Project Title: Vending Machine in KFUPM Campus

Prepared by: **Date: 12/28/2021**

Name:	**Stu-ID:**
Mohammad Melibari	201626560
Abdullah Alnaim	201668680
Mohammed Al Saleem	201766890

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Approved by	**Name**	**Signature**
Faculty Advisor	Dr. Mohammad AlDurgam	
Member-1	Dr. Tahir Mehmood	
Member-2	Dr. Ahmed Baubaid	

Abstract

In this project, we are going to help the students who live in the university dorms to face the problem that they cannot find an easy way to get food either for lunch, dinner, or breakfast, because they are very busy during the day attending the classes or they have many homework and exams. The university's restaurant has a specific period for each meal, so many students have a conflict with these dates. An easy way to solve this problem and what is our project focus on is by using a vending machine for selling food and drinks and distributing them in the students building and it will be available 24 hours per day, so every student can use it any time he wants and get it in a short time, our objective that every student can reach the vending machine maximum in 4 minutes from any buildings using Total Set Cover Problem, also we want to guarantee the food and drinks will be fresh every day, furthermore, we want to minimize the overall cost using the proper vending machine that satisfies our criteria using TOPSIS method and Analytical Hierarchy Process (AHP). The time to refill the vending machines will be optimized using the Salesman Problem. Finally, we found the type and the number of vending machines to be 4 vending machines located in 4 different buildings, also we found the best tour to refill the vending machines daily.

Summary of ISE Design Experience

<table>
<tr><td>ISE Topics</td><td>ISE 422: Set Cover Models, (3. .1)
ISE 321: Traveling Salesman Problem (TSP), (3. .2)
ISE 447: TOPSIS and analytic hierarchy process (AHP), (3. .3)</td></tr>
<tr><td>Specific Constraints</td><td>
<table>
<tr><th>Short Description of Specific Constraints</th><th>Section #</th></tr>
<tr><td>The project is considering the students housing area only.
The food and drinks should be available 24 hours every day and fresh with suitable prices.
The students can get the food and drinks easily and in a maximum of 4 minutes.
The cost of vending machines and their refill should be considered.
All the vending machines will be in center of first floor of the selected buildings.</td><td>2.3, 2.4</td></tr>
</table>
</td></tr>
<tr><td>General Constraints</td><td>
<table>
<tr><th>Constraints</th><th>Short Description
(Explain why applicable or EXPLAIN why NOT applicable)</th><th>Detailed discussion @ Section #</th></tr>
<tr><td>Health</td><td>Providing fresh and healthy food and drinks to the students.</td><td>2.1</td></tr>
<tr><td>Safety</td><td>Selecting vending machines with the highest safety specification.</td><td>2.1</td></tr>
<tr><td>Global</td><td>Our project designed for specific situation and circumstances.</td><td>2.1</td></tr>
<tr><td>Cultural</td><td>our project has no governmental regulations and that make the processes to implement the project easier.</td><td>2.1</td></tr>
<tr><td>Social</td><td>Students' community will be improved due to the change might happen from installing vending machines.</td><td>2.1</td></tr>
<tr><td>Environmental</td><td>The Vending machine energy consumption and CO2 emissions consider as environmental issue.</td><td>2.1</td></tr>
<tr><td>Economic</td><td>establishing vending machines is an improvement step to increase the student's satisfaction</td><td>2.1</td></tr>
</table>
</td></tr>
<tr><td>Alternatives and Evaluation Criteria</td><td>3.2 Alternative Solutions
3.3 Solution Evaluation</td></tr>
<tr><td>Impact of Solution</td><td>
<table>
<tr><th>Context</th><th>Short Description</th><th>Detailed discussion @ Section #</th></tr>
<tr><td>Global</td><td>The solutions would not affect or solve global issues.</td><td>4.1</td></tr>
<tr><td>Economic</td><td>The project concentrates on increasing the student's satisfaction and comfort at university's budget expense , which may affect the budget negatively a little bit.</td><td>4.1</td></tr>
<tr><td>Environmental</td><td>Reduced servicing means less time spent on the roads, with less traffic and less carbon emission.</td><td>4.1</td></tr>
<tr><td>Societal</td><td>Students' society will be enhanced as a result of this shift that may occur because of vending machine installation</td><td>4.1</td></tr>
</table>
</td></tr>
</table>

Acknowledgements

First, we thank God who helps and support us throughout our life. we would like to thank our Doctor Dr. Mohammad AlDurgam for his advice and guidance throughout our project. Also, we thank both KFUPM and SE department for allowing us to reach this point in addition, we also thank Dr. Mohammed Al-Abdel aal, Dr. Anas AL-Ghazi, and Dr. Mohammed Daffua for their advice and support.

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List of Abbreviations

AHP	:	Analytic Hierarchy Process
TOPSIS	:	Technique for Order of Preference by Similarity to Ideal Solution

Chapter 1
Introduction

In this chapter we will introduce the objective of the project, need statement, and project goals, this chapter will describe the general idea of the project, and what we want to achieve during this journey.

1.1 Project Overview

Students at KFUPM Dorms face problems with food especially at a late-night hour because restaurants at KFUPM mall and University restaurant close early, which make getting food hard and expensive for the students who are getting less than 900 SR In this project will provide the solution which is vending machines. vending machines is a machine that able you to purchase small items such as food, beverages, and candy, and coffee without human involvement, it works 24/7 and only needs to refill it with items, and it can be found in hospital, airport, and mall, and it was estimated that the average time needed to complete the purchase order is less than 30 seconds which indicate like quick process. The process of operating the vending machine has a number of problems, one of these problems is determining the right place that can serve the largest possible number of people, the second is that finding the best true to fill the machine with items, and finally determining the appropriate type of vending machine.

In our case, the machines will be distributed in the student's buildings by using the total cover technique to make sure all the students can reach the vending machine in less than 4 minutes, also the Sell Man problem will be applied to find the lowest path to refill the machines. Based on certain criteria the type of vending machines will be selected to ensure that the machine is the best choice.

1.2 Needs Statement

The students who live in the students' housing have a problem that they cannot easily get food. The students are busy during the day attending the classes or they have many homework and exams. So, they need a way to get food and drinks fast, cheap, and all the time. The university's restaurant has specific periods, and many students have a conflict with these periods. So, we want to make it possible for students to get food and drinks every day 24 hours per day and in a short time, to give them more time to study. Also, we want to guarantee the food and drinks will be fresh every day. Furthermore, we want to minimize the overall cost.

1.3 Project Goals

- Provide food and drinks to students all the time.
- The food and drinks have suitable prices.
- The students can get the food and drinks easily and in a short time.
- Provide fresh and healthy food.
- Minimize the required number of vending machines and their cost.
- Finding the best locations for the vending machines.
- Finding the best way to refill the vending machines.
- Finding the best type of vending machine.

1.4 Project Management

Table 1. Team management.

No.	Student Name	Student ID	Main Tasks
1.	Mohammad Melibari	201626560	Selecting the type of vending machines
2.	Abdullah Alnaim	201668680	Find the best refill movement
3.	Mohammed Al Saleem	201766890	Find the best vending machines' locations

Chapter 2
Problem Definition

In this chapter, we will go for deeper information and details about the project by breaking down the problem statement into several subheadings including our assumptions, objectives, and general requirements, also the specifications in order to get the highest customers and client's satisfaction, moreover, to check if it is approved by appropriate governmental agencies.

2.1 Literature Survey

After looking for some other relevant papers, we found that they are using a similar mathematical model, aimed to minimize the cost with the best location and number of entities. In our project we will use the OR (operation research) tools to implement the mathematical model and to solve the salesman problem, also we will use some fundamentals in the supply chain, and decision-making methods to select the type of vending machine.

2.2 Project Objectives

Solve the problem of students with food especially at the end of the night by establishing vending machines that sell fresh and healthy sandwiches with expected demand around 2047 in a week. Minimize the time to get the meal into four minutes from their buildings by selecting the best location. Find the required number of vending machines and their locations to ensure that all students (around 7000) can reach the vending machines easily, finding the best way to refill the machines which will reduce the time of refiling up to 12%. Finding the best vending machine that covers the students' needs such as electoral payment and, good capacity and that will increase beneficiaries, based on Vapulus "The Arab countries had witnessed a significant growth in electronic commerce and electronic payment operations, which amounted to 22%, due to the strong growth led by Saudi Arabia, which succeeded in topping the Arab list by 27%".

2.3 Project Assumptions and Constraints

- Our project is on the students' housing area only.
- The food and drinks should be available all the time.
- Every student can reach the vending machine in a maximum of 4 minutes from any building.
- The vending machines will be in the center of the first floor of the selected buildings.
- 50 m added to traveling distances to cover the time of traveling inside the buildings.

2.4 Customer Needs & Specifications

- Provide food and drinks to students 24 hours every day.
- The food and drinks have suitable prices.
- The students can get the food and drinks easily and in a short time.
- Provide fresh and healthy food.
- Finding the best locations for the vending machines.
- Finding the best way to refill the vending machines.
- Minimize the required number of vending machines and their cost.

We reached these specifications by to students by using google surveys.

2.5 General Requirements & Standards

In this subsection, we will look for the general requirements and standards whether it is related to Health, Global, safety etc., which may affect the implementation of our project.

✓ Health:

Vending machines contribute to the rise in obesity rates. They often carry high-fat, high-energy snacks, and attempts to persuade customers to switch to healthier snacks sold within the same machine have largely failed.

Vending machine food provision can be improved by:

- Increasing the availability of nutritious meals while decreasing the availability of obesogenic foods.
- reducing the size of obesogenic dietary portions (i.e., stocking the smallest portion size available for unhealthy options).

- Organizing products so that healthier options are visible at eye level.
- Increasing the price of obesogenic products to compensate for lower prices of healthy things.

  Changing the delivery time of a vending machine by increasing the time it takes to provide obesogenic products and decreasing the time it takes to deliver healthy

✓ Safety:

As a result, it is recommended that you use extreme caution when operating these vending machines. Under no circumstances should you slam the equipment. When natural calamities such as earthquakes, cyclones, or tsunamis strike, stay away from devices.
Security designs result in a significant increase in the weight of vending machines due to the stock of heavy commodities. It's estimated that a fully loaded soft drink machine weighs approximately 400kg. People are frequently injured as a result of equipment overturning due to their enormous weight.

✓ Global:

Our project is designed for specific situation and circumstances, therefore it cannot be sold as it is, because every case is subjected to different data and requirements, which make it difficult to implement our project in other cases, but the idea of the project and the analysis can be sold after making the proper modifications that fit the required case.

✓ Cultural:

As mentioned in the social section, our project has no governmental regulations and that make the processes to implement the project easier, also as mentioned before in the global section, the project can be implemented for any case after making the proper modifications that fit the required case like the number of facilities, demand, the required time to access the vending machine, etc.

