Optimizing solid waste collection using matching algorithm

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Abstract— **Solid waste collection is a complicated process which involves the interaction of various people and activities. Due to complex nature of the problem, in order to create a mathematical model one needs to make several assumptions. Some of these assumptions may not be realistic. Several researchers have done work on optimizing the transport system of the waste collection and disposal [1]. However, the sociological factor also plays an important role in minimizing the cost of waste collection. Not much work has been done in seeking techniques to optimize the sociological factor. Since the sociological factor is ignored in these models, they do not yield expected results. As such their usefulness is limited. In waste collection process people work in groups. General consensus is that when people who like each other are in a group the outcome is more. Waste collection and disposal process of the faculty of Engineering, University of Ruhuna, Sri Lanka was used in this research to study the sociological aspect of the process. Initially, with the intention of improving the output, cleaners who like each other were grouped using the stable matching algorithm. This did not improve the output. Instead a slight decline of the output was observed. Subsequently, the stable matching algorithm was used to pair cleaners, who do not like each other. This resulted in an increase in output. This strongly suggested that cultural factor also needs to be considered modeling waste collection process. However, quantifying cultural factor is a difficult task.**

Keywords- optimization; mathematical modelling; solid waste; matching algorithm

I. Introduction

A. Solid Waste

Solid waste is defined by various agencies in different ways depending on the circumstances. One such definition is 'Solid waste is material, which is not in liquid form, and has no value to the person who is responsible for it' [2]. Although human or animal excreta often end up in the solid waste stream, generally the term solid waste does not include such materials. Synonyms to solid waste are terms such as 'garbage', 'trash', 'refuse' and 'rubbish'. Even though the above definition excludes liquids some agencies include certain types of liquid waste in the solid waste category for the purpose of management [3].

United States State and Federal regulations define six different types of solid waste. One of these refers to waste generated in households, restaurants, streets, offices and public places. Most of this waste can be fitted into bags [3]. Types of waste generated at the Faculty of Engineering, University of Ruhuna belongs to this category. Even though the wastes from laboratories are not categorized as Solid waste they end up in the solid waste stream. In addition to this lot of green waste is generated daily by falling dead leaves. They are collected manually and taken by hand carts to dumping grounds.

The manner in which solid waste is collected and disposed is very important to health of the students and staff. Improper collection and disposal can create health hazards.

II. Background

Faculty of Engineering of University of Ruhuna is located in Galle district Southern province of Sri Lanka. It is situated in a 12 hectare land along Galle Wackwella road, formerly owned by Sri Lanka Broadcasting Cooperation [4].

In 1990 the Faculty of Engineering was established at Hapugala. To establish this Faculty several buildings were constructed, which included an administrations building, three departments, cafeteria, student houses and 20 staff quarters. (Fig. 1)

Substantial amount of waste is generated daily at the faculty premises. There are about 800 students and 100 academic and non academic staff working in the Faculty. About 500 Kg of solid waste is generated daily. A major source of solid waste is the dead leaves falling on to the ground. University has employed a private cleaning service to collect and dispose the solid waste.

For the purpose of cleaning the faculty premises is divided in to 10 zones. Each zone has a dumping site. Nine of these are open dumps and one is an incineration site. Fig. 1 shows the ten different zones and the corresponding disposal sites. Two cleaners are assigned to clean the open areas in each zone.

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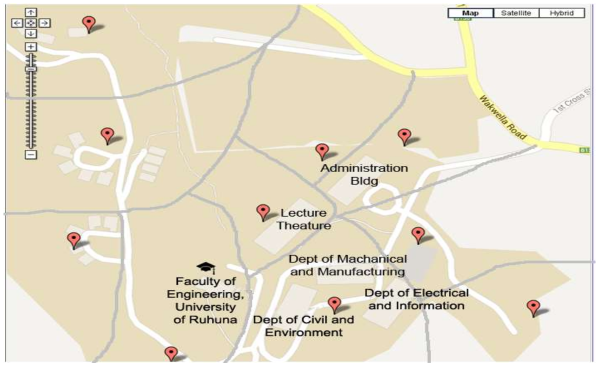

Fig. 1: Map of the study area (Base map courtesy of Google inc.)

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III. Problem Statement

Major problem faced by the cleaning agency involved in cleaning, is the lack of cooperation among cleaners. For example sometimes the supervisor complains that an area is not cleaned properly. In such a situation the cleaners who are assigned for that area blame each other.

This result in a deadlock, one cleaner claims that lack of cooperation from her partner result this situation where, the area is not cleaned properly. The other cleaner says the same. It seems that this kind of deadlock can be alleviated by grouping those who like each other together. In actual practice the grouping is done arbitrarily. It does not consider preferences of individual cleaners. Often this kind of grouping results in a situation where those who do not like each other to work together, which in turn results in poor performance in the cleaning process.

Cleaning staff consist of 20 females and 13 males. Females are generally assigned to sweeping tasks and males are assigned to work that requires heavy handling of waste. Women cleaners' salary is about 15 percent less than their male counterparts. This is discrimination against women cleaners which may not be acceptable in some countries.

