria
23	Inasis Yayasan Al-Bukhary (YAB)	Dormitory
24	Academy Golf National (AGN)	Lecture Hall
25	Cafe MISC	Cafeteria
26	Inasis MISC	Dormitory
27	Cafe BSN	Cafeteria
28	Inasis BSN	Dormitory

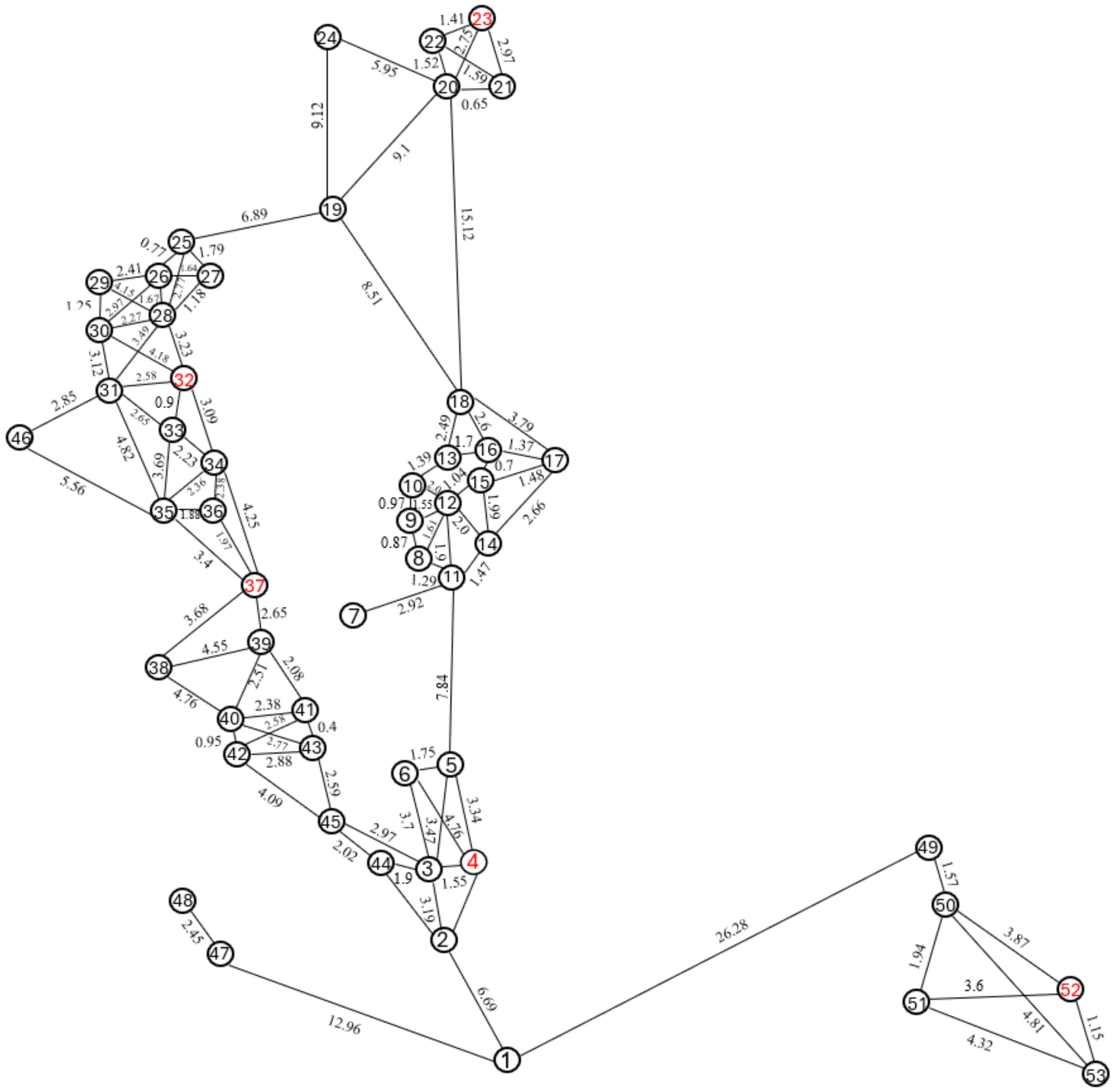
29	Inasis TM	Dormitory
30	TM Canteen	Cafeteria
31	Inasis Bank Islam	Dormitory
32	Inasis Sime Darby	Dormitory
33	Kafe Sri Jenan (Kafe Sime Darby)	Cafeteria
34	Cafe Petronas	Cafeteria
35	Cafe Inasis Bank Islam	Cafeteria
36	Inasis Petronas	Dormitory
37	Varsity Mall	Cafeteria
38	S'Antik Cafe (Cafe Pusat Islam)	Cafeteria
39	Inasis Tradewinds	Dormitory
40	Proton Cafeteria	Cafeteria
41	Inasis TNB	Dormitory
42	Inasis Proton	Dormitory
43	Cafe Inasis TNB (Medan Selera TNB)	Cafeteria
44	Inasis MAS	Dormitory
45	Kafeteria MAS	Cafeteria
46	Inasis Maybank	Dormitory
47	School of International Studies (SOIS), Dewan Kuliah Gugusan 7 (DKG 7)	Lecture Hall
48	School of Tourism, Hospitality and Event Management (STHEM), Dewan Kuliah Gugusan 8 (DKG 8)	Lecture Hall
49	Kafe Inasis Bank Rakyat	Cafeteria
50	Inasis Bank Rakyat	Dormitory