✓ Environmental:

The Vending machine energy consumption and CO_2 emissions consider as an environmental issue, as well as energy consumption and CO_2 emissions from the transportation of raw materials for contents and the processing of raw materials into contents.

✓ Social:

Students' community will be improved due to the change might happen from installing vending machines, by providing some features like the food availability along the day, unlike the university’s restaurant which restricted by specific dates, also the ease of access to vending machines within 4 minutes from the place of residence. There are no governmental regulations for our project, and it is implementation.

- ✓ Economic:

To implement this solution, we need to pay around 6000 SR for 4 vending machines and approximately 1500 to 2000 SR monthly for the operator who refills the vending machines, also for the maintenance side it is cost around 180 to 560 SR monthly, establishing vending machines is an improvement step to increase the students' satisfaction, therefore the estimated cost is acceptable against the services provided to students.

2.6 Problem Statement

Given:

1- Number of students in KFUPM dorms around 7000.

2- The number of Buildings is 43.

3-Distance between buildings.

4- Demand.

5-Date sheets for vending machines.

Assumptions:

1-Food and drinks will be made in the central kitchen.

2- Vending machines will be placed on the first floor in the center of the building.

3-The path that will be used to refill the vending machines is tarred road.

Specifications:

Direct:

1- Healthy and fresh food and drinks.

2-Reasonable price.

3-Vending machines close enough to the students.

4- Variety of products in the vending machines.

Indirect:

1- Vending machines that contain recyclable parts.

2- Vending machines with good capacity.

3- Vending machine with high power efficiency.

Find:

The solution will be as expected using vending machines in the students housing that cover all the students with a lower number of vending machines, so every student can reach the vending machines with less than 4 minutes, and the price of the food and drinks will reasonable, also the refill process will be at the lower path. Vending machines will be selected at the higher specification to meet students' need and that will encourage the student to buy from the vending machines.

Chapter 3
Solution and Validation

The solution is divided into three main parts, vending machine's locations, refill movement, and selecting the type of vending machines, we will describe in detail each one of these three parts from 4 aspects which are solution methodology, alternative solution, solution evaluation, and best solution validation.

3.1 Solution Methodology

In the section, we will go through and explain all approaches and methods we used in this project one by one to find the best solution and it is validation.

3.1.1 Vending machine's locations

Here we will use Total Set Covering to find the minimum number of machines and their locations to cover all student housing.

The distances between buildings are approximated to be equal to the actual path, to get more realistic results.

We create a covering matrix to determine if building (i) cover building (j). Where our objective is that every student can reach the vending machine in a maximum of 4 minutes from any building, and the average human walking speed ≈ 80m/min. So, to find the maximum covering distance:

4min × 80m/min = 320m, approximate it to 300m to guarantee to achieve our objective.

Also, it is important to consider the traveling time inside the building. 50m added to cover this time.

The Distance matrix and covering matrix are in the appendix.

3.1.2 Refill movement

In the Refill movement problem, our target is to come up with the lowest distance that is needed to refill the vending machines with food and drinks by using the Traveling salesman Technique.

Our assumption was the food and drinks will be made at the Central kitchen located between Preparatory Year Parking Lot and Building#57 and starting and ending point will be at Central Kitchen.

The first step was to calculate the distances between the Central kitchen and the buildings that contain Vending machines, then by using the distances between the buildings that contain Vending machines and the Central Kitchen we can form a matrix distance that will help us to find the shortest distance.

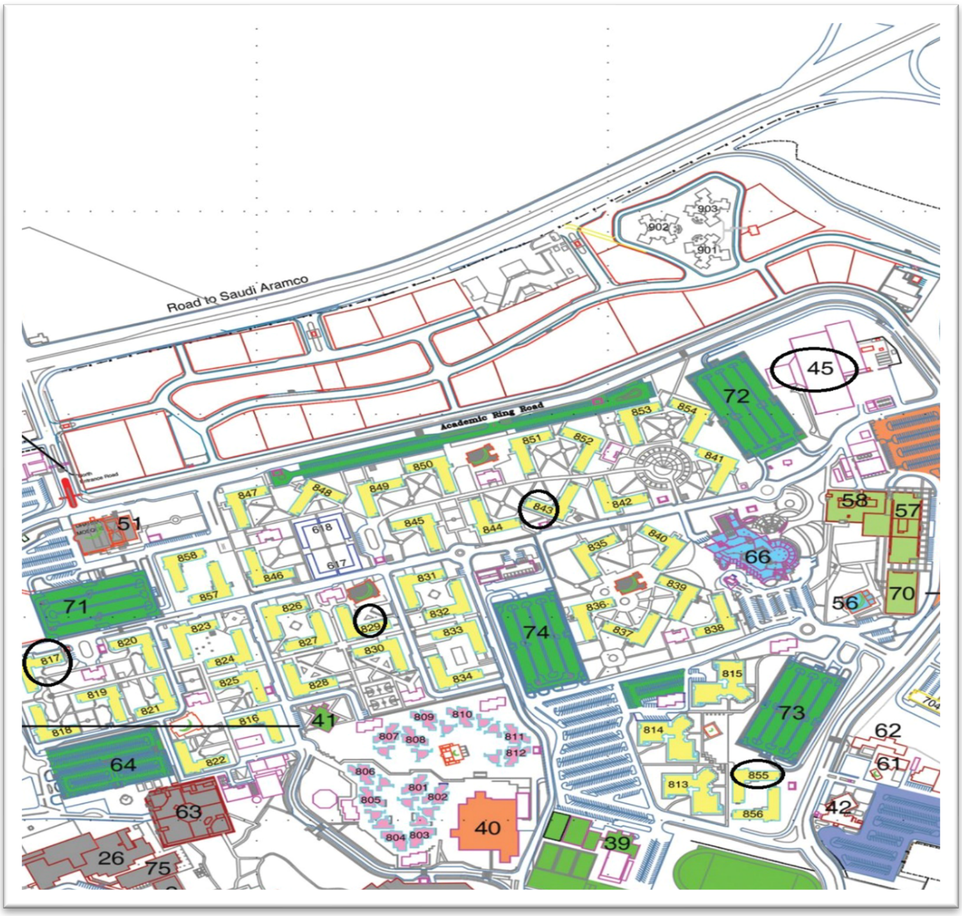


Figure 1. Student housing map.

Table 2. The distances for refill movement.

B/B	S&E point	855	843	829	817
S&E point	0	750	450	800	1100
855	750	0	800	480	840
843	450	800	0	350	650
829	800	480	350	0	380
817	1100	840	650	380	0

3.1.3 Selecting the type of vending machines

After we found the best number of vending machines that satisfy our assumptions using the optimization tool, and the best tour to refill the vending machines using salesman problem, now we should find the best selection of vending machines using TOPSIS and analytic hierarchy process (AHP) furthermore we will check our constancy using eigenvector.
First, we should set the criteria then we should put weight for each one of them based on our preferences, TOPSIS method will be applied first then AHP. Five criteria have been chosen which are the cost, various payment methods, capacity, the efficiency of energy, and lastly the design and these are the weights 0.45, 0.15, 0.2, 0.1, 0.1 respectively, the cost has the highest weight because the prices of the vending machines are high compared with other devices, and we want the vending machine to have good quality with minimum cost possible.
We chose five different vending machines from various websites like Alibaba, online vending, and Sam's club, the pictures and data sheets will be attached.

IBM	NASA
Goodyear	IRS
Ford Motor Co.	FBI
Citibank	Department of Defense
Xerox	World Bank
Boeing	Texaco
AT&T	Eastman Kodak
General Motors	Inter-American Bank

Figure 2. Some famous organizations use AHP method.

3.2 Alternative Solutions

This section will demonstrate the solutions that we approached in this project.

3.2.1 Vending machines' locations

Method 1: Using an optimization program

Variable:

$$x_j \left\{\begin{matrix} 1\ if\ a\ vending\ machine\ located\ on\ \text{building j} \\ 0\ otherwise \end{matrix}\right\}$$

Parameters:

$$a_{ij} \left\{\begin{matrix} 1\ if\ \text{building}\ i\ is\ covered\ by\ vending\ machine\ at\ \text{building j} \\ 0\ otherwise \end{matrix}\right\}$$

cost = cost of the vending machine in Dollars.

* a_{ij} come from the covering matrix, which come from distance matrix. Both are available in the appendix.

The mathematical model:

$$min.\ \sum_{j=1}^{43} cost \times x_j$$

(Minimizing the cost of vending machines by minimizing their number)

$s.t.$

$$\sum_{j=1}^{43} a_{ij} x_j \geq 1 \qquad \forall i$$

(To guarantee that each building i be covered by at least one vending machine)

$$x_j \in \{0,1\} \qquad \forall j$$

The Lingo code:

```
!Total Cover Distance;
Sets:
l/1..43/:x;
cover(l,l): a;
endsets

data:
cost=1500;
```

```
a = @OLE('C:\Users\Mohammed\Desktop\211\ISE 490\Total Cover
Distance.xlsx','A');
Enddata

Min@ = sum(l(j):cost*x(j));

@for(l(i@:(sum(cover(i,j):a(i,j)*x(j)) >= 1);
@for(l(j@:(bin(x(j)));
```

The solution:

```
Global optimal solution found.
Objective value:                              6000.000
Objective bound:                              6000.000
Infeasibilities:                              0.000000
Extended solver steps:                               0
Total solver iterations:                            26
Elapsed runtime seconds:                          0.10

                              Variable           Value
                                X( 2)         1.000000
                               X( 14)         1.000000
                               X( 28)         1.000000
                               X( 40)         1.000000
```

Figure 3. The solution for vending machines' locations by optimization program.

The vending machines will be located on the following buildings#: **817, 829, 843, 855.**

Method 2: Heuristic

The first step is calculating the sum of every available column in the covering matrix, which represents the summation of the number of buildings covered by the vending machine at building (j).

Then place a vending machine in the building with the column with the maximum sum.

Update the matrix by deleting the covered buildings.

Repeat the previous steps until covering all buildings (all the summation equal to zero).