A. Proposed solution

It was evident that the lack of performance is not a technical problem but a social problem. Hence the solution was found to be not to add new resources, but to rearrange the existing resources. As such it was decided to use a different approach to group the cleaning pairs. Stable matching algorithm widely used in this type of situation was used to pair the cleaners.

IV. Matching Elements

Matching elements in sets have a wide variety of applications in real world [5]. The simplest form of this problem is matching elements in two sets. The problem is further simplified by having equal number of elements in each set. Graph theory can be used to solve this problem [6]. When using graph theory you are given a graph with nodes and edges. Nodes represent the elements and edges represent the level of relationship. The objective is to create as many matching pairs as possible.

In early days matching algorithm was used to match boys and girls. Hence this problem was named "stable marriage problem". It was used to match men and women who are not married. The objective was to match them so that all are reasonably happy. A set of matched men and women are happy when there are no rouge couples, sometimes known as blocking pairs. Rouge couples are men and women who prefer another pair over their current partner.

The stable marriage problem is a well studied problem in set theory. The basic idea is to match elements of two sets so that there are no blocking pairs. Given a married pair, X-A and Y-B, if man X prefers the woman B more than his current woman A and woman B prefers X more than her current man Y, then X-B is called a blocking pair. The problem can be solved either using graph theory or set theory. Both procedures yield
the same optimal solution.

It is called the stable marriage problem since the standard formulation was to match n men to n women so that there are no blocking couples, sometimes known as rouge couples. If there are blocking couples the matching is unstable.

Gale Shapley proved that it is always possible to find a matching, so that all marriages are stable [7]. Gale Shapely algorithm can be used to find a stable matching. For a given set of men and women there can be more than one stable matching. Gale Shapely algorithm can be used to find two extreme solutions. One, male optimal solution and the other female optimal solution. There can be situations where there is only one stable matching. Then it is called a unique matching. As the name implies the male optimal solution favors men over women and vice versa.

V. Matching Algorithm

The algorithm can be summarized as follows.

Marriage is a very complicated problem. As such in order to solve it using mathematical modeling one needs to simplify it substantially. The following assumptions are made to make the problem solvable.

Assumptions

There are equal number of men and women

- A man can marry only one woman
- A woman can marry only one man
- A man has to marry a woman
- A woman has to marry a man

These assumptions convert the problem to a solvable one. It should be noted that if not for the last two assumptions there is no solution to the problem.

The solution procedure consists of several rounds. Initially each man and woman prepares an ordered list of preferences. Examples of two such lists are given below.

M1: W4, W2, W3, W1, W5

W1: M5, M3, M1, M4, M2

Round 1: Each man proposes to the one he loves most. At the end of round 1 a woman might have received no proposals, one proposal or many proposals. Women should respond to these situations as follows.

If she receives no proposals, do not worry. Just wait. If she receives one proposal accept it. If she has received more than one proposal get engaged to the one she loves most among them. Reject all others.

At the end of round 1, there will be equal numbers of men and women who are engaged.

Round 2: Engaged men do nothing. Unengaged men go and propose to the second one in the preference list.

Women use the same strategy as before with the following exception. If you are currently engaged and receive a proposal from a person better than the current partner, reject the current partner and engage to the new one.

What this means is that a man engaged in round 1 might find himself unengaged in round 2. On the other hand women engaged in round 1 continue to be engaged in round 2.

Round 3: Unengaged men. Propose the third woman in the list. Women use the same strategy as before.

This procedure is carried out round after round until there is no one to propose and propose to.

It can be proved the resulting set is a stable match.

It is evident that each time a man proposes he does it out of desperation. He starts with his first choice, then the second and then the third etc. On the other hand when a woman changes she get a better one than her current partner.

In the previous case men proposed, hence called the men optimal solution. It is also possible for women to propose. In this case it is called a woman optimal solution. It can be seen that a men optimal solution favors men and vice versa.

A. Application to a Solid Waste System

The above algorithm was applied to a waste collection and disposal system at the Faculty of Engineering, University of Ruhuna, Sri Lanka.

VI. FORMULATION OF THE MODEL

First step in the evaluation of performance is to establish a baseline. The following indicators were used in setting up the baseline.

- Number of complaints received from the user community.
- Number of complaints received against co workers.
- Volume of waste collected.
- Volume of waste not collected

Monthly values of these parameters were evaluated and recorded before beginning of the project. This was used as our baseline against which the performance was evaluated in subsequent tests.

As mentioned earlier there is 20 female cleaning staff who is assigned to open areas. For the purpose of this research they were divided into 2 groups A and B ten in each. Then each person in group A was given list of cleaners in group B. They were asked to rank each person in the order of their preferences. The person whom she likes the most was to be ranked 1, and the least preferred to be ranked 10. This procedure was repeated for cleaners in group B.