51	Cafe Kachi	Cafeteria
52	Inasis SME Bank	Dormitory
53	Cafe SME Bank	Cafeteria

The potential recycling station locations shows in one node if the places are located in the same building. The graph 4.3.2 shows the set covering model by using the data from the table 4.3.1. It totals have 53 nodes and the node that highlighted in red indicates the current recycling station placement in UUM. Hence, the current recycling station placements will remain unchanged, while the model will determine the additional recycling stations needed to maximize coverage across the university.

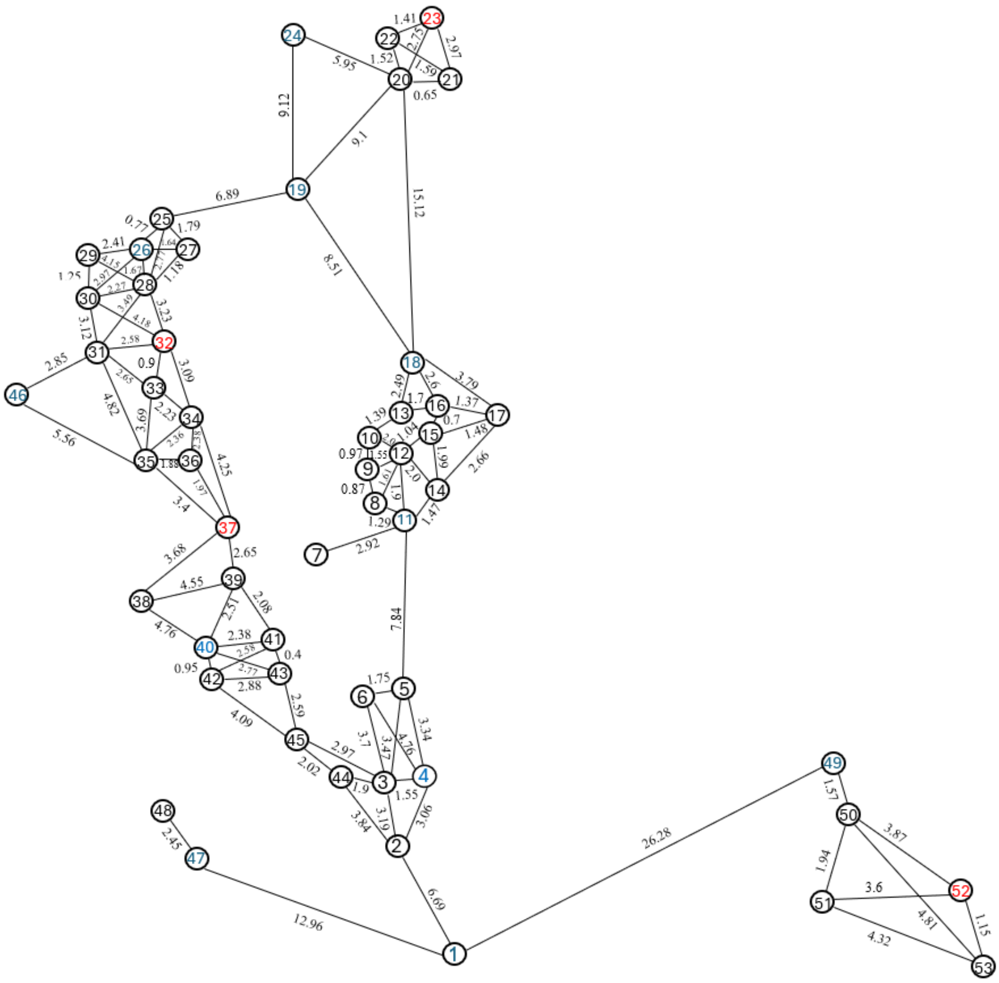
The recycling station at the office inasis for the current placement situation are counted as at inasis. As an example, the current recycling station at office inasis Sime Darby, hence the node of inasis Sime Darby is highlighted to represent it. As shown, there are four places that have recycling stations currently, which include node 4, 23, 32, 37 and 52.

Graph 4.3.2 Current Recycling Stations Placement



Graph 4.3.3 shows the recycling stations placement of proposed model by manual. As a result, there will be total 15 recycling stations should be placed which are located at node 1, 4, 11, 18, 19, 23, 24, 26, 32, 37, 40, 46, 47, 49 and 52. These recycling station placement can covered the whole area and students just need less than 5 minutes of walking times to reach each of their nearby recycling stations to recycle. Hence, the recycling rate can be increased in UUM.