Iteration 0:

d	816	817	818	819	820	821	822	823	824	825	826	827	828	829	830	831	832	833	834	835	836	837	838	839	840	841	842	843	844	845	846	847	848	849	850	851	852	853	854	855	856	857	858
816	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0
817	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
818	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
819	1	1	1	1	1	1	1	1	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1
820	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	1
821	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1
822	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
823	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	1	1
824	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	1
825	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1
826	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	1	1
827	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1
828	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1
829	1	0	0	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1
830	1	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	0	0	0	0	0	0	1	1	1	0	0	1	0	0	0	0	0	0	0	1	0
831	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	1	0
832	0	1	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	1	1	1	0	1	1	1	0	0	0	0	0	0	0	0
833	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	1	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0
834	1	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
835	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0
836	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
837	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	1	1	1	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
838	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
839	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
840	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	1	1	1	1	0	0	0	0
841	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0
842	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	1	1	1	0	0	0	0
843	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	1	1	0	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	0	0	0	0
844	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	1	0	1	1	1	1	0	0	1	1	1	1	1	1	0	0	0	0	0
845	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	1	1	1	1	1	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0
846	1	0	0	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	1	1
847	1	0	0	0	1	0	0	1	1	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	1	1
848	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0	0	0	1	1
849	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	1	0
850	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0	1	1	1	1	0	0	1	1	1	1	1	1	0	0	0	0	0
851	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	0	0	0	0
852	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	1	1	1	1	0	0	0	0	1	1	1	1	1	0	0	0	0
853	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	1	1	1	0	0	0	0	0	1	1	1	1	1	0	0	0	0
854	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0
855	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
856	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
857	1	0	0	1	1	1	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1
858	0	0	0	1	1	1	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	1	1
Sum	17	8	7	15	18	17	13	20	18	17	24	19	20	21	19	23	21	16	13	18	15	12	9	9	14	11	17	19	19	19	21	14	14	16	13	14	12	11	8	4	2	19	15

Iteration 1:

d	816	817	818	819	820	821	822	823	824	825	826	827	828	829	830	831	832	833	834	835	836	837	838	839	840	841	842	843	844	845	846	847	848	849	850	851	852	853	854	855	856	857	858
817	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
818	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
835	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0
836	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
837	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	1	1	1	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
838	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
839	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
840	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	1	1	1	1	0	0	0	0
841	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0
842	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	1	1	1	0	0	0	0
843	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	1	1	0	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	0	0	0	0
844	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	1	0	1	1	1	1	0	0	1	1	1	1	1	1	0	0	0	0	0
850	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0	1	1	1	1	0	0	1	1	1	1	1	1	0	0	0	0	0
851	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	0	0	0	0
852	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	1	1	1	1	0	0	0	0	1	1	1	1	1	0	0	0	0
853	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	1	1	1	0	0	0	0	0	1	1	1	1	1	0	0	0	0
854	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0
855	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
856	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
Sum	0	2	2	2	2	2	2	2	0	0	-	0	0	0	2	6	8	5	2	14	9	10	9	9	14	11	15	14	11	8	0	0	2	4	8	11	11	11	8	4	2	0	0

Iteration 2:

d	816	817	818	819	820	821	822	823	824	825	826	827	828	829	830	831	832	833	834	835	836	837	838	839	840	841	842	843	844	845	846	847	848	849	850	851	852	853	854	855	856	857	858
817	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
818	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
855	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
856	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
Sum	0	2	2	2	2	2	2	2	0	0	-	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0

Iteration 3:

d	816	817	818	819	820	821	822	823	824	825	826	827	828	829	830	831	832	833	834	835	836	837	838	839	840	841	842	843	844	845	846	847	848	849	850	851	852	853	854	855	856	857	858
817	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
818	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sum	0	2	2	2	2	2	2	2	0	0	-	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0

Iteration 4:

d	816	817	818	819	820	821	822	823	824	825	826	827	828	829	830	831	832	833	834	835	836	837	838	839	840	841	842	843	844	845	846	847	848	849	850	851	852	853	854	855	856	857	858
Sum	0	0	0	0	0	0	0	-	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0

The solution:

The vending machines will be located on the following buildings#: **823, 826, 842,856.**

3.2.2 Refill movement

In this section, our goal is to find the best path to reduce the total distance needed to refill the vending machines with food and drinks, to find the best path Lingo Software will be used and Reversal Heuristic.

Method 1: Using an optimization program

Parameters:

i and j, represent the location of the building machines and starting and ending point.

i, j ∈ {1 … .5}

1 = Central kitchen

2 = Building# 855

3 = Building# 843

4 = Building# 829

5 = Building# 817

d_{ij} = the distance from location i to location j

Variable:

$$x_{ij} \begin{Bmatrix} 1\ if\ path\ i\ to\ j\ selected \\ 0\ otherwise \end{Bmatrix}$$

The mathematical model:

$min. \sum_{i=1}^{5} \sum_{j=1}^{5} d_{ij} \times x_{ij}$ (Minimize the sum of all the distance that will be calculated)

$s.t.$

$\sum_{i=1}^{5} x_{ij} = 1\ \ \forall i$ (To make sure the building will be visited once time)

$\sum_{j=1}^{5} x_{ij} = 1\ \ \forall j$ (To make sure the building will be leaved once time)

The distance of i = j is equal 10000 to ensure the path will not taken (software will take the lowest distance)

$x_{ij} \in \{0,1\} \qquad \forall\, i, j$

Table 3. d_{ij} matrix.

B/B	S&E point	855	843	829	817
S&E point	10000	750	450	800	1100
855	750	10000	800	480	840
843	450	800	10000	350	650
829	800	480	350	10000	380
817	1100	840	650	380	10000

The Lingo code:

```
sets:
i/1..5/:e;
j/1..5/;
dij(i,j):dist,x;
endsets

data:
dist=10000  750 800 800 1100
     750 10000 380 480 840
     800 380 10000 140 485
     800 480 140 10000 380
     1100 840 485 380 10000 ;
enddata

min=@sum(dij(t,k):dist(t,k)*x(t,k));
@for(j(p):@sum(i(o):x(o,p))=1);
@for(i(a):@sum(j(z):x(a,z))=1);
@FOR(i(n):@FOR(j(w)|n#NE#w  #and#  w#ge#2 #and#
n#ge#2:e(n)+1<=e(w)+4*(1-x(n,w))));
@for(i(r)|r#gE#2:e(r)>=0);
@for(dij(y,u):@bin(x(y,u)));
```

The solution:

```
Solution Report - abdullahn
LINGO/WIN32 19.0.32 (3 Dec 2020 ), LINDO API 13.0.4099.242

Licensee info: Eval Use Only
License expires: 26 MAY 2022

Global optimal solution found.
Objective value:                          2710.000
Objective bound:                          2710.000
Infeasibilities:                          0.000000
Extended solver steps:                           0
Total solver iterations:                        72
Elapsed runtime seconds:                      0.11

Model Class:                                  MILP

Total variables:                  30
Nonlinear variables:               0
Integer variables:                25

Total constraints:                27
Nonlinear constraints:             0
```

Figure 4. The solution for refill movement by optimization program, 1.

```
X( 1, 1)        0.000000        10000.00
X( 1, 2)        0.000000        750.0000
X( 1, 3)        1.000000        450.0000
X( 1, 4)        0.000000        800.0000
X( 1, 5)        0.000000        1100.000
X( 2, 1)        1.000000        750.0000
X( 2, 2)        0.000000        10000.00
X( 2, 3)        0.000000        800.0000
X( 2, 4)        0.000000        480.0000
X( 2, 5)        0.000000        840.0000
X( 3, 1)        0.000000        450.0000
X( 3, 2)        0.000000        800.0000
X( 3, 3)        0.000000        10000.00
X( 3, 4)        0.000000        350.0000
X( 3, 5)        1.000000        650.0000
X( 4, 1)        0.000000        800.0000
X( 4, 2)        1.000000        480.0000
X( 4, 3)        0.000000        350.0000
X( 4, 4)        0.000000        10000.00
X( 4, 5)        0.000000        380.0000
X( 5, 1)        0.000000        1100.000
X( 5, 2)        0.000000        840.0000
X( 5, 3)        0.000000        650.0000
X( 5, 4)        1.000000        380.0000
X( 5, 5)        0.000000        10000.00
```

Figure 5. The solution for refill movement by optimization program, 2.

The solution is (Central Kitchen-843-817-829-855- Central Kitchen) Total distance = 2710 meter.

Method 2: Reversal Heuristic

Staring with random close tour that start and end at the Central Kitchen, then we swap the order until we find the shortest distance.

We can find a neighbor tour in which one arc is reversed. This reversal is called “two-at-a-time” reversal.

We can find a neighbor tour in which two arcs are reversed. This reversal is called “three-at-a-time” reversal.

and so on, since our problem is symmetric, we have up to n-2 at a time

We stop until we find the lowest distance

Starting with (S&E point-843-829-817-855- S&E point) as random selection

Z= 450+350+380+840+750= 2770 meter

Appling two at time

1-(S&E point-829-843-817-855- S&E point)

Z= 800+350+650+840+750 = 3390 meter

2-(S&E point-843-817-829-855- S&E point)

Z= 450+650+380+480+750=2710 meter

3-(S&E point-843-829-855-817- S&E point)

Z= 450+350+480+840+1100 = 3220 meter

Appling Three at time

1-(S&E point-817-829-843-855- S&E point)

Z=1100+380+350+800+750= 3380 meter

2-(S&E point-843-855-817-829-S&E point)

450+800+840+380+800=3270 meter

Appling Four at time

1- (S&E point-855-817-829-843- S&E point)

750+840+380+350+450= 2770 meter

Best solution is (S&E point-843-817-829-855- S&E point)

