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A Multi-Objective Location-Routing Problem for the Hazardous Waste Management System

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Management of hazardous waste is a significant issue due to the imposed risk on environment and human life. This risk can be a result of location of undesirable facilities and also routing hazardous waste. In this papera multi-objective mixed integer linear programming model for location routing industrial hazardous waste with three objectives has been extended. First objective is total cost minimization including transportation cost, initial investment cost, and cost saving from selling recycled waste; second objective is minimizing total transportation risk related to the population exposure along transportation routes of hazardous materials and waste residues; and third objective is total risk minimization for the population around treatment and disposal centers, also called site risk. This model can help decision makers to locate treatment, recycling, and disposal centers simultaneously and also to route waste between these facilities considering risk and cost criteria. A weighted sum method has been utilized to combine three objective functions into one objective function.

Keywords: Location-routing problem, multiple objective programming, industrial hazardous waste management, multi-objective model.

1. Introduction

One of the most intractable problems of industrialized area is the management of hazardous waste. Bangladesh has witnessed dramatic and widespread changes due to the forces of globalization, industrialization, and urbanization. There is wide and various ranges of industries to produce hazardous waste, for instance, chemicals, manufacturing, oil refining, pharmaceuticals, leatherwear and electroplating companies. These materials need specific transportation and treatment to reduce their effect on environment and human health. Three important objectives are included in transportation of hazardous waste associated with cost and risk. Hazardous waste also requires different technologies for treatment such as incineration, chemical, biological, and immobilization. The framework for management of industrial hazardous waste is shown in Fig. 1.1; it starts with generation nodes and then wastes are divided into three groups. First group is recyclable waste. Second group requires treatment facility, so they are routed to the treatment centers with incineration technology.

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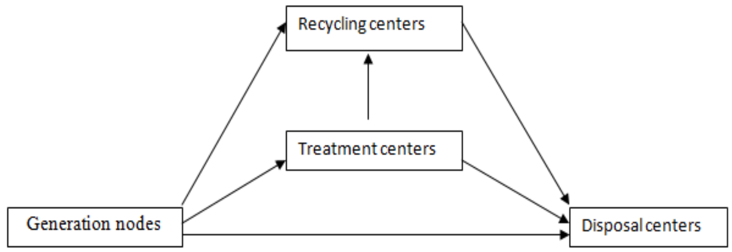
Figure 1: Framework for Hazardous Waste Management



Third group is non-recyclable and non-treatable waste. In the end, residues from treatment and recycling centers are carried to the disposal centers. At present, there have been little studies on the location of undesirable facilities and routing hazardous waste between these facilities simultaneously. In addition, using total cost, site risk and risk associated with transportation as objectives for this model can help decision makers to have a good trade-off between environmental and economic aspects. In this way, using cost parameter for each facility and also cost-saving parameter for recycled hazardous waste are suggested to have more comprehensive cost objective.

With economy growth more and more focus is being placed on environmental and health risks. For this, proper waste management should be introduced in every industrialized country. The regional network for hazardous waste management consists of a number of nodes. The nodes may be the sources generating different kinds of hazardous wastes, potential treatment facilities, potential recycling facilities, potential disposal facilities or intermediate nodes. The hazardous wastes generated at the sources must be carried to the appropriate treatment facility. Some portion of the treated waste residues then can be transferred to a disposal facility and rest to the recycling center. The activities of transportation, treatment, recycling and final disposal involve cost, and they pose some risk to the environment. Thus, the problem is to select an optimal configuration of facilities for recycling, treatment, and disposal and to select proper routing between them so that hazardous waste is managed with minimum cost and minimum risk to the environment.

The rest of the paper is organized as follows: Section 2 presents literature review. Section 3 contains research methodology. Section 4 discusses the mathematical framework, section 5 explains the data collection & analysis, section 6 presents results and this paper is concluded with section 7 which explains conclusions and the future work.