Graph 4.3.3 Recycling Stations Placement of Proposed Model



Last but not least, the 15 recycling stations should located at node 1- Cafe Campus Brew, 4- STML & SQS & SCIMPA & SMMTC, 11- School of Business Management (SBM), 18- School of Computing (SOC), Dewan Kuliah Gugusan 4 (DKG 4), 19- Sport Complex Universiti Utara Malaysia, 23- Inasis Yayasan Al-Bukhary (YAB), 24- Academy Golf National (AGN), 26- Inasis MISC, 32- Inasis Sime Darby, 37- Varsity Mall, 40- Proton Cafeteria, 46- Inasis Maybank, 47- School of International Studies (SOIS), Dewan Kuliah Gugusan 7 (DKG 7), 49- Kafe Inasis Bank Rakyat and 52- Inasis SME Bank.

4.4 Model Evaluation

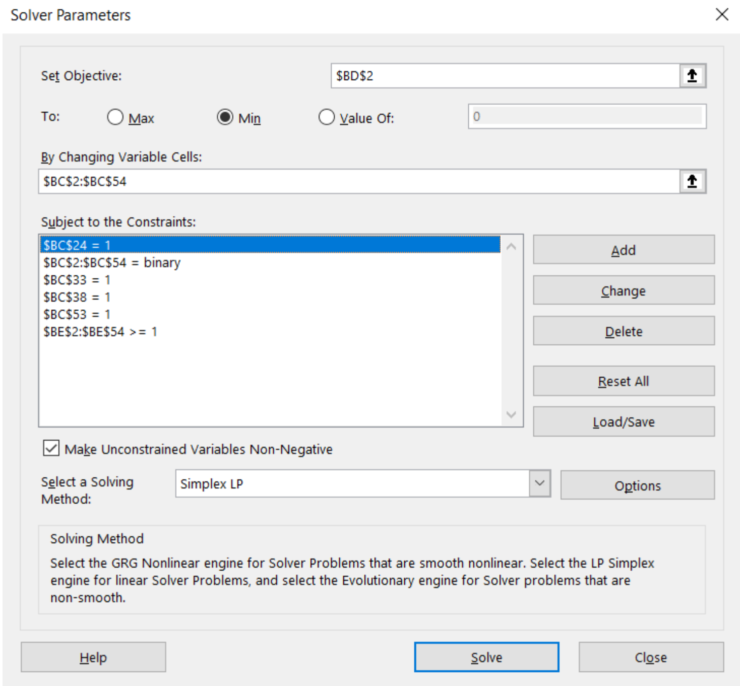
The evaluation was conducted after obtaining the results from the proposed model. In this part, the results of the proposed model were compared with the current situation. A comparison between the proposed model by using manual and a model generated by using Excel Solver is conducted.

4.4.1. Summary of Results and Comparison

In this research, the current situation of recycling station placement has only 5 of it (Pusat Budaya dan Seni does not counted in this research but it exists) while it does not cover all the areas in UUM. Hence, there are students which mentioned that the inconvenient location is one of the main reasons that cause them rarely to recycle. To increase the recycling rate within the students, the proposed model shows that at least 11 more recycling stations should be placed in this university so that students can reach the recycling station within the walking time of less than 5 minutes. The difference between the two models obviously shows that the coverage has been maximized.

For the comparison between conducted manually and conducted by using software, it gets the same results which is total 15 recycle stations should be placed in this university to reach the maximum coverage. In the excel solver, 53 x 53 matrix tables have been conducted to represent potential location as row and recycling station as column. After filling up the coverage of each location within 5 minutes walking time, the decision variable, objective function and coverage matrix is conducted. The objective function is the set objective in Excel Solver which needs to find the minimum value and decision variable is the changing variable cells. The constraints are the decision variable of each location must be binary, for decision variable of the current recycle station location must be 1 and every coverage matrix must be more or equal to 1.

Figure 4.4.1.1 Excel Solver



The following figure shows the results from Excel Solver which shows that node 1- Cafe Campus Brew , 4- STML & SQS & SCIMPA & SMMTC, 7- Manager's Coffee & Perpustakaan Sultanah Bahiyah, 9- School of Economics, Finance and Banking (SEFB), Islamic Business School (IBS) , 19- Sport Complex Universiti Utara Malaysia , 23- Inasis Yayasan Al-Bukhary (YAB), 24- Academy Golf National (AGN), 25- Cafe MISC, 31- Inasis Bank Islam, 32- Inasis Sime Darby, 37- Varsity Mall, 39- Inasis Tradewinds, 47- School of International Studies (SOIS), 49- Kafe Inasis Bank Rakyat and 52- Inasis SME Bank. A total of 15 locations should become a recycling station. It gets the same number of recycling stations, but different nodes of recycling stations are chosen. Hence, this is the alternative way of recycling stations placement in UUM.