Z= 450+650+380+480+750=2710 meter

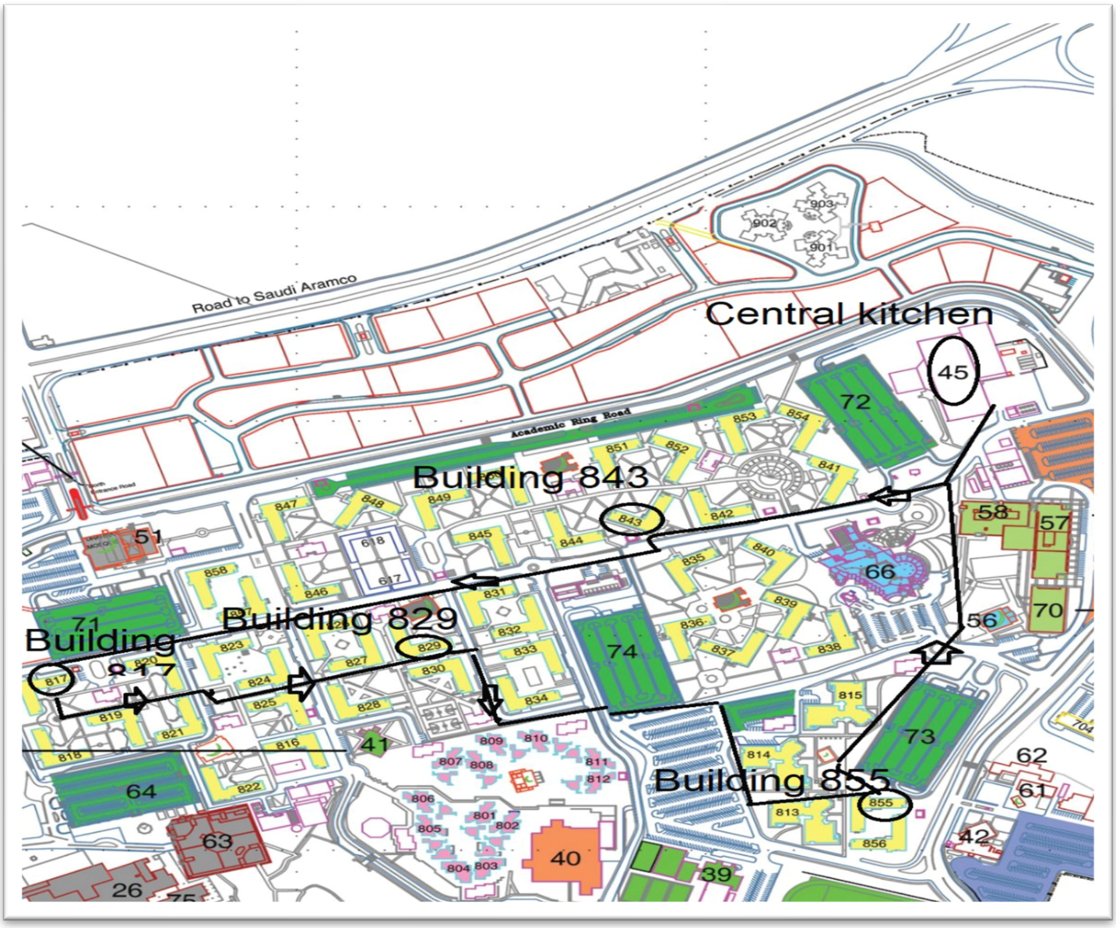


Figure 6. Direction of the refill movement.

3.2.3 Selecting the type of vending machines

TOPSIS method:

It is referred to Technique of Order Preference by Similarity to Ideal Solution, and this method considers three types of attributes or criteria:

- Qualitative benefit attributes/criteria
- Quantitative benefit attributes
- Cost attributes or criteria

In this method two artificial alternatives are hypothesized:

- Ideal alternative: the one which has the best level for all attributes considered.
- Negative ideal alternative: the one which has the worst attribute values.

TOPSIS selects the alternative that is the closest to the ideal solution and farthest from negative ideal alternative.

The following table will show the differences between vending machines with respect to the selected criteria, Cost in dollar, Various Types of Payment Methods (VTPM), Capacity (CP) in number of pieces, Electric Efficiency (EE) in Watt/Hour, and Design.
The VTPM and the Design we evaluated them subjectively, so we put score for them from 1-5 therefore no units applicable for both.

	COST($)	**VTPM**	**CP(Pcs)**	**EE(watt)**	**DE**
WEIGHT	0.45	0.15	0.2	0.1	0.1
FC6601	1500	1	300	350	3
CRANE764	2995	3	375	250	2
SEL40	4689	3	630	25	4
35890117	4574	3	353	125	2
ZG-CSC	2213	5	550	510	5

Step1 :
Each criterion has it is own unit, so we cannot go for further analysis until the units become uniform, to do this, we should construct normalized decision matrix,

	COST ($)	**VTPM**	**CP (Pcs)**	**EE(watt)**	**DE**
WEIGHT	0.45	0.15	0.2	0.1	0.1
FC6601	1500	1	300	350	3
CRANE764	2995	3	375	250	2
SEL40	4689	3	630	25	4
35890117	4574	3	353	125	2
ZG-CSC	2213	5	550	510	5
$\sum x^2$	59025591	53	1054634	461350	58
$(\sum x^2)^{0.5}$	7682.811	7.28011	1026.954	679.2275	7.615773

normalize scores or data as follows:

$r_{ij} = x_{ij} / (\Sigma x^2_{ij})^{0.5}$ for i = 1, …, m; j = 1, , n

	COST	VTPM	CP	EE	DE
WEIGHT	0.45	0.15	0.2	0.1	0.1
FC6601	0.195241	0.137361	0.292126	0.515291	0.393919
CRANE764	0.389831	0.412082	0.365158	0.368065	0.262613
SEL40	0.610323	0.412082	0.613465	0.036807	0.525226
35890117	0.595355	0.412082	0.343735	0.184033	0.262613
ZG-CSC	0.288046	0.686803	0.535565	0.750853	0.656532

Step 2 :

The preferences of the decision maker are important, and it is the main part of the analysis, the weight is not a collective data, it is given by the decision maker to represent his desire, in this step we are going to Construct the weighted normalized decision matrix by multiplying each column of the normalized decision matrix by its associated weight, an element of the new matrix is:

$v_{ij} = w_j \, r_{ij}$

	COST	VTPM	CP	EE	DE
WEIGHT	0.5	0.15	0.2	0.1	0.1
FC6601	0.097621	0.020604	0.0584252	0.051529	0.039392
CRANE764	0.194916	0.061812	0.0730315	0.036807	0.026261
SEL40	0.305162	0.061812	0.122693	0.003681	0.052523
35890117	0.297677	0.061812	0.068747	0.018403	0.026261
ZG-CSC	0.144023	0.10302	0.1071129	0.075085	0.065653

Step 3: Determine the ideal and negative ideal solutions.

- Ideal solution:
  $A^* = \{ v_1^*, \ldots, v_n^* \}$, where

  $v_j^* = \{ \max (v_{ij}) \text{ if } j \in J ; \min (v_{ij}) \text{ if } j \in J' \}$

- Negative ideal solution:
  $A' = \{ v_1', \ldots, v_n' \}$, where

  $v' = \{ \min (v_{ij}) \text{ if } j \in J ; \max (v_{ij}) \text{ if } j \in J' \}$

A*	0.097621	0.10302	0.122693	0.003681	0.065653
A'	0.305162	0.020604	0.0584252	0.075085	0.026261

Step 4: Calculate the separation measures for each alternative as follows:

- The separation from the ideal alternative is:
  $S_i^* = [\Sigma j (v_j^* - v_{ij})^2]^{½} \qquad i = 1, \ldots, m$

	COST	VTPM	CP	EE	DE	S*=(∑vj*vij)^0.5
FC6601	0	0.006792	0.00413	0.002289	0.00069	0.117906435
CRANE764	0.009466	0.001698	0.002466	0.001097	0.001552	0.127592154
SEL40	0.043073	0.001698	0	0	0.000172	0.211999722
35890117	0.040023	0.001698	0.00291	0.000217	0.001552	0.215405551
ZG-CSC	0.002153	0	0.000243	0.005099	0	0.086570976

- Similarly, the separation from the negative ideal alternative is:
  $S'_i = [\Sigma j (v_j' - v_{ij})^2]^{½} \qquad i = 1, \ldots, m$

	COST	VTPM	CP	EE	DE	S'=(∑vj*vij)^0.5
FC6601	0.043073	0	0	0.000555	0.000172	0.209286078
CRANE764	0.012154	0.001698	0.000213	0.001465	0	0.124623132
SEL40	0	0.001698	0.00413	0.005099	0.00069	0.107780958
35890117	5.6E-05	0.001698	0.000107	0.003213	0	0.071228646
ZG-CSC	0.025966	0.006792	0.00237	0	0.001552	0.191521336

Step 5: Calculating the relative closeness to the ideal solution C_i^*

$C_i^* = S'_i / (S_i^* + S'_i)$, $0 < C_i^* < 1$

Select the option with C_i^* closest to 1.

	Ci*	Ranking
FC6601	0.639642	1
CRANE764	0.494114	4
SEL40	0.337046	2
35890117	0.2485	3
ZG-CSC	0.613454	5

As we can see from the above results , vending machine (FC6601) is the best selection that is satisfy our criteria, and we will do one more professional analysis using AHP to make sure that our selection is the best, before that we are going to find the weight and check our constancy using eigen vector and lambda max.

To find the weight, first we will rank the score of the criteria and alternatives relying on the next table:

Intensity of importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective
3	Somewhat more important	Experience and judgement slightly favour one over the other.
5	Much more important	Experience and judgement strongly favour one over the other.
7	Very much more important	Experience and judgement very strongly favour one over the other. Its importance is demonstrated in practice.
9	Absolutely more important.	The evidence favouring one over the other is of the highest possible validity.
2,4,6,8	Intermediate values	When compromise is needed

Figure 7.Scale of rating the criteria.

A basic, but very reasonable, assumption: If attribute A is more important than attribute B and is rated at 9, then B must be absolutely less important than A and is valued at 1/9.

And we rated the criteria as following:

	COST	VTPM	CP	EE	DE
COST	1	4	3	5	7
DTPM	1/4	1	1/2	2	5
CP	1/3	2	1	4	6
EE	1/5	1/2	1/4	1	2
DE	1/7	1/5	1/6	1/2	1
Total	1.93	7.70	4.92	12.50	21.00

Then we will divide each cell in each column by the associated total of that column to normalize the scores , then we will take the average of each row to find the required weights as follows:

	COST	VTPM	CP	EE	DE	Weight
COST	0.52	0.52	0.61	0.40	0.33	0.48
DTPM	0.13	0.13	0.10	0.16	0.24	0.15
CP	0.17	0.26	0.20	0.32	0.29	0.25
EE	0.10	0.06	0.05	0.08	0.10	0.08
DE	0.07	0.03	0.03	0.04	0.05	0.04

The next step is to generate a Consistency Ratio (CR) to see how consistent the decisions were compared to extensive samples of completely random decisions. The decision maker should be logically consistent and coherent, Incoherent who says E is less than likely than F, F is less transitivity property, now we will find the eigen vector in order to find (CR).

Step1 :

Take the squared power of matrix A, i.e., A^2=A.A and Find the row sums of A^2 and normalize this array to find E_0.

	COST	VTPM	CP	EE	DE	ROW SUM
COST	5	17.9	10.41667	33.5	62	128.8167
DTPM	1.780952	5	3.083333	9.75	18.75	38.36429
CP	2.82381	8.533333	5	16.666667	32.33333	65.35714
EE	0.894048	2.7	1.683333	5	9.4	19.67738
DE	0.49127	1.554762	0.986905	2.7809524	5	10.81389
					Total	263.0294

E0
0.489743
0.145856
0.248479
0.074811
0.041113

Step2 :

Take the squared power of matrix A, i.e., A^4= A^2. A^2 and Find the row sums of A^4 and normalize this array to find E_1.

	COST	VTPM	CP	EE	DE	ROW SUM
COST	146.7031	454.7341	276.9381	855.5552	1607.331	3341.261
DTPM	44.44454	138.6669	84.30188	260.6937	489.2635	1017.371
CP	74.22074	231.1502	140.6913	434.3817	815.0762	1695.52
EE	23.12	71.98	43.75	135.47	254.48	528.8071
DE	12.95	40.27	24.46	75.87	142.66	296.2237
					Total	6879.182

E1 ,x
0.485706
0.147891
0.246471
0.076871
0.043061

Step3 :

Find D= E_1 - E_0.