TABLE I. GROUP A PREFERENCES

A0	B6	B4	B2	B3	B0	B5	B1	B7	B9	B8
A1	B6	B5	B9	B1	B7	B2	B8	B0	B3	B4
A2	B2	B0	B4	B6	B9	B1	B3	B5	B8	B7
A3	B0	B4	B5	B3	B8	B6	B1	B9	B7	B2
A4	B1	B3	B0	B6	B8	B9	B4	B7	B2	B5
A5	B5	B1	B4	B9	B7	B0	B6	B2	B3	B8
A6	B8	B4	B1	B6	B7	B9	B3	B2	B0	B5
A7	B4	B2	B1	B0	B7	B5	B3	B9	B6	B8
A8	B9	B4	B6	B8	B0	B2	B5	B1	B7	B3
A9	B3	B9	B7	B2	B5	B1	B8	B4	B6	B0

TABLE II. GROUP B PREFERENCES

B0	A1	A0	A4	A6	A8	A9	A2	A3	A5	A7
B1	A3	A6	A7	A4	A0	A1	A5	A2	A9	A8
B2	A5	A1	A0	A2	A7	A4	A6	A3	A8	A9
B3	A8	A2	A3	A1	A9	A5	A7	A4	A6	A0
B4	A9	A4	A7	A3	A8	A2	A6	A5	A1	A0
B5	A2	A0	A1	A7	A8	A9	A4	A5	A3	A6
B6	A1	A6	A4	A8	A7	A0	A2	A9	A3	A5
B7	A6	A7	A2	A3	A4	A5	A9	A8	A0	A1
B8	A7	A8	A0	A3	A1	A5	A2	A4	A6	A9
B9	A4	A5	A1	A0	A8	A2	A6	A7	A9	A3

TABLE III. NEW PAIRS AND THEIR LIKINGS

A0	B6	1
A1	B5	2
A2	B2	1
A3	B9	8
A4	B1	1
A5	B7	5
A6	B8	1
A7	B0	4
A8	B4	2
A9	B3	1
Total		24

The preferences of cleaners in the two groups are presented in tables I and II.

Then Using Gale Shapely algorithm ten pairs were selected so that there are no blocking pairs.

Table III shows the new pairs and how far away they are from their preferred workers.

There was no significant improvement in the output. On the contrary, a slight decline was observed.

Next, the people who do not like each other were paired. For this purpose it was necessary to create two tables as in the previous case but this time indicating their dislikes.

The person whom one dislikes most is to be ranked 1 and person whom she dislikes least to be ranked 10.

The results are presented in table IV and V. It can be seen that tables IV is the reverse the table I and table V is the reverse table II.

With this change a 30 percent improvement of the performance was observed. One possible reason is that when people who like each others are grouped together they begin to socialize.

The result of this pairing is presented in table VI

TABLE II. GROUP A DISLIKES

A0	B8	B9	B7	B1	B5	B0	B3	B2	B4	B6
A1	B4	B3	B0	B8	B2	B7	B1	B9	B5	B6
A2	B7	B8	B5	B3	B1	B9	B6	B4	B0	B2
A3	B2	B7	B9	B1	B6	B8	B3	B5	B4	B0
A4	B5	B2	B7	B4	B9	B8	B6	B0	B3	B1
A5	B8	B3	B2	B6	B0	B7	B9	B4	B1	B5
A6	B5	B0	B2	B3	B9	B7	B6	B1	B4	B8
A7	B8	B6	B9	B3	B5	B7	B0	B1	B2	B4
A8	B3	B7	B1	B5	B2	B0	B8	B6	B4	B9
A9	B0	B6	B7	B8	B1	B5	B2	B7	B9	B3

TABLE III. GROUP B DISLIKES

B0	A7	A5	A3	A2	A9	A8	A4	A6	A0	A1
B1	A8	A9	A2	A5	A1	A0	A7	A4	A6	A3
B2	A9	A8	A3	A6	A4	A7	A0	A2	A1	A5
B3	A0	A6	A4	A7	A5	A9	A3	A1	A2	A8
B4	A0	A1	A5	A6	A2	A8	A7	A3	A4	A9
B5	A6	A3	A5	A4	A9	A8	A1	A7	A0	A2
B6	A5	A3	A9	A2	A0	A7	A4	A8	A6	A1
B7	A1	A0	A8	A9	A5	A4	A2	A3	A7	A6
B8	A9	A6	A4	A2	A5	A1	A0	A3	A8	A7
B9	A3	A9	A7	A6	A2	A8	A1	A0	A5	A4

VII. CONCLUSION

Life in work places is full of conflicts. These conflicts occur as a result of people blaming each other for poor performance. Generally, managers try to avoid these conflicts by grouping those who like each other together. Gale Shapely algorithm can be used to formulate groups in such a way that people who like each other work together.

General consensus is that if groups are formed in such a manner the output is improved. However, this research proved it to be the opposite. This suggests that there are other factors like cultural, economic and social which affect the performance. Quantifying these factors is a difficult task but need to be done in order to refine this model and make it useful.

TABLE IV. NEW PAIRS AND THEIR DISLIKINGS

A0	B9	2
A1	B4	1
A2	B7	1
A3	B1	4
A4	B2	2
A5	B8	1
A6	B5	1
A7	B6	2
A8	B3	1
A9	B0	1
Total		16

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