Figure 4.4.1.2 Recycling Stations Placement of Proposed Model

	A	BC	BD	BE	BF	BG
1	Potential locati	Decision Variable	Objective Function	Coverage Matrix		
2	Location 1	1	15	1	>=	1
3	Location 2	0		1	>=	1
4	Location 3	0		1	>=	1
5	Location 4	1		1	>=	1
6	Location 5	0		1	>=	1
7	Location 6	0		1	>=	1
8	Location 7	1		1	>=	1
9	Location 8	0		2	>=	1
10	Location 9	1		1	>=	1
11	Location 10	0		1	>=	1
12	Location 11	0		1	>=	1
13	Location 12	0		2	>=	1
14	Location 13	0		1	>=	1
15	Location 14	0		2	>=	1
16	Location 15	0		1	>=	1
17	Location 16	0		1	>=	1
18	Location 17	0		1	>=	1
19	Location 18	0		1	>=	1
20	Location 19	1		1	>=	1
21	Location 20	0		1	>=	1
22	Location 21	0		1	>=	1
23	Location 22	0		1	>=	1
24	Location 23	1		1	>=	1
25	Location 24	1		1	>=	1
26	Location 25	1		1	>=	1
27	Location 26	0		2	>=	1
28	Location 27	0		3	>=	1
29	Location 28	0		3	>=	1
30	Location 29	0		2	>=	1
31	Location 30	0		3	>=	1
32	Location 31	1		2	>=	1
33	Location 32	1		2	>=	1
34	Location 33	0		2	>=	1
35	Location 34	0		3	>=	1
36	Location 35	0		3	>=	1
37	Location 36	0		2	>=	1
38	Location 37	1		2	>=	1
39	Location 38	0		2	>=	1
40	Location 39	1		2	>=	1
41	Location 40	0		1	>=	1
42	Location 41	0		2	>=	1
43	Location 42	0		1	>=	1
44	Location 43	0		1	>=	1
45	Location 44	0		1	>=	1
46	Location 45	0		1	>=	1
47	Location 46	0		1	>=	1
48	Location 47	1		1	>=	1
49	Location 48	0		1	>=	1
50	Location 49	1		1	>=	1
51	Location 50	0		2	>=	1
52	Location 51	0		2	>=	1
53	Location 52	1		1	>=	1
54	Location 53	0		1	>=	1

4.5 Cost Calculation

To calculate the cost of placing the recycle bins in each location that proposed, the price of recycle bins is surveyed. One 120 litres recycle bins cost around RM 135 and each place should have 3 colours of recycle bins which is to collects plastics and alunimium, papers and glass. Hence, one set of recycle bins that included one blue bin, one brown bin and one orange bin total cost RM405.

Therefore, if a cafeteria is chosen as a recycle station, it must be 2 sets of recycling bins. According to the questionnaire, there is one question that student feedback that agree of cafeteria are should have more than one set of recycling bins placed. Hence, every potential location which is cafeteria will be placed with two sets of recycling bins to fulfil students' needs. There are 6 more locations that need one set of recycle bins excluding the existing one, 4 more cafeterias that need two sets of recycling bins and one more for the station inasis SME Bank because the current bins that are located only collect plastic bottle and bottle cap.

$$(7 \text{ x } RM405) + (4 \text{ x } RM\ 3240) = RM\ 2835 + RM12960 = RM\ 15795 \text{ (maximum)}$$

$$11 \text{ x } RM405 = RM\ 4455 \text{ (minimum)}$$

As a result, the total cost to place recycling station that can have the maximum coverage in the university cost RM4455 which equals 11 sets of recycle bins or 33 recycle bins if every station only has one set of recycle bins. On the other hand, if the cafeteria needed two sets of recycle bins to fulfil students' needs, the cost would be RM15795, which required 15 sets of recycle bins or 45 recycle bins.

4.6 Conclusion

In this chapter, the proposed model is compared with the actual situation in the university by showing the set covering model using nodes and branches. The cost that will be used to set up the recycling stations according to the proposed model are calculated. It was found that this is the optimal solution for recycling station placements which have the minimum cost.

CHAPTER 5
CONCLUSION

5.1 Introduction

The last chapter highlights all aspects of the study, which includes that summary, contributions, limitations and suggestions for future research.

5.2 Summary of the Study

This research contains five chapters which are introduction, literature review, methodology, implementation and results and conclusion. Chapter One briefly describes the introduction of this study, research background, problem statement, research question, research objectives, scope of this study and significance of this study. It provided a general description of this study and highlighted the importance of recycle management in this world. This chapter is concluded with an outline of the study that serves readers a brief description of what to expect in the following chapters.

Chapter Two provides an overview of previous research on the set covering problems in several types of location and the solution techniques that have been used to solve it. The relevant constraints, types of problems and methods used were identified and summarized as tables. After considering every factor, the Integer Programming model that was used for Set Covering model was chosen as the most suitable techniques to solve the problem of recycling station placement for this research.