IF the elements of D are close to zero, THEN X= E_1, STOP. ELSE set A:=A^2 , set E_0:=E_1 and go to Step 1. And here we have all elements of D are close to zero , so E_1 is the eigin vector X.

E1-E0
-0.00404
0.002036
-0.00201
0.00206
0.001948

Step4:

This step is to calculate λ_{max}, which will give you the Consistency Index and Ratio , Consider [$Ax = \lambda_{max}$ x] where x is the Eigenvector.

A*x
2.502464
0.761599
1.270003
0.395697
0.22154

(A*x)/x	
5.152218	
5.149725	
5.152746	
5.14757	
5.144798	
AVG=ʎmax	5.149412

Step5 : Lastly, we should find the Consistency Index and Consistency Ratio depending on the next table :

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

Figure 8. Order of the random matrix.

The correction is minor relative to the actual values of the eigenvector elements if the inconsistency is less than 10%.

A CR of, say, 90% would indicate that the paired judgments are essentially random and absolutely untrusted.

CI= $(\lambda\ max - n)/(n - 1)$

CR= CI / 1.12

CI	0.0373529
CR	0.0333508

So, we can see that we are coherent because the CR value is less than 0.1, and now we can move to the last stage by using AHP.

Analytic Hierarchy Process:

AHP develop a hierarchy of decision and define the alternative course of actions.

AHP algorithm is basically composed of two steps:

- Determine the relative weight of decision criteria
- Determine the relative rankings (priorities) of alternatives

Step1 : Structure a hierarchy.

Define the problem, determine the criteria, and identify the alternatives.

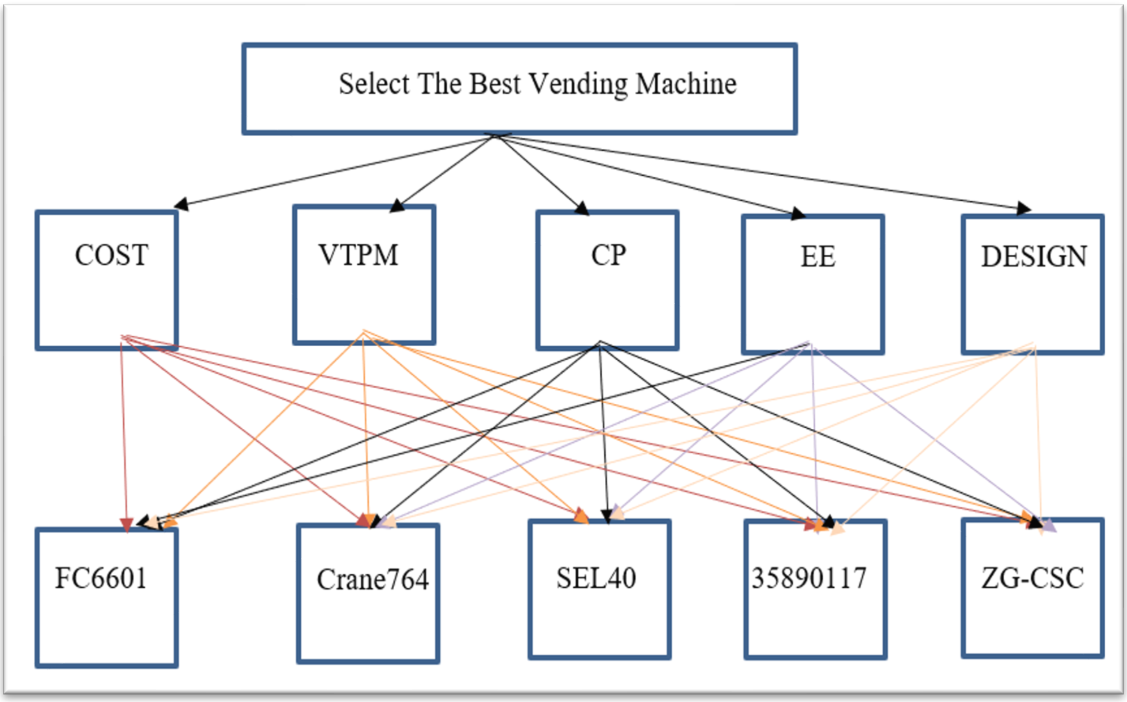


Figure **9**. hierarchy Structure.

Step2 :

Making pairwise comparisons and rating the relative importance between the criteria.

	COST	**VTPM**	**CP**	**EE**	**DE**
COST	1	4	3	5	7
DTPM	1/4	1	1/2	2	5
CP	1/3	2	1	4	6
EE	1/5	1/2	1/4	1	2
DE	1/7	1/5	1/6	1/2	1

This table show the pairwise comparison between criteria them self and we already did this step before while we were calculating the weights.

Step3:

In this step we will make a pairwise comparison between vending machines with respect to each criterion separately and score them as before from 1- 9, therefore 6 tables will be constructed, after that we will normalize each column and take the average of each row to get the priority of vending machines with respect the certain characteristic as follows:

COST

	FC6601	CRANE764	SEL40	35890117	ZG-CSC
FC6601	1.00	4.00	9.00	8.00	2.00
CRANE764	0.25	1.00	4.00	3.00	0.50
SEL40	0.11	0.25	1.00	0.50	0.25
35890117	0.13	0.33	2.00	1.00	0.33
ZG-CSC	0.33	2.00	4.00	3.00	1.00
Total	1.82	7.58	20.00	15.50	4.08

	FC6601	CRANE764	SEL40	35890117	ZG-CSC	Priority
FC6601	0.55	0.53	0.45	0.52	0.49	0.51
CRANE764	0.14	0.13	0.20	0.19	0.12	0.16
SEL40	0.06	0.03	0.05	0.03	0.06	0.05
35890117	0.07	0.04	0.10	0.06	0.08	0.07
ZG-CSC	0.18	0.26	0.20	0.19	0.24	0.22

VTPM

	FC6601	CRANE764	SEL40	35890117	ZG-CSC
FC6601	1.00	0.20	0.20	0.20	0.14
CRANE764	5.00	1.00	1.00	1.00	0.33
SEL40	5.00	1.00	1.00	1.00	0.33
35890117	5.00	1.00	1.00	1.00	0.33
ZG-CSC	7.00	3.00	3.00	3.00	1.00
Total	23.00	6.20	6.20	6.20	2.14

	FC6601	CRANE764	SEL40	35890117	ZG-CSC	Priority
FC6601	0.04	0.03	0.03	0.03	0.07	0.010951
CRANE764	0.22	0.16	0.16	0.16	0.16	0.018411
SEL40	0.22	0.16	0.16	0.16	0.16	0.018411
35890117	0.22	0.16	0.16	0.16	0.16	0.018411
ZG-CSC	0.30	0.48	0.48	0.48	0.47	0.056071

CP

	FC6601	CRANE764	SEL40	35890117	ZG-CSC
FC6601	1.00	0.33	0.11	0.50	0.14
CRANE764	3.00	1.00	0.17	0.14	0.33
SEL40	9.00	6.00	1.00	8.00	3.00
35890117	2.00	7.00	0.13	1.00	0.33
ZG-CSC	7.00	3.00	0.33	3.00	1.00
Total	22.00	17.33	1.74	12.64	4.81

	FC6601	CRANE764	SEL40	35890117	ZG-CSC	Priority
FC6601	0.05	0.02	0.06	0.04	0.03	0.04
CRANE764	0.14	0.06	0.10	0.01	0.07	0.07
SEL40	0.41	0.35	0.58	0.63	0.62	0.52
35890117	0.09	0.40	0.07	0.08	0.07	0.14
ZG-CSC	0.32	0.17	0.19	0.24	0.21	0.23

EE

	FC6601	CRANE764	SEL40	35890117	ZG-CSC
FC6601	1.00	0.25	0.14	0.17	5.00
CRANE764	4.00	1.00	0.20	0.25	7.00
SEL40	7.00	5.00	1.00	3.00	9.00
35890117	6.00	4.00	0.33	1.00	8.00
ZG-CSC	0.20	0.14	0.11	0.13	1.00
Total	18.20	10.39	1.79	4.54	30.00

	FC6601	CRANE764	SEL40	35890117	ZG-CSC	Priority
FC6601	0.05	0.02	0.08	0.04	0.17	0.07
CRANE764	0.22	0.10	0.11	0.06	0.23	0.14
SEL40	0.38	0.48	0.56	0.66	0.30	0.48
35890117	0.33	0.38	0.19	0.22	0.27	0.28
ZG-CSC	0.01	0.01	0.06	0.03	0.03	0.03

DE

	FC6601	CRANE764	SEL40	35890117	ZG-CSC
FC6601	1.00	3	0.33	3.00	0.20
CRANE764	0.33	1.00	0.20	1.00	0.14
SEL40	3.00	5.00	1.00	5.00	0.33
35890117	0.33	1.00	0.20	1.00	0.14
ZG-CSC	5.00	7.00	3.00	7.00	1.00
Total	9.67	17.00	4.73	17.00	1.82

	FC6601	CRANE764	SEL40	35890117	ZG-CSC	Priority
FC6601	0.10	0.18	0.07	0.18	0.11	0.13
CRANE764	0.03	0.06	0.04	0.06	0.08	0.05
SEL40	0.31	0.29	0.21	0.29	0.18	0.26
35890117	0.03	0.06	0.04	0.06	0.08	0.05
ZG-CSC	0.52	0.41	0.63	0.41	0.55	0.50

Step4 :

In the last step we will figure out the impact of each criterion on the selection of the vending machine by multiplying the weights, and we will sum them up to find the composite for each type, then we will select the vending machine based on the highest composite.

	CO	VTPM	CP	EE	DE	Composite	Ranking
Weight	0.48	0.15	0.25	0.08	0.04	NA	NA
FC6601	0.51	0.01	0.04	0.07	0.13	0.26	1
CRANE764	0.16	0.02	0.07	0.14	0.05	0.11	4
SEL40	0.05	0.02	0.52	0.48	0.26	0.20	2
35890117	0.07	0.02	0.14	0.28	0.05	0.10	5
ZG-CSC	0.22	0.06	0.23	0.03	0.50	0.19	3

Finally, we have got the same result as the TOPSIS method, undoubtedly that illustrate vending machine (FC6601) is the best selection that satisfy the criteria.

3.3 Solution Evaluation

In the section we will show how we evaluate the alternative solutions from previous subsection.

3.3.1 Vending machine's location

Both solutions have the same number of vending machines, the difference is the locations. So, we will compare the total distance between buildings and nearest vending machines by simple Lingo code.

