A multi-objective mathematical model for the industrial hazardous waste collection-routing problem with an environmental consideration

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Abstract: Industrial hazardous materials which are created during the production and manufacturing processes are dangerous and will face us to different immediate or long-term human and environmental risks. Increasing of industrial developments has led to a significant importance of hazardous waste management. Industrial hazardous waste management includes the collection, transportation, treatment, recycling and disposal of industrial materials. In this paper a new multi-objective collection-routing mathematical model is developed for the industrial hazardous materials management problem considering of minimizing human and environmental risks as well as cost. Numerical study confirms that the risk of our model is less than classical risks.

Keywords: Collection-routing problem, Industrial hazardous waste, Multi objective model, Environmental risk

1. Introduction

This paper proposes a new multi-objective collection-routing mathematical model to help decision makers to optimally locate treatment, recycle and disposal centers (TDRcs) utilizing their different related technologies, as well as optimal routing decisions. In this study total cost is minimized considering of human and environmental risks. The remaining parts of this paper are organized as follows: In section 2 a review of related existing models are presented. In section 3 the mathematical model for the problem is investigated. In section 4 a numerical example is illustrated and finally section 5 includes conclusions and suggestions for future researches.

2. Literature review

Hazardous waste management problem have been extensively considered in the recent literature. Nema & Gupta [1] suggested a multi-objective integer programming approach to determine the optimal configuration of facilities with minimum cost and environmental risk. Alumur and Kara [2] applied a model to identify technologies and locations of treatment and disposal centers, routing of different types of waste to treatment centers with compatible technologies. Zhao and Zhao [3] consider different waste types, treatment technologies, waste-technology compatibility and the capacity of these centers to determine the locations of treatment and disposal centers and the routing of different types of hazardous waste. Other related works can be refereed to [2] , [3] , [4] , [5]. Most of the papers take into consideration costs more than risks and few articles account environmental risks. We attempt to consider more real-life aspects of the hazardous waste management problem than existing models in hazardous material(hazmat) management literature.

3. The mathematical model

This research has been organized based on the research of Samanlioglu [6] . In contrast to her model we consider different waste types and compatible technologies for each recycling and disposal center as well as routing different types of waste to and from these centers. The proposed mathematical model in this paper considers total risk related to population living near the recycling center, total penalty-cost that we pay for satisfy people living near the new TDRcs and total penalty-cost paid to the government and Environmental Protection Agency for environment pollution in addition to previous aspects. The mathematical model in this paper also include another new objective of maximizing distance between generation centers from TDRcs to reduce human and environment risks.

The new parameters, decision variables, objectives and constraints added to the model are as follows (others are as the same as [6]):

Objectives:

$$\begin{aligned} f_1(x) = & \sum_{i\in G}\sum_{j\in T}\sum_{w\in W} c_{i,j}x_{w,i,j} + \sum_{i\in T}\sum_{j\in D}\sum_{w\in W} cz_{i,j}z_{w,i,j} + \sum_{i\in H}\sum_{j\in D}\sum_{w\in W} cv_{i,j}v_{w,i,j} + \sum_{i\in G}\sum_{j\in H}\sum_{w\in W} cr_{i,j}I_{w,i,j} \\ & + \sum_{i\in T}\sum_{j\in H}\sum_{w\in W} crr_{i,j}k_{w,i,j} + \sum_{i\in T}\sum_{q\in Q} fc_{q,i}f_{q,i} + \sum_{i\in D}\sum_{e\in E} fd_{e,i}dz_{e,i} + \sum_{i\in H}\sum_{u\in U} fh_{u,i}b_{u,i} + \\ & \sum_{i\in T}\sum_{q\in Q} pt_{q,i}popA_{q,i}Cpt_{q,i} + \sum_{i\in D}\sum_{e\in E} pd_{e,i}popB_{e,i}Cpd_{e,i} + \\ & \sum_{i\in H}\sum_{u\in U} ph_{u,i}popR_{u,i}Cp_{u,i} + \sum_{q\in Q}\sum_{i\in T} CPLA_{q,i}f_{q,i} + \sum_{e\in E}\sum_{i\in D} CPLB_{e,i}dz_{e,i} + \sum_{u\in U}\sum_{i\in H} CPLC_{u,i}b_{u,i} \end{aligned} \quad (1).$$