Chapter Three describes the methodology of the proposed approach which is set covering method to recycle station placement problem. The research design of this study was shown in this chapter. There are six stages of it, and it was all conducted to achieve the four research objectives. The method of data collection, constraint and model development was explained. The primary data is collected through observation and questionnaires and the current recycle station placement is shown in this chapter. An Integer Programming model was developed to address the recycle station placement problem after the data is collected. The decision variables, objective functions and constraints are clearly defined in the model development section. This model is to minimize the number of recycling stations by ensuring that the maximum coverage of university.

Chapter Four describes how the data has been analyzed and interpreted in this study. This chapter focuses on the implementation of the proposed model and result interpretation. The information that collected from the questionnaire is interpreted in this chapter. For implementation and result of the proposed model, the objective function, constraints of this model are explained. The constraints show that the walking distance between potential location and demand points must be less than 5 minutes, and decision variable will be in binary only and the decision variables of current recycle station must be 1 which represents a recycle station is located at this point. Other than that, the coverage matrix, node number, location name and the type of location are shown in this chapter. The results are shown by using nodes and branches, a total of 15 recycle stations should be placed in this university to cover the whole area. The result is then compared with the current placement and result that generated by using Excel Solver. Excel Solver has shown the same number of recycling stations but in alternative ways and the cost is calculated according to the number of stations.

5.3 Contributions of the Study

The contributions of this study are:

1. This study aims to optimize the placement of recycle station by maximizing the coverage and minimizing the total cost. The proposed IP model systematically addresses the trade-off between cost efficiency and accessibility, providing a practical solution for effective recycling management within a university campus.
2. By considering walking distance constraints (less than five minutes between demand points and recycling stations), this study ensures the practicality and usability of the

recycling stations. This approach enhances convenience for users and increases the likelihood of recycling participation across the campus.

3. The study evaluates the current recycling station placement against the optimized model generated through Excel Solver. The comparison highlights areas for improvement and offers alternative placement strategies that achieve similar coverage with potentially lower costs or better distribution.

4. By proposing a systematic and quantitative methodology for recycling station placement, this study contributes to sustainable waste management practices. The findings serve as a practical reference for universities and other organizations aiming to enhance their recycling infrastructure.

5.4 Limitations of the Study

This study focuses specifically on optimizing the placement of recycling stations to maximize coverage for students on campus. The current model considers only the recycling needs of students, excluding other groups such as university staff and workers in locations like administrative offices and facilities such as the other management office. Including these groups in the analysis would provide a more comprehensive solution for the entire university community and could potentially increase the overall recycling rate.

Some of the cafes and food establishments, which are significant sources of recyclable waste, were not included in the current study due to their potential for relocation or closure in the future. Incorporating such dynamic factors into the model would introduce significant mathematical complexity, making it challenging to identify feasible and stable solutions within a reasonable timeframe. The recycling station placement model must be periodically updated to reflect changes in the university layout, student population, and recycling behaviors. This requires the involvement of individuals with expertise in Integer Programming and optimization to ensure the model remains effective and aligned with current conditions.

5. 5 Suggestions for Future Research

While this study has achieved significant results in optimizing recycling station placement for students, there remain opportunities for further exploration and enhancement in future research. Future research could expand the scope of this study by including all university members, such as staff, faculty, and workers, in addition to students. Locations like administrative offices, academic buildings, and shared facilities could be integrated into the model to create a more comprehensive recycling system. Incorporating these additional areas could significantly improve the recycling rate across the entire university.

The model could be enhanced by accounting for dynamic changes in campus infrastructure, such as cafes or other facilities that may open, close, or relocate over time. This would require a more flexible and adaptable approach to optimize the recycling station placement under varying conditions. Researchers could explore adaptive optimization techniques to address this complexity.

On the other hand, the proposed model focuses on the current placement scenario, but future studies could explore the development of long-term placement strategies that account for anticipated changes in campus layouts, student population growth, and recycling behaviors. Such strategies could involve creating dynamic models that are periodically updated to align with evolving conditions and ensure the sustainability of the recycling system.

Moreover, future research could consider additional factors such as minimizing including maintenance fee and collecting fee. While this study prioritizes maximizing student convenience, incorporating financial constraints could help balance environmental goals with economic sustainability. This study is slightly calculated the expenses of buying the bins but not too fully covered the economic sustainability. Hence, future research can be conducted from economic aspects to minimizing the cost.

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APPENDICES

MINIMIZING COSTS AND MAXIMIZING COVERAGE: RECYCLING STATION PLACEMENT IN UNIVERSITI UTARA MALAYSIA BY USING SET COVERING APPROACH

Good day, fellow UUM students!

My name is Kh'ng Wei Xin, and I'm a final-year student pursuing a Bachelor of Science with Honours (Decision Science) from the School of Quantitative Sciences (SQS) at Universiti Utara Malaysia. Currently, I am conducting my research about "Minimizing Costs and Maximizing Coverage: Recycling Station Placement in Universiti Utara Malaysia Using the Set Covering Approach." under SQQZK4993 Academic Project.