Lingo code for method 1: (817, 829, 843,855)

```
!Total Distance for method 1;
Sets:
b/1..43/;
v/1..4/;
bv(b,v):vending;
endsets

data:
vending = @OLE('C:\Users\Mohammed\Desktop\211\ISE 490\Total Cover
Distance.xlsx','S_1');
Enddata

Min@ = sum(b(i@:(min(v(j): vending(i,j)));
```

The total distance = 5655 meter.

Lingo code for method 2: (823, 826, 842,856)

```
!Total Distance for method 2;
Sets:
b/1..43/;
v/1..4/;
bv(b,v):vending;
endsets

data:
vending = @OLE('C:\Users\Mohammed\Desktop\211\ISE 490\Total Cover
Distance.xlsx','S_2');
Enddata

Min@ = sum(b(i@:(min(v(j): vending(i,j)));
```

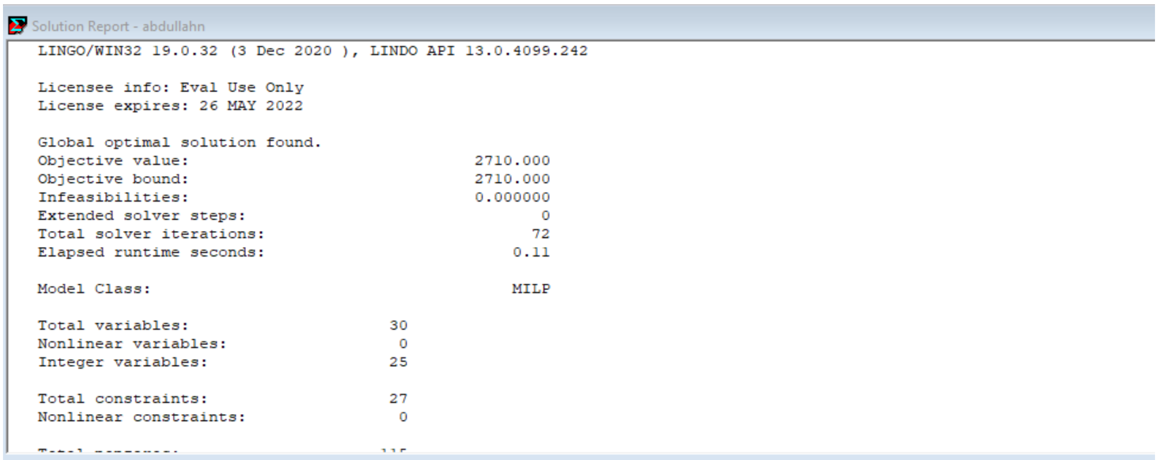
The total distance = 5745 meter.

3.3.2 Refill movement

Both solutions have the same result (Central Kitchen-843-817-829-855- Central Kitchen)

Total distance = 2710 meter.

Method -1



```
Solution Report - abdullahn
LINGO/WIN32 19.0.32 (3 Dec 2020 ), LINDO API 13.0.4099.242

Licensee info: Eval Use Only
License expires: 26 MAY 2022

Global optimal solution found.
Objective value:                              2710.000
Objective bound:                              2710.000
Infeasibilities:                              0.000000
Extended solver steps:                               0
Total solver iterations:                            72
Elapsed runtime seconds:                          0.11

Model Class:                                      MILP

Total variables:                     30
Nonlinear variables:                  0
Integer variables:                   25

Total constraints:                   27
Nonlinear constraints:                0
```

Method -2

Appling two at time

2-(S&E point-843-817-829-855- S&E point)

Z= 450+650+380+480+750 = 2710 meter.

3.3.3 Selecting the type of vending machines

Both methods TOPSIS and AHP showed the same results which is the vending machine named (**FC6601**) as we can see in the next two tables:

Name	CO	VTPM	CP	EE	DE	Composite	Ranking
FC6601	0.51	0.01	0.04	0.07	0.13	0.26	1
CRANE764	0.16	0.02	0.07	0.14	0.05	0.11	4
SEL40	0.05	0.02	0.52	0.48	0.26	0.20	2
35890117	0.07	0.02	0.14	0.28	0.05	0.10	5
ZG-CSC	0.22	0.06	0.23	0.03	0.50	0.19	3

Name	Ci*	Ranking
FC6601	0.639642	1
CRANE764	0.494114	4
SEL40	0.337046	2
35890117	0.2485	3
ZG-CSC	0.613454	5

3.4 Best Solution Validation

3.4.1 Vending machine's location

The locations from method 1 (Using an optimization program, buildings 817, 829, 843,855) are the best places for the vending machines. Where they cover all students housing and minimize the total distance and the number of the vending machines.

3.4.2 Refill movement

The path that will be used to refill the vending machines is a circular path, and the solution of method 1 is the same as the solution of method 2 and there is no problem if we use the opposite direction.

3.4.3 Selecting the type of vending machines

Vending machine (**FC6601**) is the best solution that satisfies the requirements and the criteria where it has the least cost with the highest quality possible, there were also some other vending machines that were close to the best solution like (**ZG-CSC**) we can use it as an alternative solution in case of some problem happened during the processes of the first vending machine.

Chapter 4
Impact & Implementation

This section related to the impact of the proposed solutions , and the ethical and professional responsibilities that should be taken in consideration before we implement the solutions in real life.

4.1 Impact of the Proposed Solutions

In this subsection, we will explain how the proposed solutions will have an impact on global, economic, environmental, and societal contexts.

✓ Global:

The solutions would not affect or solve global issues, but actually, the solutions can participate to increase people's satisfaction in so many institutions around the world.

✓ Economic:

The project concentrates on increasing the student's satisfaction and comfort at the university's budget expense, which may affect the budget negatively a little bit. Students might pay less for food, instead of going to restaurants and paying a lot of money, they will just pay less than half of the amount they pay to restaurants. A job will be created in terms of the worker who is responsible for refilling the vending machines.

✓ Environmental:

In terms of sustainability:

- A vending machine only uses approximately the same energy as a refrigerator.
- Vending machines can be serviced at a 'need only' basis with smart messaging technology and off-site monitoring systems.
- Reduced servicing means less time spent on the roads, with less traffic and less carbon emission.
- Delivery trucks can be pre-packed for each vending machine; meaning smaller, lighter, and more fuel-efficient vehicles can be used.

- ✓ Societal:

Students' society will be enhanced as a result of this shift that may occur because of vending machine installation, by providing some capabilities such as food availability throughout the day, as opposed to the university's restaurant, which is limited to specific dates, furthermore, ease of access to vending machines within 4 minutes of residence. Implanting the solution will help to improve students' diet which consists of healthy food and beverages.

4.2 Ethical and Professional Responsibilities

Where we will place vending machines for students, it is important to consider their health. So, we will make sure that the food and drinks are healthy and fresh every day. We do not want to hear there is a student who has a stomachache or is poisoned because of vending machine's food or drink.

Moreover, the prices should be suitable and reasonable for the students. The main goal of our project is to help the students, not make a profit from their needs.

Chapter 5
Conclusion

In this last chapter, we will summarize the project including our observations, results, experiences, and knowledge we have been through during this journey, moreover, we will represent the possible things that we can improve in this project, but we could not do due to some limitations.

5.1 Summary

This project was worked on it based on a critical issue that the students at KFUPM faced a problem with food especially at night, and the result that was obtained will improve the quality of life at the students housing, the concentration was to guarantee that the students can reach the vending machines with maximum travel time 4 minutes and to select the best type of vending machines that meet the ambitions of the students. The issues on this project were to collect the data especially the distance between the buildings since we have 43 buildings and to find both the best location for the vending machines and the number of machines, also the best type of vending machines. The optimal solution for the location and the number of machines was determined by using mathematical models of Set Covering. Also, the best path for refilling the machines was found by using the mathematical model of the sell man problem to facilitation the process of refilling the vending machines. However, for the type of vending machines selected by TOPSIS and AHP methods.

From working on this project, our skills in mathematical modeling and decision making are improved dramatically, and we learned to collect data as a survey and analyze it.

5.2 Limitations and Future Study

For further work, if we have chance to improve the project, we will consider the Arena simulation to visualize refill movement and compare between situations. Also, we will do cost analysis, feasibility study, and forecasting to convince KFUPM to adopt our project.

Finally, we hope for future students to get benefit from our project as a reference and benchmark for their projects.

Appendix

Table 4. Distance Matrix.

