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A Multi-Objectives Mathematical Model For Solving Industrial Hazardous Waste Location-Routing-Problem In Johor Region

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Abstract: Industrial hazardous waste management that may poses risk to surroundings includes collection and transportation of the waste, treatment, recycling and disposal. This research aims to determine the Pareto optimal of multiple objective function by implementing the Weighted Sum Method and to propose a new strategic treatment with technologies; chemical and incineration, recycling and disposal centres for location-routing problem in Johor region. The mathematical models consider two goal functions: transportation of hazardous items and waste residues, and also the capital costs of setting up new treatment, recycling, and disposal centers, as well as reducing transportation risk exposure due to population exposure along hazardous material and waste residue transportation routes, all result in decreasing total transportation costs. The outcomes of the problem solved show a conflict between the two objectives. The cost value can therefore be minimized by slightly increasing the transportation risk value and vice versa. For merge two objectives function under one objective function, a Weighted Sum Method is used with the assist of CPLEX solver to deal with the problem in Johor region. All potential candidates to open up a new hazardous waste management centres were proposed in certain industrial area w Pareto Optimal Solution.

Keywords: Multiple Objective Function, Weighted Sum Method, Location-Routing

1. Introduction

Hazardous waste is any substances that can be harmful to surrounding either solid, semi-solid, liquid or in the form of any gas. Hazardous waste can be classified into three types which are industrial hazardous waste material (HAZMAT), medical waste, and household hazardous waste. The HAZMAT is a substance that may be either one useful or dangerous when exposed to flammable, poisonous, toxic or corrosive surroundings. With the increasing of waste in Malaysia, and at the same time Malaysia is heading to be an industrial country, the HAZMAT management problem becomes more significant.

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Routing consists of finding an optimal route in relation to total time, cost or distance between two or more nodes. The definition of routing problem according to Jia & Ierapetritou [8] is any graph or network where the path has to involve visiting certain necessary vertices and crossing certain necessary edges. The goals of the location routing problem model are to assist in determining the locations of treatment centers that use various technologies, routing various types of industrial hazardous wastes to compatible treatment centers, and routing hazardous waste and waste residues to those centers, as well as the locations of disposal centers and waste residues [7]. Therefore, a more organized and structured on location and routing in managing HAZMAT are needed. The objectives for this research are to determine the Pareto optimal solution of multiple objectives by implementing Weighted Sum Method and to propose a new strategic treatment, recycling and disposal centres for location-routing problem in Johor region.

Multiple Objective Optimization (MOO) can be categorized into two types of method which are Pareto and scalarization [4]. MOO is an approach for this research to find a Pareto optimal solution for objectives more than one and it does not require a complicated equation to solve. Furthermore, a Pareto optimum value in MOO is one that may be obtained when one objective function cannot be increased without lowering the other objective function [5]. This can be denoted as $f_1(x)$ and $f_2(x)$ as a convex combination of objectives with a various unit. After normalized these objectives, by summing the weighted normalized objective can be created to combine the objective function and lastly it can be converted to a single objective model. According to [2], this method will combine all objectives into one scalar by multiplying each objective function by a weighting factor and sum up the entire objective. From the past few years, multiple objective problems on the location-routing problem are widely explored in industrial management [1, 11].

Nomenclature

$N = (V, A)$	Transportation network of nodes V and arcs A
$G = \{1, ..., g\}$	Hazmat generation nodes, $G \in V$
$T = \{1, ..., g\}$	Potential treatment nodes, $T \in V$
$D = \{1, ..., g\}$	Potential disposal nodes, $D \in V$
$W = \{1, ..., w\}$	Hazardous waste type
$H = \{1, ..., h\}$	Potential recycling nodes, $H \in V$
$Q = \{1, ..., q\}$	Treatment technologies

Parameters

$c_{i,j}$	Cost of transporting one unit of hazardous waste on link $(i, j) \in A, i \in G, j \in T$
$r_{w,q}$	Proportion of mas reduction of waste type $w \in W$ generated at generation node $q \in Q$
γ_i	Proportion of total hazardous waste recycled at node $i \in H$
$tc_{q,i}$	Capacity of treatment technology $q \in Q$ at node $i \in T$
$tc^m_{q,i}$	Minimum amount of hazardous waste required to establish treatment technology $q \in Q$ at node $i \in T$
$dc_{q,i}$	Disposal capacity of disposal centre $i \in D$
$dc^m_{q,i}$	Minimum amount of waste residues required to establish a disposal centre at node $i \in D$
$rc_{q,i}$	Recycling capacity of node $i \in H$
$rc^m_{q,i}$	