Your input is essential! By sharing your recycling habits and preferences, you'll be helping to identify the best locations for recycling bins across campus to make recycling more accessible and effective for everyone. The recycle station that mentioned in this form is referred to one set of recycle bins for Paper, Plastic and Glass. This survey will take only **3-5 minutes** to complete, and all responses are completely confidential. The information you provide will be used solely for academic purposes.

Together, let's work towards a more sustainable UUM!

This survey consists of three sections:

- Section A: Demographic Information
- Section B: Recycling Behavior
- Section C: Recycling Bins Accessibility

Your cooperation and honest feedback are greatly appreciated and will directly contribute to a cleaner, greener UUM. Thank you for making a difference and helping to improve our campus environment!

Section A: Demographic Information

Basic information about you

Gender *

- ◯ Male
- ◯ Female

Current Semester *

- ◯ Semester 1
- ◯ Semester 2
- ◯ Semester 3
- ◯ Semester 4
- ◯ Semester 5
- ◯ Semester 6
- ◯ Semester 7
- ◯ Semester 8
- ◯ Other: ______

College *

- ◯ College of Business (COB)
- ◯ College of Arts and Sciences (CAS)
- ◯ College of Law, Government and International Studies (COLGIS)

Current Residence Location *

- ◯ On-campus (e.g., INASIS Petronas)
- ◯ Off-campus (KACHI)

Section B: Recycling Behavior

Your habits and preferences when it comes to recycling on campus.

Are you aware of the current locations of recycling bins or stations on campus? *

- ◯ Yes
- ◯ No

How often do you recycle within the UUM campus? *

- ◯ Daily
- ◯ Weekly
- ◯ Monthly
- ◯ Rarely
- ◯ Never

What materials do you most often dispose of on campus that could be recycled? *

- ☐ Plastic
- ☐ Aluminum
- ☐ Paper
- ☐ Glass

Section C: Recycling Bins Accessibility

Your thoughts on the best locations and distances for convenient recycling stations.

How satisfied are you with the current placement of recycling stations on campus? *

Very Dissatisfied

1 ○

2 ○

3 ○

4 ○

5 ○

Very Satisfied

What are the main reasons that prevent you from recycling on campus?

☐ Lack of recycling bins

☐ Inconvenient locations

☐ Lack of information about what can be recycled

☐ Not enough time

☐ Other: ______

In which areas of the campus do you think more than one set of recycling bins should be placed? *

○ Lecture halls

○ Cafeterias

○ Dormitories

○ Libraries

○ Sports facilities

What is the **maximum** time you are willing to walk to reach a recycling station? *

○ Less than 2 minutes

○ 2-5 minutes

○ 5-10 minutes

○ More than 10 minutes

If a recycling station were located within your preferred distance, how often would you use it? *

○ Every time I have recyclables

○ Occasionally

○ Rarely

○ Never

If there were campus-wide recycling campaigns or incentives (e.g., discounts, prizes), would you participate? *