d	816	817	818	819	820	821	822	823	824	825	826	827	828	829	830	831	832	833	834	835	836	837	838	839	840	841	842	843	844	845	846	847	848	849	850	851	852	853	854	855	856	857	858
816	0	285	250	180	180	120	100	170	110	70	165	140	60	170	185	260	280	275	235	450	420	465	560	550	550	650	540	500	390	345	215	230	360	370	440	505	580	610	685	600	660	200	275
817	285	0	105	110	150	180	240	190	250	270	295	355	315	380	425	450	50	520	485	660	650	725	825	775	770	880	740	660	515	575	295	345	410	470	550	650	730	780	870	840	900	250	335
818	250	105	0	100	190	155	175	220	250	250	315	355	290	380	425	475	510	510	465	670	640	715	810	770	790	880	745	670	490	540	335	410	470	525	615	710	785	780	870	800	860	280	290
819	180	110	100	0	90	70	140	120	155	160	215	250	190	280	325	375	410	410	365	570	540	615	710	670	690	780	645	570	390	440	135	310	370	425	515	610	685	680	770	700	760	190	195
820	180	150	190	90	0	105	190	45	120	145	150	200	195	240	285	370	375	380	360	515	500	555	650	610	620	700	565	490	310	360	155	230	290	345	435	530	605	600	690	710	770	105	110
821	120	180	155	70	105	0	95	115	120	110	185	200	150	240	265	330	365	360	320	525	495	550	650	615	625	730	595	555	470	410	210	325	360	410	490	580	665	715	780	660	720	170	205
822	100	240	175	140	190	95	0	195	180	150	245	240	160	270	285	360	380	375	335	550	520	565	660	650	650	750	640	600	490	445	315	330	460	470	540	605	680	710	785	635	695	265	300
823	170	190	220	120	45	115	195	0	80	115	110	160	165	195	240	325	330	335	315	470	455	510	605	565	575	655	520	445	265	315	110	185	245	300	390	485	560	555	645	665	725	65	100
824	110	250	250	155	120	120	180	80	0	35	75	95	80	130	175	220	260	265	255	415	410	480	575	525	525	625	480	425	335	290	115	235	260	290	380	440	530	585	670	600	660	95	165
825	70	270	250	160	145	110	150	115	35	0	100	100	55	135	165	220	260	265	255	415	410	480	575	525	525	625	480	425	335	290	145	270	265	290	380	440	530	585	670	600	660	130	205
826	165	295	315	215	150	185	245	110	75	100	0	80	125	100	150	160	225	235	230	370	360	440	540	490	475	570	425	365	275	215	60	180	190	210	290	390	470	525	610	590	650	65	140
827	140	355	355	250	200	200	240	160	95	100	80	0	85	40	80	130	165	170	160	325	305	385	485	430	435	670	525	465	375	315	160	280	290	310	390	364	420	475	560	520	580	165	240
828	60	315	290	190	195	150	160	165	80	55	125	85	0	110	130	220	225	220	170	385	355	430	530	475	495	620	475	415	325	290	175	295	305	390	475	449	505	560	645	520	580	170	245
829	170	380	380	280	240	240	270	195	130	135	100	40	110	0	50	90	125	130	140	285	265	345	445	390	410	630	485	425	335	275	130	240	220	210	270	324	380	435	520	480	540	160	235
830	185	425	425	325	285	265	285	240	175	165	150	80	130	50	0	90	95	90	80	255	220	300	410	345	365	490	345	285	195	185	180	290	270	235	275	319	375	430	515	450	510	210	285
831	260	450	475	375	370	330	360	325	220	220	160	130	220	90	90	0	70	105	155	205	215	295	390	340	315	415	270	210	225	100	165	230	175	145	185	245	295	355	435	480	540	215	290
832	280	50	510	410	375	365	380	330	260	260	225	165	225	125	95	70	0	35	105	165	150	230	330	275	275	390	245	185	120	135	235	300	245	210	220	255	285	340	425	410	470	285	360
833	275	520	510	410	380	360	375	335	265	265	235	170	220	130	90	105	35	0	85	175	135	215	315	260	285	410	260	200	145	165	270	335	280	245	255	280	300	355	440	410	470	320	390
834	235	485	465	365	360	320	335	315	255	255	230	160	170	140	80	155	105	85	0	250	190	270	310	315	330	465	320	280	230	240	265	365	325	300	330	360	390	445	530	380	440	295	370
835	450	660	670	570	515	525	550	470	415	415	370	325	385	285	255	205	165	175	250	0	100	150	210	225	110	220	75	65	120	185	370	420	495	265	205	175	155	210	295	380	440	420	495
836	420	650	640	540	500	495	520	455	410	410	360	305	355	265	220	215	150	135	190	100	0	80	170	125	145	275	175	165	220	230	380	440	365	315	275	275	255	310	340	300	360	430	505
837	465	725	715	615	555	550	565	510	480	480	440	385	430	345	300	295	230	215	270	150	80	0	100	85	145	280	210	215	245	310	450	505	450	390	355	325	300	345	355	235	295	500	575
838	560	825	810	710	650	650	660	605	575	575	540	485	530	445	410	390	330	315	310	210	170	100	0	60	140	240	230	265	345	410	550	600	525	490	430	370	315	335	320	230	290	600	675
839	550	775	770	670	610	615	650	565	525	525	490	430	475	390	345	340	275	260	315	225	125	85	60	0	75	200	170	205	285	355	500	540	465	430	370	310	255	275	270	310	370	550	625
840	550	770	790	690	620	625	650	575	525	525	475	435	495	410	365	315	275	285	330	110	145	145	140	75	0	135	195	145	215	300	480	510	420	365	300	230	175	200	200	365	425	530	605
841	650	880	880	780	700	730	750	655	625	625	570	670	620	630	490	415	390	410	465	220	275	280	240	200	135	0	145	205	300	360	565	575	475	415	330	240	160	135	80	470	530	615	690
842	540	740	745	645	565	595	640	520	480	480	425	525	475	485	345	270	245	260	320	75	175	210	230	170	195	145	0	60	150	220	415	435	345	280	205	135	90	130	165	440	500	465	540
843	500	660	670	570	490	555	600	445	425	425	365	465	415	425	285	210	185	200	280	65	165	215	265	205	145	205	60	0	90	155	360	375	290	225	150	105	115	160	215	450	510	410	465
844	390	515	490	390	310	470	490	265	335	335	275	375	325	335	195	225	120	145	230	120	220	245	345	285	215	300	150	90	0	65	270	290	210	150	115	130	175	235	305	465	525	320	375
845	345	575	540	440	360	410	445	315	290	290	215	315	290	275	185	100	135	165	240	185	230	310	410	355	300	360	220	155	65	0	215	220	145	80	90	155	225	280	355	525	585	265	320
846	215	295	335	135	155	210	315	110	115	145	60	160	175	130	180	165	235	270	265	370	380	450	550	500	480	565	415	360	270	215	0	120	150	180	280	365	440	495	550	650	710	50	105
847	230	345	410	310	230	325	330	185	235	270	180	280	295	240	290	230	300	335	365	420	440	505	600	540	510	575	435	375	290	220	120	0	90	120	250	340	420	470	550	730	790	145	125
848	360	410	470	370	290	360	460	245	260	265	190	290	305	220	270	175	245	280	325	495	365	450	525	465	420	475	345	290	210	145	150	90	0	60	160	250	330	380	460	670	730	195	200
849	370	470	525	425	345	410	470	300	290	290	210	310	390	210	235	145	210	245	300	265	315	390	490	430	365	415	280	225	150	80	180	120	60	0	95	200	280	330	410	630	690	230	250
850	440	550	615	515	435	490	540	390	380	380	290	390	475	270	275	185	220	255	330	205	275	355	430	370	300	330	205	150	115	90	280	250	160	95	0	100	180	225	310	590	650	320	355
851	505	650	710	610	530	580	605	485	440	440	390	364	449	324	319	245	255	280	360	175	275	325	370	310	230	240	135	105	130	155	365	340	250	200	100	0	80	130	215	555	615	415	450
852	580	730	785	685	605	665	680	560	530	530	470	420	505	380	375	295	285	300	390	155	255	300	315	255	175	160	90	115	175	225	440	420	330	280	180	80	0	55	140	525	585	480	520
853	610	780	780	680	600	715	710	555	585	585	525	475	560	435	430	355	340	355	445	210	310	345	335	275	200	135	130	160	235	280	495	470	380	330	225	130	55	0	85	555	615	540	575
854	685	870	870	770	690	780	785	645	670	670	610	560	645	520	515	435	425	440	530	295	340	355	320	270	200	80	165	215	305	355	550	550	460	410	310	215	140	85	0	530	590	620	650
855	600	840	800	700	710	660	635	665	600	600	590	520	520	480	450	480	410	410	380	380	300	235	230	310	365	470	440	450	465	525	650	730	670	630	590	555	525	555	530	0	60	650	725
856	660	900	860	760	770	720	695	725	660	660	650	580	580	540	510	540	470	470	440	440	360	295	290	370	425	530	500	510	525	585	710	790	730	690	650	615	585	615	590	60	0	710	785
857	200	250	280	190	105	170	265	65	95	130	65	165	170	160	210	215	285	320	295	420	430	500	600	550	530	615	465	410	320	265	50	145	195	230	320	415	480	540	620	650	710	0	75
858	275	335	290	195	110	205	300	100	165	205	140	240	245	235	285	290	360	390	370	495	505	575	675	625	605	690	540	465	375	320	105	125	200	250	355	450	520	575	650	725	785	75	0

Table 5. Covering Matrix.

d	816	817	818	819	820	821	822	823	824	825	826	827	828	829	830	831	832	833	834	835	836	837	838	839	840	841	842	843	844	845	846	847	848	849	850	851	852	853	854	855	856	857	858
816	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0
817	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
818	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
819	1	1	1	1	1	1	1	1	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1
820	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	1
821	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1
822	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
823	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	1	1
824	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	1
825	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1
826	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	1	1
827	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1
828	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1
829	1	0	0	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1
830	1	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	0	0	0	0	0	0	1	1	1	0	0	1	0	0	0	0	0	0	0	1	0
831	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	1	0
832	0	1	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	1	1	1	0	1	1	1	0	0	0	0	0	0	0	0
833	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	1	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0
834	1	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
835	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0
836	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
837	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	1	1	1	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
838	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
839	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
840	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	1	1	1	1	0	0	0	0
841	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0
842	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	1	1	1	0	0	0	0
843	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	1	1	0	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	0	0	0	0
844	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	1	0	1	1	1	1	0	0	1	1	1	1	1	1	0	0	0	0	0
845	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	1	1	1	1	1	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0
846	1	0	0	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	1	1
847	1	0	0	0	1	0	0	1	1	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	0	0	0	0	0	1	1
848	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	1	1
849	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	1	1
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851	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	0	0	0	0
852	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	1	1	1	1	0	0	0	0	1	1	1	1	1	0	0	0	0
853	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	1	1	1	0	0	0	0	0	1	1	1	1	1	0	0	0	0
854	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0
855	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
856	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
857	1	0	0	1	1	1	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1
858	0	0	0	1	1	1	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1

Survey form:

During the early stages of the project, Google survey was distributed to students living in student dorms in order to collect some helpful data. The questions were about the building number, and do you agree with the idea of vending machines and the expected time to reach to the nearest vending machine and how many times would you buy from the vending machines.