2. Literature Review

Hazardous Material (HAZMAT) transportation has received considerable attention in the past couple of decades all over the world. Several studies have addressed the location and routing problem of waste management system such as ReVelle et al. (1991) blend methods of shortest paths, a zero-one mathematical program for sitting and the weighting method of multi-objective programming to show how to derive optimal solutions for their program. Their objective was minimizing the convex combination of the transportation cost and transportation risk. Erkut and Verter

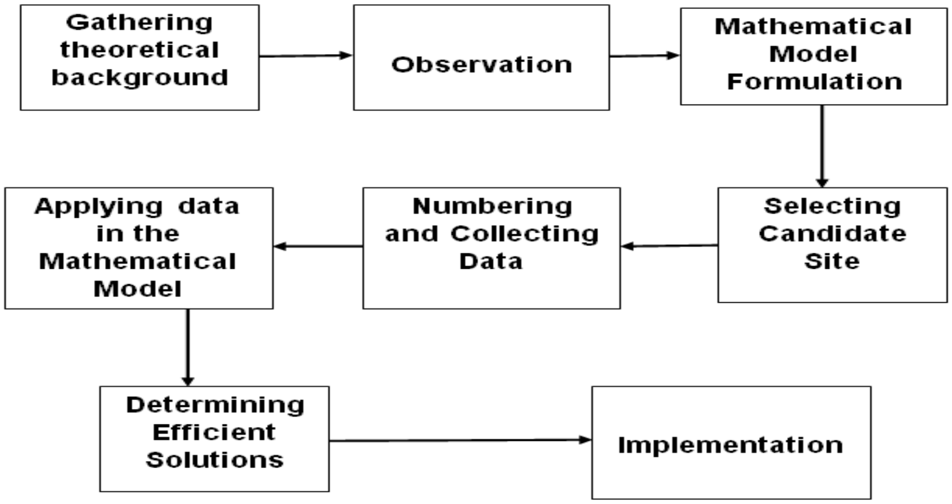
(1995) provided a framework for quantitative risk assessment in hazardous materials transport. Their basic model is to assess risks of shipping hazardous materials through large population centers that cannot be modeled as single points on a plane. In their extended model, large population centers are treated as two-dimensional objects on the plane. Nema and Gupta (2003) proposed a model which is useful for the environmental control agencies, involved in regional planning for hazardous waste management and policy evaluation in terms of some management strategies. Such as: minimizing risk for a given budget, minimizing cost for a compromise on risk levels, deciding on capacities for treatment and disposal facilities and reflecting on issues of equitable distribution of risk. They developed a multi-objective goal programming model to select treatment and disposal facilities and to allocate hazardous wastes and waste residues from generators to these facilities along transportation routes. Rakas et al. (2004) developed a model for determining locations of undesirable facilities and formulated as multi-objective problem of locating undesirable facilities faces many conflicting criteria. They considered objectives such as minimization of total costs and political opposition. The model was based on Fuzzy Mathematical Programming. Cappanera et al. (2004) utilized the Lagrangian relaxation and branch and bound approaches to obtain optimal solution with minimal total cost. Their problem was to solve the simultaneously locating obnoxious facilities and routing obnoxious materials between a set of built-up areas and the facilities is addressed. Erkut and Ingolfsson (2005) proposed a model by redefining the decision problem as one of satisfying demand at the destination which satisfy the axioms and are relatively tractable. They believe that for satisfying risk models three reasonable axioms is needed: path evaluating via monotonicity axiom, optimality principle for selecting path and attribute monotonicity axiom. Rodríguez et al. (2006) used different method for locating undesirable facility. The objective is to locate the facility as far away as possible from an identified set of population centers; the maximum criterion attempts to maximize the sum of the distances from the undesirable (obnoxious) facility to the population centers.Alumur and Kara (2007) proposed a new mixed integer programming model in which they combined the applicable aspects from different models and includes some constraints such as the compatibility constraint and additional constraints. The model has the objective of minimizing the total cost and the transportation risk. Bonvicini and Spadoni (2008) developed a model named OPTIPATH to reduce the risk associated with transportation of hazardous materials by routing that is by the choice of alternative less risky paths. Emek and Kara (2007) focus on incineration, for which the main additional requirement is to satisfy the air pollution standards imposed by the governmental restrictions and they cost-based mathematical model in which the satisfaction of air pollution standards is also incorporated. They also developed a methodology to include the Gaussian Plume equation. Kazantzi et al. (2011) proposed a model of the traditional transportation network problem with safety. The objective of the paper is to minimization of transportation cost as well as reduction of risks. Zhao (2010) proposed a goal programming based on algorithm handled by modern commercial optimization software for small and medium-scale problems is designed to minimize the two objectives that is minimization of cost and risk. Xie et al. (2012) proposed a multimodal hazmat model that simultaneously optimizes the locations of transfer yards and transportation routes and have applied in two case studies of different network sizes to demonstrate its applicability. Before proposing a model to locate facilities, finding suitable sites based on important criteria is necessary. One of the popular methods to select site in waste management is using GIS. Gorsevski et al. (2012) used multi-criteria decision method based on geographical information system (GIS) for landfill site selection. The multi-criteria decision framework considers environmental and economic factors which are standardized by fuzzy membership functions and combined by integration of analytical hierarchy process (AHP) and ordered weighted average (OWA) techniques. Mahamid and Thawaba (2010) also utilized GIS tool to find proper landfill site. For this purpose they had considered environmental factors. In this paper, GIS tool will be utilized to find an appropriate site for treatment, recycling and disposal centers based on some important criteria. Samanlioglu (2013) proposed a model to help decision makers decide on locations of treatment centers utilizing different technologies, routing different types of industrial hazardous wastes to compatible treatment centers, locations of recycling centers and routing hazardous waste and waste residues to those centers and locations of disposal centers and routing waste residues there. Their objective was minimizing total cost, which includes total transportation cost of hazardous materials and waste residues and fixed cost of establishing treatment, disposal and recycling centers, minimizing total transportation risk related to the population exposure along transportation routes of hazardous materials and waste residues and minimizing total risk. A Lexicographic Weighted Tchebycheff formulation is developed and computed for this purpose.