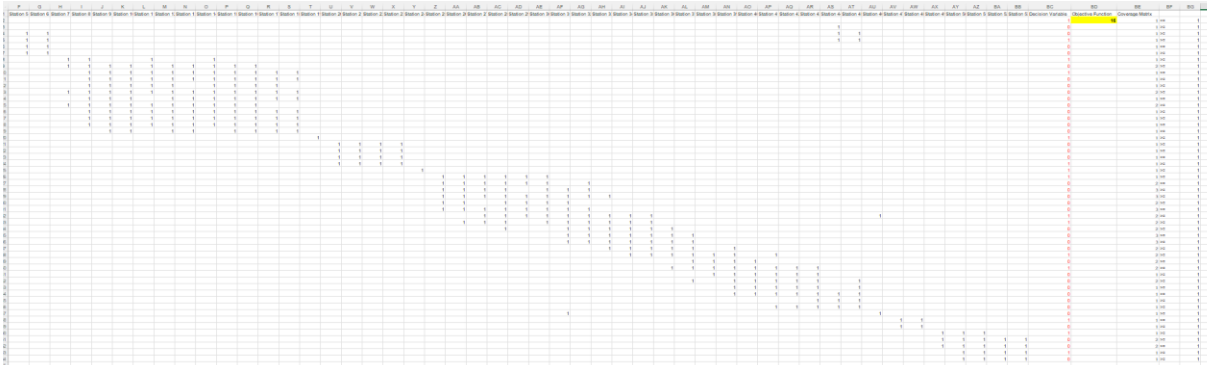
○ Yes

○ No

○ Maybe

Gender	Current Semester	College	Current Residence Location	Are you aware of the current locations of re	How often do you recycle within the UUM c	What materials do you most often dispose
Female	Semester 7	College of Arts and S	Off-campus (KACHI)	No	Never	Plastic, Paper
Male	Semester 7	College of Arts and S	On-campus (e.g., INASIS Pet	Yes	Weekly	Aluminum
Female	Semester 7	College of Arts and S	Off-campus (KACHI)	No	Rarely	Plastic, Paper
Female	Semester 7	College of Business (	Off-campus (KACHI)	No	Rarely	Plastic, Aluminum, Paper
Female	Semester 7	College of Business (	On-campus (e.g., INASIS Pet	Yes	Rarely	Plastic, Paper
Female	Semester 7	College of Arts and S	Off-campus (KACHI)	No	Monthly	Plastic
Female	Semester 7	College of Arts and S	Off-campus (KACHI)	No	Never	Paper
Female	Semester 7	College of Business (	Off-campus (KACHI)	Yes	Weekly	Plastic, Aluminum, Paper, Glass
Male	Semester 7	College of Arts and S	Off-campus (KACHI)	Yes	Rarely	Paper
Female	Semester 8	College of Business (	On-campus (e.g., INASIS Pet	Yes	Rarely	Paper
Male	Semester 7	College of Business (	Off-campus (KACHI)	No	Never	Plastic, Paper
Female	Semester 7	College of Business (	Off-campus (KACHI)	Yes	Rarely	Plastic, Paper
Female	Semester 7	College of Business (	Off-campus (KACHI)	Yes	Rarely	Plastic, Paper
Male	Semester 7	College of Arts and S	Off-campus (KACHI)	Yes	Weekly	Aluminum, Paper
Female	Semester 6	College of Arts and S	Off-campus (KACHI)	Yes	Rarely	Plastic, Paper
Female	Semester 5	College of Law, Gove	On-campus (e.g., INASIS Pet	Yes	Monthly	Aluminum, Paper
Male	Semester 7	College of Business (	Off-campus (KACHI)	Yes	Rarely	Plastic, Paper
Male	Semester 7	College of Law, Gove	On-campus (e.g., INASIS Pet	Yes	Rarely	Plastic
Female	Semester 5	College of Business (	On-campus (e.g., INASIS Pet	Yes	Weekly	Plastic, Paper
Male	Semester 5	College of Business (	On-campus (e.g., INASIS Pet	Yes	Rarely	Paper
Male	Semester 5	College of Arts and S	On-campus (e.g., INASIS Pet	Yes	Rarely	Plastic, Paper
Male	Semester 5	College of Business (	On-campus (e.g., INASIS Pet	Yes	Weekly	Plastic, Paper
Female	Semester 7	College of Business (	On-campus (e.g., INASIS Pet	Yes	Never	Plastic, Paper
Male	Semester 5	College of Arts and S	On-campus (e.g., INASIS Pet	No	Rarely	Plastic, Paper
Male	Semester 7	College of Arts and S	Off-campus (KACHI)	Yes	Rarely	Plastic, Glass
Female	Semester 7	College of Law, Gove	On-campus (e.g., INASIS Pet	No	Never	Paper
Female	Semester 5	College of Business (	Off-campus (KACHI)	Yes	Rarely	Plastic, Paper
Female	Semester 7	College of Arts and S	On-campus (e.g., INASIS Pet	No	Monthly	Plastic, Paper
Female	Social animal wryyyy	College of Business (	On-campus (e.g., INASIS Pet	No	Rarely	Paper
Female	Semester 5	College of Arts and S	Off-campus (KACHI)	Yes	Never	Paper
Male	Semester 7	College of Arts and S	Off-campus (KACHI)	Yes	Rarely	Paper
Female	Semester 7	College of Arts and S	On-campus (e.g., INASIS Pet	Yes	Rarely	Plastic
Female	Semester 7	College of Arts and S	Off-campus (KACHI)	Yes	Never	Plastic, Paper
Female	Semester 4	College of Arts and S	Off-campus (KACHI)	No	Rarely	Plastic, Aluminum, Paper
Female	Semester 7	College of Business (	On-campus (e.g., INASIS Pet	No	Never	Plastic, Paper
Female	Semester 7	College of Arts and S	Off-campus (KACHI)	Yes	Rarely	Plastic
Female	Semester 3	College of Arts and S	On-campus (e.g., INASIS Pet	Yes	Monthly	Plastic
Female	Semester 7	College of Business (	On-campus (e.g., INASIS Pet	Yes	Weekly	Plastic, Paper
Female	Semester 1	College of Arts and S	On-campus (e.g., INASIS Pet	Yes	Never	Plastic, Aluminum
Male	Semester 7	College of Arts and S	Off-campus (KACHI)	Yes	Never	Plastic
Male	Semester 3	College of Arts and S	On-campus (e.g., INASIS Pet	No	Never	Paper
Male	Semester 5	College of Business (	On-campus (e.g., INASIS Pet	Yes	Monthly	Paper
Male	Semester 5	College of Arts and S	On-campus (e.g., INASIS Pet	No	Never	Plastic
Female	Semester 5	College of Business (	Off-campus (KACHI)	Yes	Monthly	Plastic, Paper
Male	Semester 5	College of Law, Gove	On-campus (e.g., INASIS Pet	No	Never	Aluminum, Glass