$cz_{i,j}$	Cost of transporting one unit of waste residue on link $(i,j) \in A, i \in T, j \in D$
$cv_{i,j}$	Cost of transporting one unit of waste residue on link $(i,j) \in A, i \in H, j \in D$
$cr_{i,j}$	Cost of transporting one unit of recyclable waste on link $(i,j) \in A, i \in G, j \in H$
$crr_{i,j}$	Cost of transporting one unit of recyclable waste on link $(i,j) \in A, i \in T, j \in H$
$fc_{q,i}$	Fixed cost of opening a treatment technology $q \in Q$ at node $i \in T$
fd_i	Fixed cost of opening a disposal centre at node $i \in D$
$gen_{w,i}$	Amount of hazardous waste type $w \in W$ generated at generation node $i \in G$
fh_i	Fixed cost of opening a recycling centre at node $i \in H$
$POPgt_{i,j}$	Number of people within a given distance of the link $(i,j) \in A, i \in G, j \in T$
$POPtd_{i,j}$	Number of people within a given distance of the link $(i,j) \in A, i \in T, j \in D$
$\alpha_{w,i}$	Proportion of recycling of hazardous waste type $w \in W$ generated at generation node $i \in G$
$\beta_{w,q}$	Proportion of recycling of hazardous waste type $w \in W$ generated at generation node $q \in Q$
	Minimum amount of waste residues required to establish a recycling centre at node $i \in H$
$com_{w,q}$	1 if waste type $w \in W$ is compatible with (can be treated with) technology $q \in Q$; 0 otherwise

Decision Variables

$x_{w,i,j}$	Amount of hazardous waste type $w \in W$ transported through link $(i,j) \in A, i \in G, j \in T$
$z_{i,j}$	Amount of waste residue transported through link $(i,j) \in A, i \in T, j \in D$
$l_{i,j}$	Amount of recyclable waste transported through link $(i,j) \in A, i \in G, j \in H$
$k_{i,j}$	Amount of recyclable waste residue transported through link $(i,j) \in A, i \in T, j \in H$
$v_{i,j}$	Amount of waste residue transported through link $(i,j) \in A, i \in H, j \in D$
$y_{w,q,i}$, $y_{w,q,j}$	Amount of hazardous waste type $w \in W$ treated at node $i, j \in T$ with technology $q \in Q$
dis_i, dis_j	Amount of waste residue disposed at node $i, j \in D$
hr_i, hr_j	Amount of waste recycled at node $i, j \in H$
$f_{q,i}$	1 if treatment technology $q \in Q$ is established at node $i \in T$; 0 otherwise
dz_i	1 if disposal centre is established at node $i \in D$; 0 otherwise
b_i	1 if recycling centre is established at node $i \in H$; 0 otherwise

2. Methodology

In this research, the mathematical model for solving location-routing of industrial hazardous waste materials (HAZMAT) problem is implemented from the model established by previous researcher [10]. In order to determine the effective solution from Pareto Frontier, one of the objectives must downgrade another objective in order to achieve the Pareto optimal. It is an uncommon occurrence when each goal function is determined to be at its best. In truth, there may be a conflict in order to get an efficient solution for each purpose. Hence, a formulation of the Weighted Sum Method is implemented to solve the multiple objectives problem by using CPLEX software. Furthermore, the Geographical Information

System (GIS) is used to identify the appropriate location for the HAZMAT management problem which focuses on the Johor region.