The problem of identifying potential risks and their consequences in HAZMAT transportation has been a great concern and largely acknowledged. As Bangladesh is getting more and more industrialize, HAZMAT transportation and treatment problem should be given adequate concern so that transportation of this material can be cost and risk effective. This work includes (1) consideration of population risk for all routes, (2) consideration of income from selling recycled waste in cost objective as cost saving parameter. In this paper routing of a piece of generated hazardous waste to disposal centers has been done directly. This work attempts to extend a multi-objective model of location-routing industrial hazardous waste problem with three objectives and based on them selection of optimum locations for facilities has been done.

3. Methodology

In this paper a multi-objective linear programming model with Weighted Sum Approach is used to give functional value to the solution. Objective functions denote cost minimization, risk of population associated with transportation and site risk.

Figure 2: Methodology



4. Mathematical Statements

4.1 Mathematical Model Formulation

4.1.1 Nomenclature

G = {1, . . . ,g} hazmat generation nodes
T = {1, . . . ,t} potential treatment nodes
D = {1, . . . ,d} potential disposal nodes
R= {1, . . . ,h} potential recycling nodes

4.1.2 Parameters

CGT_{ij}	Cost of transporting one unit of hazardous waste on link $i\in G$, $j \in T$
CTD_{ij}	Cost of transporting one unit of waste residue on link $i\in T$, $j \in D$
CRD_{ij}	Cost of transporting one unit of waste residue on link $i\in R$, $j \in D$
CGR_{ij}	Cost of transporting one unit of recyclable waste on link $i\in G$, $j \in R$
CTR_{ij}	Cost of transporting one unit of recyclable waste residue on link $i\in T$, $j \in R$
CGD_{ij}	Cost of transporting one unit from generation node to disposal $i\in G, j \in D$
Ft_i	Fixed cost of opening a treatment technology $i\in T$
Fd_i	Fixed cost of opening a disposal center at node $i\in D$
Fr_i	Fixed cost of opening a recycling center at node $i\in R$
Pgt_{ij}	Number of people within a given distance of the link $(i, j) \in A$, $i\in G$, $j \in T$
Ptd_{ij}	Number of people within a given distance of the link $(i, j) \in A$, $i\in T$, $j \in D$
PT_{ij}	Number of people around node $i\in T$ with technology
PD_i	Number of people around node $i\in D$
gen_i	Amount of hazardous waste generated at generation node
α	Proportion of recycling of hazardous waste generated at generation node

β	Proportion of recycling of hazardous waste after treating at treatment center
δ	Proportion of disposal waste generated at generation node
R_w	Proportion of mass reduction at treatment center
C_r	Proportion of recycled hazardous waste at recycling center
tc_i	Capacity of treatment center
tc_i^m	Minimum amount of hazardous waste required to establish treatment center
dc_i	Disposal capacity of disposal center $i \in D$
dc_i^m	Minimum amount of waste residue required to establish a disposal center
rc_i	Recycling capacity of node $i \in R$
rc_i^m	Minimum amount of waste required to establish a recycling center
C_i	Price of unit recycled item
hr_i	Amount of waste at recycled center
V_{ij}	Amount of transferred waste at disposal center