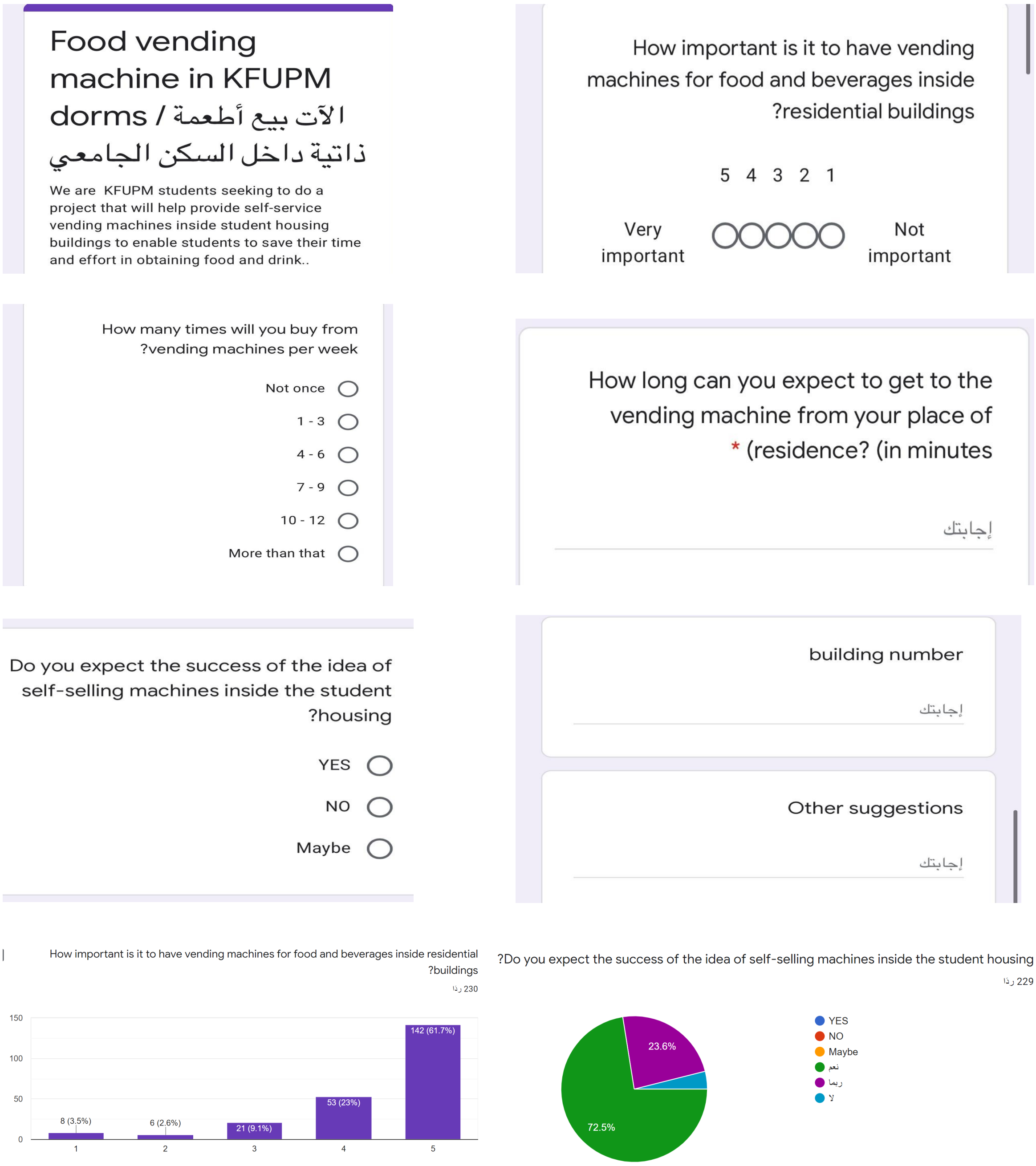

Figure 10. Survey form questions.

Measuring demand:

Based on the survey result, the excepted demand is calculated for each building. The table below summarizes expected the demands in student dorms.

Table 6: Student buildings demands

Building	Demand	Building	Demand
858	35	836	43
857	31	835	33
856	27	834	50
855	75	833	31
854	52	832	42
853	92	831	26
852	27	830	28
851	38	829	25
850	51	828	73
849	81	827	62
848	35	826	51
847	41	825	36
846	126	824	29
845	50	823	40
844	39	822	36
843	123	821	32
842	44	820	25
841	36	819	23
840	58	818	57
839	48	817	98
838	26	816	39
837	42		

Measuring Distances:

We used the Wikimpia website to measure the distances between the buildings. The distances between buildings are approximated to be equal to the actual path, to get more realistic results.

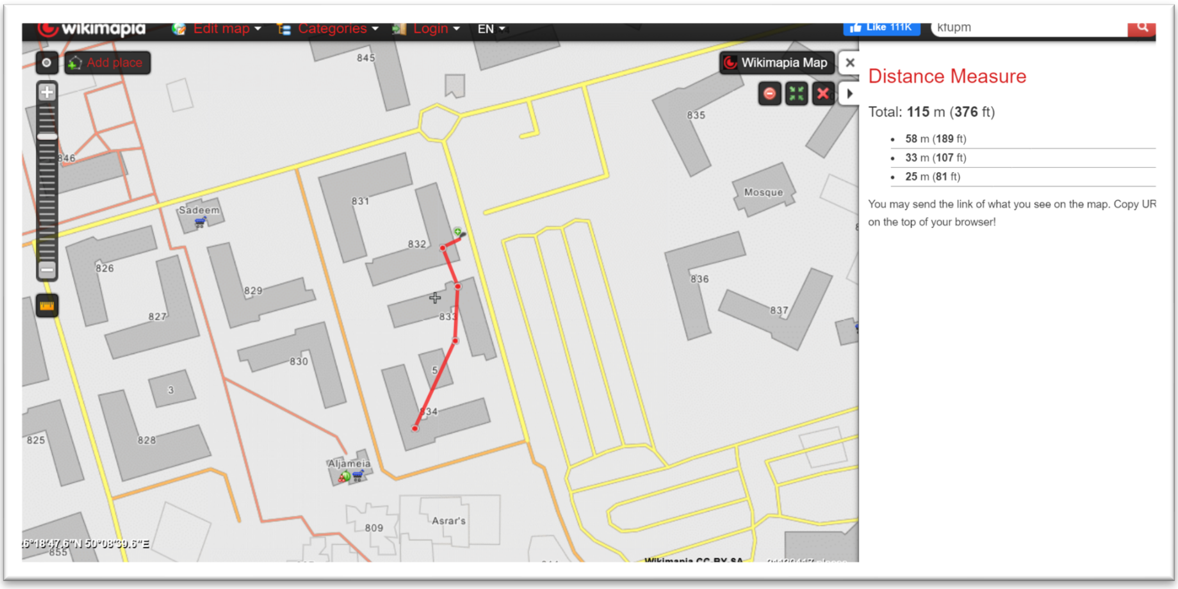

Figure 11. Measuring distance using Wikimapia

Types of vending machines:

FC6601

Merchandise Type	maximum 48 choices
Products capacity	240-720PCS
Dimension	1900mm(H)*960mm(W)*855mm(D)
Weight	280KG
Interface	MDB
Temperature	4-25 ℃
Electricity	AC 100-240V,50/60 Hz

Main Features

*High strength steel construction with durable powder coat pained surface.
*Re-configurable product selection spacing for variable package size.
*Comprehensive self-diagnostics+software upgrades.
*Easy to use customer interface.
*Drop sensing system virtually eliminates misvends and guarante product delivery.
*Triple glazed viewing window.
*Secure and lockable cash box.
*With temperature sensor,the temperature are adjustable.
*Glass heater embedded on glass to prevent condensing of moisture.
*GPRS or 3G remote monitoring system support.
*Excellent capacity and size ratio.
*Energy efficient compressor with R134a refrigerant can meet the ROHS requirement.
*Flexible layout for snack/fresh food/cans and bottle drinks etc.
*Adopt international MDB standard design.
*The payment system support cash (bill+coin) / cashless.
*Electric leakage protection function.
*Explosion proof,dust-proof,waterproof luminescent metal keyboard.
*The customized logo and sticker accepted.
*Electrical supply AC100-240V,50/60HZ
*Integral,push button,mains safety circuit breaker.

CRANE764

Specifications

Capacity: 300 to 450 items
Selections: 35 to 40 selections of chips, pastry, or candy
Electricity: 115 Volts, 60Hz, 3 amps (Model 764 – 9 amps)
Style: Black
Listings: cULus, CE, FCC, NAMA
Actual Dimensions: 40″ Wide x 35.5″ Deep x 72″ High
Actual Weight: 750 Lbs.
Shipping Weight: 825 lbs.
Shipping Length: 40″
Shipping Width: 48″
Shipping Height: 76″

SEL40

Features

- Electronic pricing up to $655.35
- Accepts $1 and $5 bills as well as coins
- Premium dollar bill validator and coin changer included
- iVend™ product delivery sensor system ensures product deliver or credit back
- Industry standard DEX recording and display of vend count and cash count
- Easy-touch keypad
- Simple to set up and maintain—load, price, vend
- Large glass product display
- Credit/debit card mobile payment compatible (card reader not included)
- Rugged steel doors
- 6 flex trays featuring adjustable height and spacing
- MDB compatible

Capacity

- Holds 630 items (226 snack/pastry, 440 candy)
- 40 snack selections

Electrical Requirements

- Requires one 110 VAC grounded outlet (indoor installation only)

Environmental Considerations

- Energy-efficient LED lighting
- Low energy cost: uses .62 kwh/day

Additional Information

- Americans with Disabilities Act (ADA) compliant
- Lifetime toll-free support: 1-800-833-4411
- Includes full product manual
- Made in the USA

35890117

Features

- Electronic pricing
- Accepts $1, $5, $10, $20 dollar bills, coins and tokens
- Premium dollar bill validator and coin changer included
- 1-piece design for easy setup and product loading
- Easily accessible electronics.
- Industry standard DEX recording and display of vend count and cash count
- iVend™ product delivery sensor system ensures product deliver or credit back
- Easy-touch keypad
- All-steel construction
- Welded seams to provide durability and anti-theft
- Equipped with school timer mode for controlled vend times
- Simple to set up and maintain—load, price and vend
- Large glass product display
- Vends all popular drink packages including soft drinks, non-carbonated drinks, waters, energy drinks, including new-age beverages.
- Point-of-sale window for promotions or customer information
- Rugged steel doors
- Card reader option available

- Process and monthly fees apply

- Cashless payment system runs off cellular towers so no landline or WiFi needed

- Card reader accepts mobile payments like Apple Pay or Google Wallet

- Merchant allows two tier pricing for cash/ credit sales

Capacity

- Standard capacity of 353 items (94 snack/pastry, 123 candy, 136 beverages)
- 20 snack selections and 9 drink selections
- Vend 9 types of favorite sodas, waters, and energy beverages in 12 oz cans, 16 oz cans or 16.9, 20 and 24 ounce bottles
- Additional pre-cooled drawer to store up to 10 beverages for future use
- Simple changeover from bottles to cans—no additional hardware needed
- 4 drink selections require 12 oz cans

Electrical Requirements

- Requires one 110 VAC grounded outlet (indoor installation only)
- Uses 3 kWh/ day
- 9'L power cord
- MDB compatible

ZG-CSC

Model	ZG-D720-10G(5HP)
Size	H: 1940mm W:1036mm D:790mm
Weight	245 KG
Selections	50-70
Capacity	300-800pcs
Shelves	6
Temperature	4-25°C (Adjustable)
Power supply	AC110V/220V-240V, 50-60HZ
Payment system	Bill, coin, coin dispenser(MDB protocol)
Standard Protocols	MDB/DEX/RS232

References

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Vending Machine (**FC6601)**

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Vending Machine (**CRANE764)**

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Vending Machine (**35890117)**

(https://www.alibaba.com/product-detail/Zoomgu-CE-certificate-factory-provide-Snack_62194817327.html?spm=a2700.wholesale.0.0.4182d1c8p8hAPQ)

Vending Machine (**ZG-CSC)**

(https://www.vapulus.com/ar/%D8%A7%D9%84%D8%AF%D9%81%D8%B9-%D8%A7%D9%84%D8%A5%D9%84%D9%83%D8%AA%D8%B1%D9%88%D9%86%D9%8A-%D9%81%D9%8A-%D8%A7%D9%84%D8%B3%D8%B9%D9%88%D8%AF%D9%8A%D8%A9/)