2.1 The Mathematical Model

HAZMAT management decisions are mainly difficult due to the presence of at least partially competing goals and priorities related to total costs, potential risk, risk equity, social rejection, safety, and others. The mathematical model of the HAZMAT management problems considered consist of two objectives which implemented from [10].

$$Minimize\ f_1(x) = \sum_{i\in G}\sum_{j\in T}\sum_{w\in W} c_{i,j}x_{w,i,j} + \sum_{i\in T}\sum_{j\in D} cz_{i,j}z_{i,j} + \sum_{i\in H}\sum_{j\in D} cv_{i,j}v_{i,j}$$

$$+\sum_{i\in G}\sum_{j\in H} cr_{i,j}l_{i,j} + \sum_{i\in T}\sum_{j\in H} crr_{i,j}k_{i,j} + \sum_{i\in T}\sum_{q\in Q} fc_{q,i}f_{q,i} + \sum_{i\in D} fd_i dz_i + \sum_{i\in H} fh_i b_i\ , \qquad Eq.\ 1$$

$$Minimize\ f_2(x) = \sum_{i\in G}\sum_{j\in T}\sum_{w\in W} POPgt_{i,j}x_{w,i,j} + \sum_{i\in T}\sum_{j\in D} POPtd_{i,j}z_{i,j}\ , \qquad Eq.\ 2$$

$$gen_{w,i} = \alpha_{w,i}gen_{w,i} + \sum_{j\in T} x_{w,i,j}, \forall i\in G, \forall W \in w, \qquad Eq.\ 3$$

$$\sum_{w\in W} \alpha_{w,i}gen_{w,i} = \sum_{j\in H} l_{i,j}, \forall i \in G\ , \qquad Eq.\ 4$$

$$\sum_{i\in G} x_{w,i,j} = \sum_{q\in Q} y_{w,q,j}, \forall W \in w, \forall j \in T\ , \qquad Eq.\ 5$$

$$\sum_{w\in W}\sum_{q\in Q} y_{w,q,i}(1-r_{w,q})(1-\beta_{w,q}) = \sum_{j\in D} z_{i,j}, \forall i \in T\ , \qquad Eq.\ 6$$

$$\sum_{w\in W}\sum_{q\in Q} y_{w,q,i}(1-r_{w,q})\beta_{w,q} = \sum_{j\in H} k_{i,j}, \forall i \in T\ , \qquad Eq.\ 7$$

$$\sum_{i\in T} k_{i,j} + \sum_{i\in G} l_{i,j} = hr_j, \forall j \in H\ , \qquad Eq.\ 8$$

$$hr_i(1-\gamma_i) = \sum_{j\in D} v_{i,j}, \forall i \in H\ , \qquad Eq.\ 9$$

$$\sum_{i\in H} v_{i,j} + \sum_{i\in T} z_{i,j} = dis_j, \forall j \in D, \qquad Eq.\ 10$$

$$\sum_{w\in W} y_{w,q,i} \le tc_{q,i}, \forall q \in Q, \forall i \in T\ , \qquad Eq.\ 11$$

$$dis_i \le dc_i dz_i, \forall i \in D\ , \qquad Eq.\ 12$$

$$hr_i \le dc_i dz_i, \forall i \in D, \qquad Eq.\ 13$$

$$\sum_{w\in W} y_{w,q,i} \ge tc^m_{q,i} f_{q,i}, \forall q \in Q, \forall i \in T\ , \qquad Eq.\ 14$$

$$dis_i \ge dc^m_i dz_i, \forall i \in D\ , \qquad Eq.\ 15$$

$$hr_i \ge rc^m_i b_i, \forall i \in H\ , \qquad Eq.\ 16$$

$$y_{w,q,i} \ge tc_{q,i}com_{w,q}, \forall w \in W, \forall q \in Q, \forall i \in T\ , \qquad Eq.\ 17$$

$$\begin{aligned}
&x_{w,i,j} \geq 0, \forall w \in W, \forall i \in G, \forall j \in T,\\
&y_{w,q,i} \geq 0, \forall w \in W, \forall q \in Q, \forall j \in T,\\
&z_{i,j} \geq 0, \forall i \in T, \forall j \in D,\\
&k_{i,j} \geq 0, \forall i \in T, \forall j \in H,\\
&l_{i,j} \geq 0, \forall i \in G, \forall j \in H,\\
&v_{i,j} \geq 0, \forall i \in T, \forall j \in D,\\
&dis_i \geq 0, \forall i \in D,\\
&hr_i \geq 0, \forall i \in H,
\end{aligned} \qquad Eq.\ 18$$

$$\begin{aligned}
&f_{q,i} \in \{0,1\} \forall q \in Q, \forall i \in T,\\
&dz_i \in \{0,1\} \forall i \in D,\\
&b_i \in \{0,1\} \forall i \in H,
\end{aligned} \qquad Eq.\ 19$$