4.1.3 Decision variables

X_{ij}	Amount of hazardous waste transported through link $(i, j) \in A$, $i \in G$, $j \in T$
Z_{ij}	Amount of waste residue transported through link $(i, j) \in A$, $i \in T$, $j \in D$
L_{ij}	Amount of recyclable waste transported through link $(i, j) \in A$, $i \in G$, $j \in R$
K_{ij}	Amount of recyclable waste residue transported through link $(i, j) \in A$, $i \in T$, $j \in R$
S_{ij}	Amount of hazardous waste transported through link $(i, j) \in A$, $i \in G$, $j \in D$
V_{ij}	Amount of waste residue transported through link $(i, j) \in A$, $i \in R$, $j \in D$
Y_i	Amount of hazardous waste treated at node i, $j \in T$ with technology
Dis_i	Amount of waste residue disposed at node i, $j \in D$
hr_i	Amount of waste recycled at node i, $j \in R$
f_i	1 if treatment technology is established at nodei$\in$T; 0 otherwise
dz_i	1 if disposal center is established at node $i \in D$; 0 otherwise
b_i	1 if recycling center is established at node $i \in R$; 0 otherwise

4.1.4 Objective Functions

The aim of the mathematical model is to answer questions related to: the locations of treatment centers with different technologies; routing different types of hazardous wastes to compatible treatment centers; the locations of recycling centers and routing hazardous wastes and waste residues to these centers; and, the locations of disposal centers and routing waste residues to these centers. The mathematical model of the proposed hazardous waste management problem is a three-objective, mixed integer, location routing model.

Minimize $f_1(x) = \sum_{i \in G} \sum_{j \in T} CGT_{ij} X_{ij} + \sum_{i \in T} \sum_{j \in D} CTD_{ij} Z_{ij} + \sum_{i \in G} \sum_{j \in D} CGD_{ij} S_{ij} + \sum_{i \in R} \sum_{j \in D} CRD_{ij} V_{ij} + \sum_{i \in G} \sum_{j \in R} CGR_{ij} L_{ij} + \sum_{i \in T} \sum_{j \in R} CTR_{ij} K_{ij} + \sum_{i \in T} ft_i fi_i + \sum_{i \in R} fr_i b_i + \sum_{i \in D} fd_i dz_i - C_i \{hr_i - V_{i,j}\}$

Minimize $f_2(x) = \sum_{i\in G}\sum_{j\in T} Pgt_{ij}X_{ij} + \sum_{i\in T}\sum_{j\in D} Ptd_{ij}Z_{ij} + \sum_{i\in G}\sum_{j\in H} Pgr_{ij}L_{ij} + \sum_{i\in R}\sum_{j\in D} Prd_{ij}V_{ij} + \sum_{i\in T}\sum_{j\in R} Ptr_{ij}K_{ij}$

Minimize $f_3(x) = \sum_{i\in T} PT_i y_i + \sum_{i\in D} PD_i dis_i$

4.1.5 Constraints

$gen_i = L_{ij} + X_{ij} + S_{ij}$	$\forall i \in G$	(1)
$L_{ij} = \alpha_w * gen_i$	$\forall i \in G$	(2)
$hr_i = L_{ij} + K_{ij}$	$\forall j \in H$	(3)
$K_{ij} = \alpha * Y_i$	$\forall i \in T$	(4)
$X_{ij} = Y_i = \beta * gen_i$	$\forall j \in T$	(5)
$S_{ij} = \delta * gen_i$	$\forall j \in D$	(6)
$Z_{ij} = R_w * Y_i - K_{ij}$	$\forall i \in T$	(7)
$V_{ij} = (1-C_r) * hr_i$	$\forall j \in H$	(8)
$Dis_i = S_{ij} + Z_{ij} + V_{ij}$	$\forall j \in D$	(9)
$hr_i \le rc_i b_i$	$\forall j \in H$	(11)
$Y_i \ge tc_i^m f_i$	$\forall i \in T$	(12)
$Y_i \le tc_i f_i$	$\forall i \in T$	(13)
$Dis_i \ge dc_i^m dz_i$	$\forall i \in D$	(14)
$Dis_i \le dc_i dz_i$	$\forall i \in D$	(15)
$X_{ij} \ge 0$	$\forall i \in H, \forall j \in T$	(16)
$Y_i \ge 0$	$\forall i \in T$	(17)
$Z_{ij} \ge 0$	$\forall i \in T, \forall j \in D$	(18)
$L_{ij} \ge 0$	$\forall i \in G, \forall j \in H$	(19)
$V_{ij} \ge 0$	$\forall i \in H, \forall j \in D$	(20)
$Dis_i \ge 0$	$\forall i \in D$	(21)
$hr_i \ge 0$	$\forall i \in H$	(22)
$f_i \in \{0,1\}$	$\forall i \in T$	(23)
$dz_i \in \{0,1\}$	$\forall i \in D$	(24)
$b_i \in \{0,1\}$	$\forall i \in H$	(25)