How satisfied are you with the current place	What are the main reasons that prevent yo	In which areas of the campus do you think	What is the maximum time you are willing t	If a recycling station were located within yo	If there were campus-wide recycling campa
1	Lack of recycling bins	Dormitories	2-5 minutes	Occasionally	Maybe
2	Inconvenient locations	Lecture halls	5-10 minutes	Occasionally	Yes
2	Lack of recycling bins, Inconvenient locatio	Dormitories	2-5 minutes	Rarely	Maybe
2	Lack of recycling bins, Inconvenient locatio	Cafeterias	Less than 2 minutes	Occasionally	Yes
3	Lack of recycling bins, Inconvenient locatio	Dormitories	Less than 2 minutes	Occasionally	Maybe
5	Inconvenient locations	Libraries	5-10 minutes	Never	Maybe
4	Lack of recycling bins, Inconvenient locatio	Dormitories	2-5 minutes	Rarely	Yes
4	Inconvenient locations, Lack of information	Cafeterias	5-10 minutes	Occasionally	Yes
3	Lack of recycling bins, Inconvenient locatio	Lecture halls	2-5 minutes	Every time I have recyclables	Yes
2	Lack of recycling bins, Inconvenient locatio	Cafeterias	Less than 2 minutes	Occasionally	Yes
2	Lack of recycling bins, Inconvenient locatio	Dormitories	2-5 minutes	Every time I have recyclables	Maybe
2	Lack of recycling bins, Lack of information	Cafeterias	2-5 minutes	Every time I have recyclables	Yes
4	Inconvenient locations, Not enough time	Dormitories	5-10 minutes	Occasionally	Maybe
3	Inconvenient locations, Lack of information	Cafeterias	More than 10 minutes	Rarely	Yes
3	Inconvenient locations, Lack of information	Cafeterias	More than 10 minutes	Rarely	No
4	Lack of recycling bins, Inconvenient locatio	Dormitories	2-5 minutes	Every time I have recyclables	Yes
4	Lack of information about what can be recy	Lecture halls	5-10 minutes	Occasionally	Maybe
4	Lack of recycling bins, Inconvenient locatio	Cafeterias	More than 10 minutes	Occasionally	Yes
4	Lack of recycling bins	Dormitories	5-10 minutes	Every time I have recyclables	Yes
3	Lack of recycling bins, Inconvenient locatio	Libraries	2-5 minutes	Rarely	Yes
4	Lack of recycling bins, Inconvenient locatio	Lecture halls	Less than 2 minutes	Every time I have recyclables	Yes
3	Lack of recycling bins, Inconvenient locatio	Dormitories	2-5 minutes	Every time I have recyclables	Yes
1	Inconvenient locations, Lack of information	Cafeterias	2-5 minutes	Every time I have recyclables	Maybe
2	Lack of recycling bins, Inconvenient locatio	Cafeterias	Less than 2 minutes	Occasionally	Maybe
1	Inconvenient locations, Not enough time	Lecture halls	5-10 minutes	Occasionally	Yes
4	Lack of recycling bins	Lecture halls	Less than 2 minutes	Every time I have recyclables	Maybe
2	Lack of recycling bins, Inconvenient locatio	Cafeterias	Less than 2 minutes	Occasionally	Yes
4	Lack of recycling bins, Not enough time	Libraries	2-5 minutes	Occasionally	Maybe
2	Lack of recycling bins, Inconvenient locatio	Dormitories	5-10 minutes	Occasionally	Maybe
3	Inconvenient locations	Cafeterias	More than 10 minutes	Every time I have recyclables	Maybe
3	Lack of recycling bins, Inconvenient locatio	Cafeterias	2-5 minutes	Every time I have recyclables	Maybe
2	Lack of recycling bins, Inconvenient locatio	Dormitories	2-5 minutes	Every time I have recyclables	Yes
2	Inconvenient locations, Not enough time	Dormitories	2-5 minutes	Occasionally	Yes
3	Lack of recycling bins, Inconvenient locatio	Cafeterias	Less than 2 minutes	Every time I have recyclables	No
3	Lack of information about what can be recy	Cafeterias	Less than 2 minutes	Occasionally	Maybe
2	Inconvenient locations	Dormitories	Less than 2 minutes	Rarely	Maybe
3	Inconvenient locations, Not enough time	Sports facilities	5-10 minutes	Every time I have recyclables	Yes
1	Lack of recycling bins, Lack of information	Dormitories	5-10 minutes	Occasionally	Maybe
4	Inconvenient locations, Not enough time	Libraries	2-5 minutes	Occasionally	Maybe
2	Inconvenient locations, Lack of information	Cafeterias	5-10 minutes	Occasionally	Maybe
3	Inconvenient locations	Dormitories	Less than 2 minutes	Rarely	Maybe
2	Lack of recycling bins	Cafeterias	5-10 minutes	Occasionally	Yes
3	Inconvenient locations, Not enough time	Sports facilities	Less than 2 minutes	Rarely	No
3	Inconvenient locations	Dormitories	2-5 minutes	Every time I have recyclables	Yes
1	Inconvenient locations, Lack of information	Cafeterias	Less than 2 minutes	Never	No


Decision Variable
Objective Function
Coverage Matrix
16