The first objective is to reduce the overall cost of transporting hazardous materials and waste products, as well as the fixed costs of operating treatment, disposal, and recycling facilities, as shown in Eq. 1. The total cost of transporting hazardous waste and waste remains is calculated using the quantity transported, the distance traveled, and the average fuel cost. The second objective as stated in Eq. 2 is to reduce the total transportation risk associated with population exposure along hazardous materials and waste residue transit routes. The amount of hazardous waste type produced at the generating node is determined by constraint in Eq. 3. Eq. 4 is to determine the total amount of recyclable waste transferred through link from generating node to recycling centre. Eq. 5 is to determine the total amount of hazardous waste type which is transferred from generating node to treatment nodes. Eq. 6 come up with the flow to determine total amount of waste residues transferred through treatment nodes to disposal nodes while Eq. 7 come up with flow to determine total amount of recyclable waste residues transported from treatment nodes to recycling nodes. Eq. 8 shows the flow on recyclable waste from generating nodes and recyclable waste residues at treatment centres to recycling centres. Eq. 9 is about the flow of amount of waste residues transported through recycling centres to disposal centres. Eq. 10 determines the amount of waste from recycling centres and treatment centres to the disposal centres. Eq. 11, 12, 13 are designate on capacity limitation requirement for constraint treatment, disposal and recycling centres, respectively. The minimal amount of hazardous wastes or waste residues taken to construct these treatment, disposal, and recycling centers are specified in Eq. 14, 15 and 16, respectively. Eq. 17 only sent the generated hazardous waste to treatment centres if and only if those waste is can be treated with compatible technologies. Eq. 18 are the non-negativity constraints, meanwhile Eq. 19 stated the binary variables.

If *w* represents different kinds of hazardous waste, *q* represents the number of treatment technologies, g refers to the number of generation nodes, t represents represents the number number of potential treatment nodes, *d* represents the number of potential disposal nodes, and *h* represents the number of potential recycling nodes. Thus the model has (*qt* + *d* + *h*) 0-1 decision variables and (*wgt* + *td* + *gh* + *th* + *hd* + *wtq* + *d* + *h*) is the actual decision variables that can be achieved. The model's decision variables are represented graphically as in Figure 1 reproduced from [10].

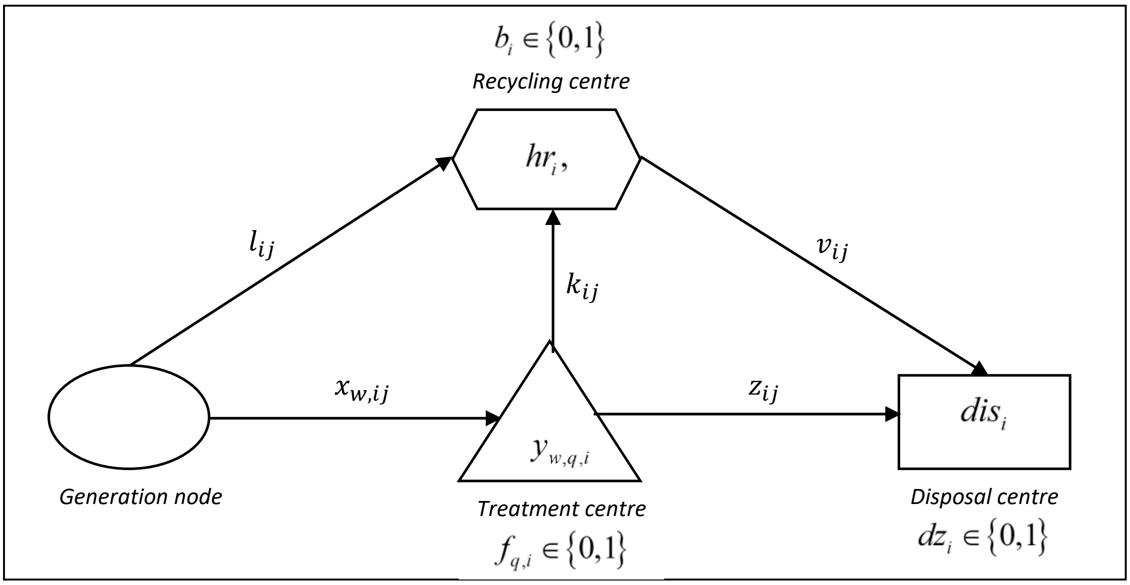

Figure 1: Decision variables of the mathematical model. Reproduced from [10]