4.1.6 Solution Approach

As the proposed model is multi-objective, a multi-objective solution technique should be adopted. The problem will be solved by weighted sum method. Even though many multi-objective solution techniques exist, a linear composite objective function is employed for ease of application. A convex combination of cost and risk is used to define the impedance for each link. Since cost and risk have different units, they are needed to be scalarized. According to Alumur and Kara (2007) one may use different scalarization approaches, such as dividing each term by the maximum, minimum or total sum of that term. In this paper each term is divided by their maximums. In the multi-objective model, the impedance of each link is calculated by the following formulation:

F(x) = (λ_1*Cost of link/Max link Cost) + (λ_2* Transportation Risk of link/Max transportation link Risk) + (λ_3* Side risk of link/Max side link Risk)

Where $\lambda_1+\lambda_2+\lambda_3=1$
Here,
F(x) = the main function
$\lambda_1=\lambda_2=\lambda_3=$ weight

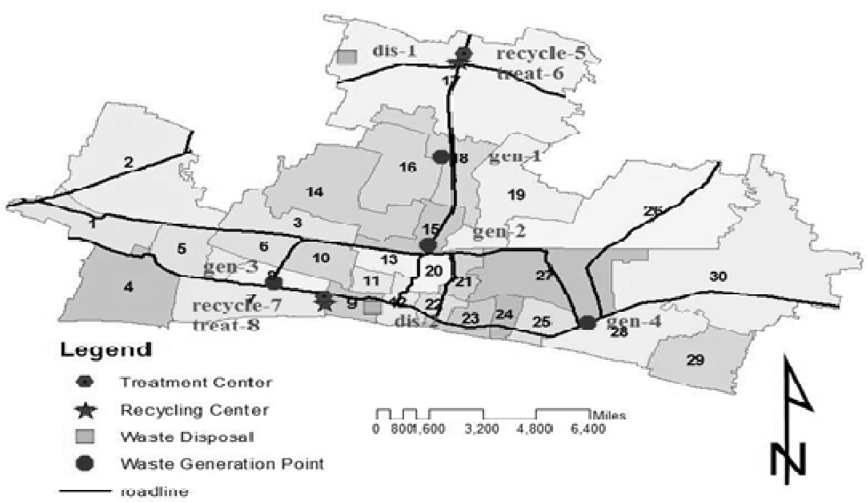
5. Data Collection and Analysis

In this section, proposed models have been estimated in real life project. For this Rajshahi city corporation has been selected as study area. Relevant data has been collected from BBS. Information about population number per length, population around disposal, treatment and recycling center has been taken from 'City Portal of Rajshahi, Bangladesh' and distance between the nodes has been calculated from 'Distance Calculator Bangladesh'. The distance has been calculated in kilometer.

Risk of transportation associated with people= Number of people per unit length of the link*Length of the link*Amount of waste being transported

Site risk associated with people = Area of the ward*Number of people*Amount of waste being treated or disposed

Figure 3: Selected Generation, Treatment, Recycling and Disposal Centers

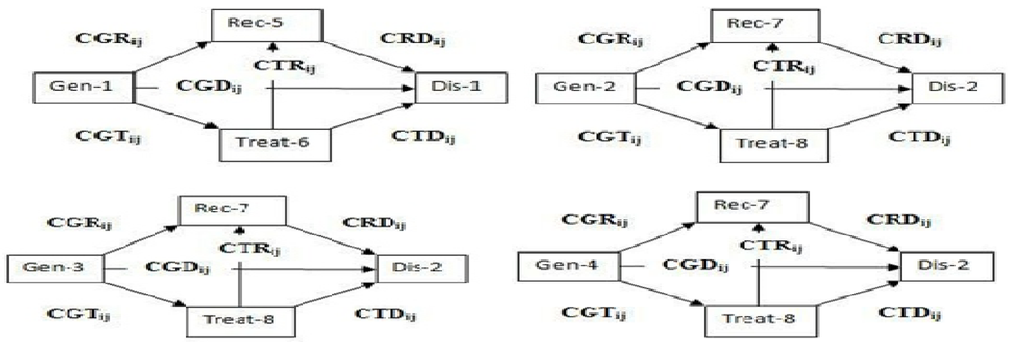


Ward number 18, 15, 8 and 28 has been taken as generation node respectively. Ward number 18 denotes generation node-1, 15 generation node-2, 8 generation node-3 and 28 generation node-4. There is already a disposal center located at Nawdapara. Applying GIS and considering economic and environmental factor required for side selection. It is found that ward number 17 and 9 suitable for establishing treatment and recycling center and ward number 9 for establishing new disposal center.