2.2 Pareto Optimal Solution by implementing the Weighted Sum Method

For this research, two objectives are considered in order for solving the HAZMAT management problem in Johor region. WSM, according to [2], is the process of integrating all objectives into a single scalar by multiplying each objective function by a weighting factor and summarizing the total objective. As a set of objectives with a convex combination and a distinct unit, this can be denoted as $f_1(x)$ and $f_2(x)$. The formulation of WSM for this solution is obtained as: $minimize\ f(x) = \sum_{m=1}^{M} w_m f_m(x)$. The criterion for selecting a weight must be equal to the total weight which is 1 where $w_1 + w_2 = 1$ based on [9]. So for a solution, the weight can be chosen from 0 to 1. Pareto optimal solution or Pareto optimal front of the solution can be dominated or non-dominated for the objective function. The non-dominated solutions can be express as if no solution is at upper or next to the right solutions, we can call them a non-dominated solution. The two-dimensional interface optimization with two objective functions and the non-dominated solution can be defined in Pareto optimal front [3]. The point of anchor is the point at which the objective function has the highest value, whereas the point of utopia is where an objective function's least value and the lowest value of another objective function converge. The utopia point needs to identify first to find the optimal value by determine the Euclidean distance. The point of utopia is the intersection of the first objective function's maximum or minimum value with the other objective function's minimum or maximum value [6]. Hence, after obtaining the utopia point, the formula to find the Euclidean distance is $AB^2\sqrt{AC^2 + BC^2}$.

2.3 Geographical Information System

We take into consideration the bandwidth of population exposure along the road are around industrial area for each potential nodes. The Geographical Information System (GIS) is also used for measuring the distance of each node to another node in order to calculate the cost of transporting between node. Furthermore, GIS also implemented to locate new treatment, recycling and disposal centres for managing HAZMAT problem in Johor region.

3 Results and Discussion

In order to solve the mathematical model for solving HAZMAT management problem in Johor region, the Weighted Sum Method (WSM) is used to find the Pareto optimality for this problem. The location of potential centres to be opened is identified based on the industrial area with high population for each district; Batu Pahat, Johor Bahru, Kluang, Kota Tinggi, Kulaijaya, Muar, Pontian, and Segamat.

3.1 Locating New HAZMAT Centres using Arcmap Geographical Information System

Three recycling and technology treatment centres and two disposal centres are proposed to be opened in Johor. Incineration and chemical treatment are two types of treatment centers with various treatment technologies that are considered appropriate. There are three kinds of HAZMAT that are included in this research. The first type consists of hazardous waste that can be incinerated, while the second type consists of hazardous waste that is not acceptable for incineration but is suitable for chemical treatment. The third type of hazardous waste which is acceptable for chemical treatment and incineration. Note that 5 generating nodes are located randomly near the treatment centres since the industrial area that generate HAZMAT is larger in this research. Hence, the distance from generating nodes to treatment centre and recycling centre are also assumed.

There are three potential nodes for recycling centre which are solution number (2), (5) and (1). For potential nodes of treatment centre for incineration is solution number of (7) while solution number (3) and (6) are for chemical treatment. For disposal, there are 2 nodes which are solution number (8) and (4). Since the population of the industrial area in Johor Bahru and Senai are more than 100,000 people, hence these high populations are suitable for recycling centre. The treatment and disposal may involve combustion and only few percent that HAZMAT will be transferred to the recycling centre. For potential treatment nodes, the lowest population area is considered since it needs special care, truck and equipment to carry the waste residues to disposal centre. Lastly, to determine the potential centre of disposal, the intermediate population of the highest and lowest are chosen. From the data that has been collected and assumed, the new HAZMAT management centres are located in Johor region using Arcmap GIS 10.8 as in Figure 2.

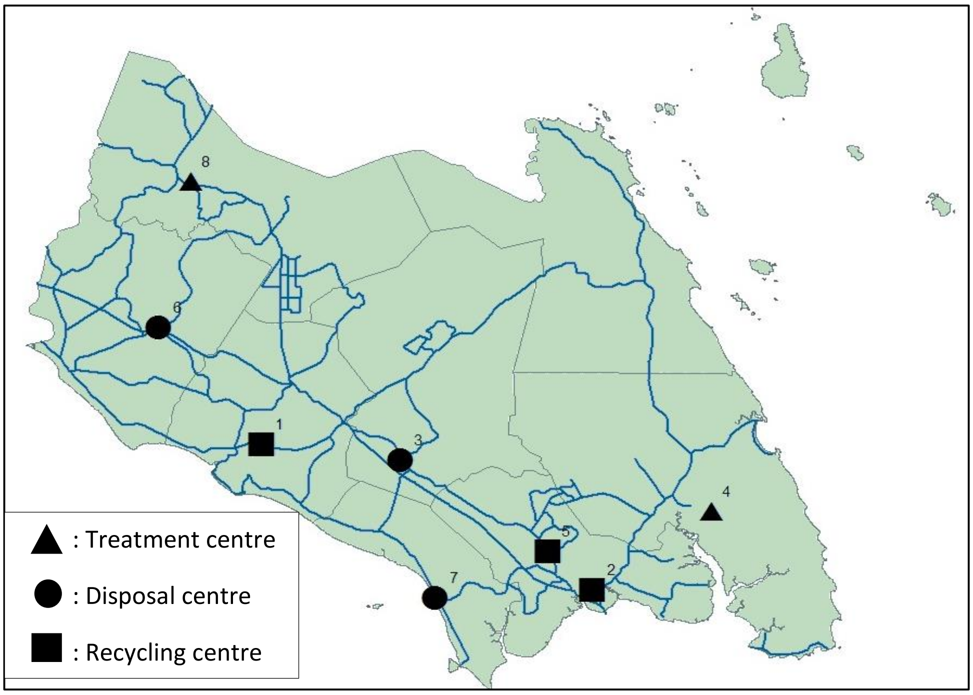

Figure 2: Location of new HAZMAT management centres in Johor

There is currently no data available on the amount of HAZMAT produced by industry in Johor. Therefore, for all types of waste, the amount of HAZMAT produced are assumed to be the same and proportional to the population of the industrial area. The total cost of transporting hazardous waste and waste residues is determined based on the amounts transferred, the length of transport and the average consumption of fuel. For this research, the fuel consumptions are RM1.98/litre in Malaysia on average and a truck uses on average 0.0003 litre/meter. The waste transportation costs per unit

$(cz_{i,j}, cv_{i,j}, crr_{i,j})$ are considered to be 70% of those of hazardous waste, as hazardous waste requires special treatment, trucks and equipment, similar to [9] and [1]. We also assumed that RM50 million, RM20 million and RM20 million, respectively were the fixed costs of establishing a treatment, disposal and recycling centre.

For all kinds of hazardous waste and waste residues, the population exposure bandwidth is identified as a region of the industrial area. To determine the total transportation risk associated to the population exposure along the transportation routes of hazardous materials and waste residues, the number of people is determined in between 100 to 300 people for each centre from one node to another (along the route). If any exposure occurs, it is assumed that HAZMAT transported from the generation nodes to treatment centres and waste residues transported from the treatment centres to the disposal centres may be hazardous to people.

Since HAZMAT is typically not appropriate for recycling immediately after generation, it is only presumed that a small percentage is sent after generation to recycling centres. This number is taken as either 10%, 0%, and 5% for waste consistent with chemical, incineration, or both treatment technologies, respectively, based on information gathered from the existing centres by Samanlioglu, 2013. However, 30% of the waste residues at a chemical treatment centre are assumed to be sent to recycling after chemical treatment, similar to [1] and none are sent to recycling after incineration as they are only made of ashes. In addition, incineration mass reduction is 80 %, while the mass reduction is 20% after chemical treatment. Also, after the recycling process, 5% is assumed to be sent to disposal centres.