5.1 Optimum Path Selection

Eight Possible paths can be obtained for each generation node. Calculation is done to obtain the optimum path which is calculated in 'EXCEL'. From the calculations following optimum paths are found for gen-1,2,3,4 respectively :

Figure 4: Optimum Path for Gen-1, Gen-2, Gen-3, Gen-4.



6. Results

6.1 Value of the Objective Functions

After selection of alternative paths, required data have been taken and substituted in equation of the objective functions. To solve the cost objective f1, 'LINGO'16' is used. Results of three objective functions are as follows:

Minimize $f_1(x)$ = 160866.9ton km
Minimize $f_2(x)$ =8017871.66 ton people
Minimize$f_3(x)$ = 1185516.36 ton people

6.1.1 Weighted Sum Approach

Putting this three objective function value in the Weighted Sum equation, F(x) will be found. Site risk is associated with the people living around the treatment and recycling center. As the people around the treatment and recycling center will be affected continuously, site risk should be given proper weight. Risk of the people associated with transportation is only considered when the waste is transported. So site risk is given greater weight than transportation risk. As this thesis work is on hazardous waste management so risk should be given high weight. But Cost objective should be given such weight so that the cost is also optimized. Considering all this factors weight of cost, transportation risk and site risk objective is 0.4, 0.2, and 0.4 respectively.

Where,
$\lambda_1+\lambda_2+\lambda_3=1$
$\lambda_1=0.4$, $\lambda_2=0.2$ and $\lambda_3=0.4$
F(x) = $\lambda_1 f_1(x)/\text{Max}f_1(x) + \lambda_2 f_2(x)/\text{Max}f_2(x) + \lambda_3 f_3(x)/\text{Max}f_3(x)$

=0.4*(160902.9/1712296.3) + 0.2*(8017871.66/99430621) + 0.4*(1185516.36/55279918.3)
=0.062

7. Conclusion

The hazmat management problem is a multi-criteria decision making problem by nature since there are several potential conflicting criteria to consider while making decisions related to the location and routing of hazmat. Previous works did not consider site risk along with transportation risk. But in this paper, three potentially conflicting significant criteria which need to be minimized simultaneously to attain compromising, efficient solutions are presented. These are: total cost, which includes the transportation cost of hazardous materials and waste residues and the fixed cost of establishing treatment, disposal and recycling centers; the total transportation risk of hazmat related to population exposure; and site risk. Amalgamation of these three criteria has made the proposed model more efficient for practical application. To attain efficient solutions, as the multi-objective optimization method, the weighted sum method has implemented. Optimum solution for the problem were computed, taking into consideration the fact that decision-makers might have different preferences with respect to the importance they attach to each objective function, by generating 3 dispersed weight vectors. The model was implemented in the Rajshahi City Corporation. While some assumptions were made due to lack of some information, in the implementation, many real-life aspects of the industrial hazmat management problem were considered and realistically implemented in the model. Based on the BBS of Rajshahi city, 4 wards were included in the implementation. These 4 wards were assumed to generate industrial hazmat and they were also assumed to be candidate sites for treatment, disposal and recycling centers. According to the collected data this problem was solved by weighted sum approach and from the result optimum location and routing for treatment, recycling and disposal center has been chosen. For 4 generation nodes, 2 treatment centers, 2 recycling centers and 2 disposal centers have been suggested.

8. Recommendations for Further Research

In this work Weighted Sum Approach has been used to solve the problem. Other methods like Augmented Weighted Tchebycheff Approach, Augmented ε-constraint Approach, Goal Programming model can be used to solve the problem. Rajshahi City Corporation was considered to analysis this problem. But a large area can be considered while selecting generation node and providing treatment center, recycling center and disposal center. Different types of waste and treatment center with different technology can be introduced. It will be beneficial if the location and routing problem can be applied in highly industrialize area. Care should be taken while selecting this node. Because providing a safe environment and risk free routing is also one of the objectives of this work.

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