3.2 Solutions of Pareto Optimal using Weighted Sum Method

The result in Table 1 shows a tradeoff between goals function of cost, $f_1(x)$ and the risk, $f_2(x)$. The dispute between two goals emerged between 0 and 1 increments of 0.1 by differing the values of w_1 and w_2. It is apparent that the cost value is increased in order to lower the risk value. Table 2 shows the same outcome as Table 1. Using various weight considerations, the location of treatment, recycling, and disposal centers is changing.

Table 1: Solution of two objectives function with the associated weight vectors

Solution Number	w_1	w_2	$f_1(x)$	$f_2(x)$	Euclidean distance
1	0	1.0	4800	1450×10^3	-
2	0.1	0.9	4800	1305×10^3	1160804.135
3	0.2	0.8	9600	1160×10^3	1015918.914
4	0.3	0.7	14400	1015×10^3	871071.891
5	0.4	0.6	19200	870×10^3	726285.922
6	0.5	0.5	24000	725×10^3	581606.603
7	0.6	0.4	28800	580×10^3	437139.840
8	0.7	0.3	33600	435×10^3	293200.000
9	0.8	0.2	38400	290×10^3	151298.513
10	0.9	0.1	43200	145×10^3	43200.000
11	1.0	0	48000	145×10^3	-

Table 2: Location of different facilities considering various weight vectors

Solution Number	Weights		Treatment centres		Recycling centres	Disposal centres
	w_1	w_2	Chemical treatment	Incineration treatment		
1	0	1	6	-	1	8
2	0.1	0.9	6	3	1	8
3	0.2	0.8	6, 7	3	1	8
4	0.3	0.7	6, 7	3	1, 5	4, 8
5	0.4	0.6	6, 7	3	1, 5	4, 8
6	0.5	0.5	6, 7	3	1, 5	4, 8
7	0.6	0.4	6, 7	3	1, 2, 5	4, 8
8	0.7	0.3	6, 7	3	1, 2, 5	4, 8
9	0.8	0.2	6, 7	3	1, 2, 5	4, 8
10	0.9	0.1	6, 7	3	1, 2, 5	4, 8
11	1	0	6, 7	3	1, 2, 5	4, 8

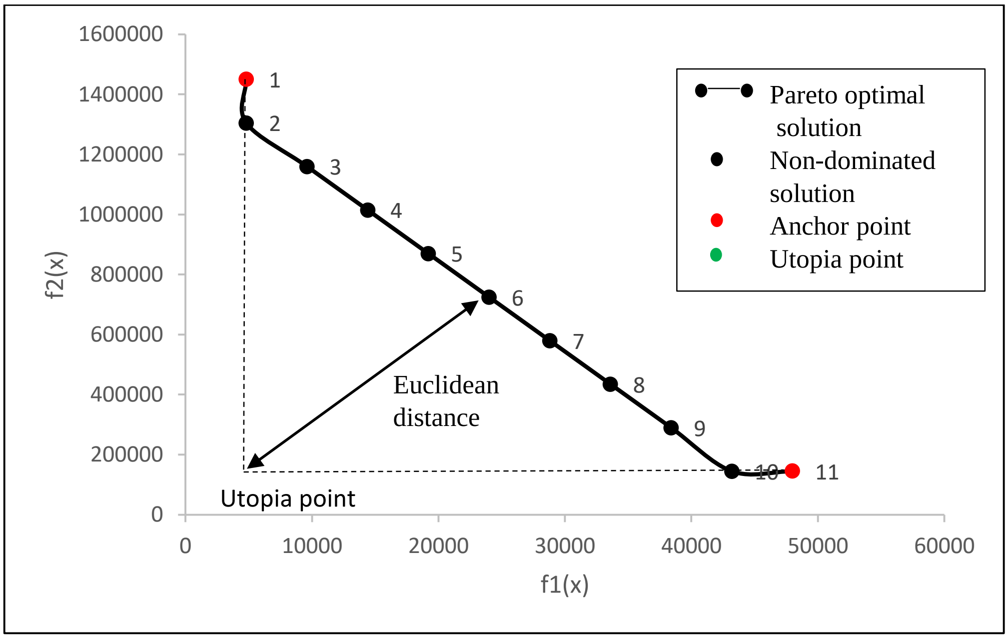

Figure 3: Pareto optimal solution of $f_1(x)$ versus $f_2(x)$

In Figure 3, the obtained Pareto optimal solutions for all objective functions are non-dominated solutions. The anchor point and utopia point are two words to consider when using the Pareto method to obtain the Pareto optimal solution. As a result, the shortest Euclidean distance can be used to estimate the ideal value of the Pareto optimal solution (see Table 1). Since the value of Pareto optimal solution for each solution number is different, the Euclidean distance or optimal value for each solutions number (1) to (10) is also vary. Therefore, it can be concluded that the longest distance among the solution is at solution number (2) while the shortest is at solution number (10).

To make it more clearly understand, the solution of solved model with $w_1 = 0.5$ and $w_2 = 0.5$ is presented in Figure 4 where the relation between chosen nodes is presented based on Table 2 reading.

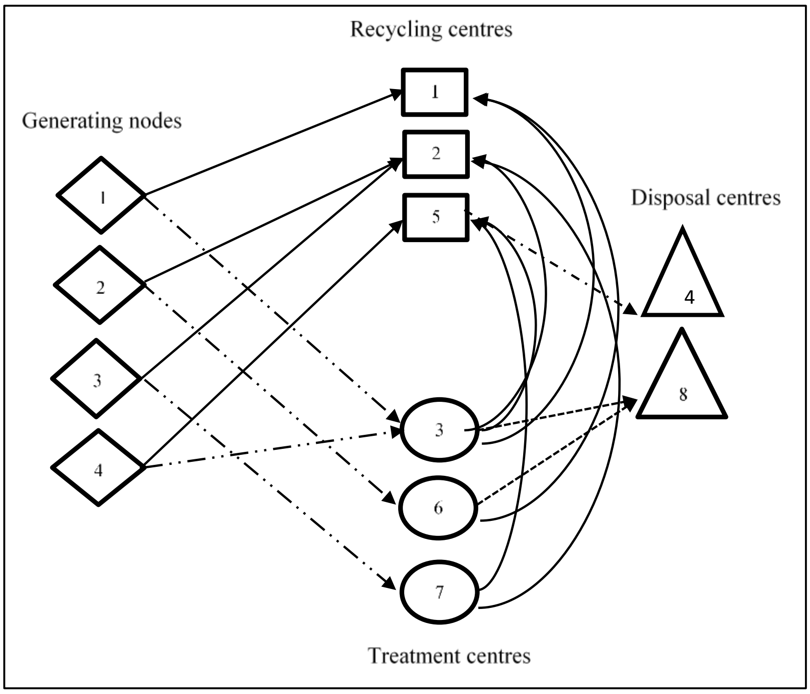

Figure 4: Solution of the model with equal weight vectors

4. Conclusion

Industrial hazardous waste materials (HAZMAT) management problem is an important problem that should be handled with special care. A mixed integer programming approach is used to solve the HAZMAT management problem in this research. To prevent oversimplifying the reality of the HAZMAT management problem, three separate waste categories, two compatible technologies, and maximum and minimum capacity needs of those centers are assessed. The model was implemented in Johor region to identify the most efficient solution using the Weighted Sum Method, and 11 individual Pareto Optimal solutions were computed, taking into consideration that decision-makers may have diverse desires in terms of the value they assign to each objective function. Due to lack of information, assumptions for the data were made by referring to [1] and [10] studies in order to propose a new strategic treatment, recycling and disposal centres for location-routing problem. In this research, there only 8 potential districts were observed by considering all candidate's sites might be generation, treatment, disposal, and notably recycling center sites at the same time since according to [1] even though they proposed a more realistic mathematical model, there is no need for such a crowded network until 530 nodes since we did not observe the CPU times for running the CPLEX software.

WSM is unable to provide a viable solution in the non-convex parts of the Pareto optimal solution. Hence, we suggest for future research to improve the method to find the efficiency of Pareto optimal by using Weighted Tcbycheff. Besides, it is recommended that this model can be developed with exact data or related data for HAZMAT management problem and take into consideration the existing location of treatment, recycling and disposal centre from the authorities. Furthermore, the number of populations can be focused in small scope area such as into 800 meter around the potential node to find the best optimal solution for the multiple objective optimization. Lastly, for future research, researcher can consider mathematical model including the amount transship from generating node to disposal centre.

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