$$f_2(x) = \sum_{w\in W}\sum_{q\in Q}\sum_{i\in T} POPA_{q,i}y_{w,q,i} + \sum_{w\in W}\sum_{e\in E}\sum_{i\in D} POPB_{e,i}dis_{w,e,i} + \sum_{w\in W}\sum_{u\in U}\sum_{i\in H} POPC_{u,i}hr_{w,u,i} \quad (2).$$

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Parameters:

$P_t \; P_d \; P_r$	proportion of environment pollutions with opening TDRcs
$POPB_{e,i}$	number of people around node $i \in D$ with technology $e \in E$
$POPC_{u,i}$	number of people around node $i \in H$ with technology $u \in U$
$POPgh_{i,j}$	Number of people within a given distance of the link $i \in G \;\; j \in H$
$POPth_{i,j}$	Number of people within a given distance of the link $i \in T \;\; j \in H$
$POPhd_{i,j}$	Number of people within a given distance of the link $i \in H \;\; j \in D$

Decision variables:

$CPL_t \; CPL_d \; CPL_r$	penalty costs pay for establishing TDRcs
$D_{e,i}$	1 if disposal technology $e \in E$ is established at node $i \in D$;0 otherwise
$B_{u,i}$	1 if recycle technology $u \in U$ is established at node $i \in H$;0 otherwise

$$f_3(x) = \sum_{i\in G}\sum_{j\in T}\sum_{w\in W} POPgt_{i,j} x_{w,i,j} + \sum_{i\in T}\sum_{j\in D}\sum_{w\in W} POPtd_{i,j} z_{w,i,j} + \sum_{i\in H}\sum_{j\in D}\sum_{w\in W} POPhd_{i,j} v_{w,i,j}$$
$$+\sum_{i\in G}\sum_{j\in H}\sum_{w\in W} POPgh_{i,j} l_{w,i,j} + \sum_{i\in T}\sum_{j\in H}\sum_{w\in W} POPth_{i,j} k_{w,i,j} \qquad (3).$$

$$f_4(x) = z \le \beta_t \sum_{q\in Q}\sum_{j\in T} D_{i,j} f_{q,i} + \beta_d \sum_{e\in E}\sum_{j\in D} D_{i,j} dz_{e,i} + \beta_h \sum_{u\in U}\sum_{j\in H} D_{i,j} b_{u,i} \qquad (4).$$

Constraints:

$$CPL_{q,t} = \sum_{w\in W} f_{w,q,t} Pl_t \quad \forall q\in Q, \forall t\in T$$

$$CPL_{e,d} = \sum_{e\in E} B_{w,e,d} Pl_d \quad \forall e\in E, \forall d\in D$$

$$CPL_{u,h} = \sum_{w\in W} f_{w,u,h} Pl_r \quad \forall u\in U, \forall h\in H$$

4. NUMERICAL EXAMPLE

A small numerical example with 4 nodes is presented to demonstrate the usefulness of the proposed model. Fig.1 exhibits the proposed network of the numerical example.

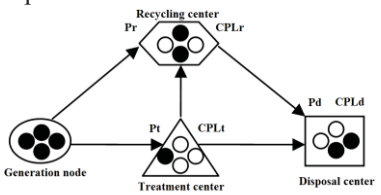

Figure 1: proposed hazmat management network of the numerical example.

Table 1 displays utopia and nadir points of each objective function individually minimized. The problem is solved by GAMS software 5 times with a 5 different dispersed weight vectors where $\lambda \ge 0$ are the weights $(\sum \lambda_i = 1)$ in a lexicographic weighted Tchebicheff formulation to determine representative efficient solution of the problem from the pareto frontier. Based on the preferences of decision makers one would select the most preferred solution to implement.

TABLE 1
SOLUTIONS OBTAINED WHEN EACH OBJECTIVE FUNCTION IS INDIVIDUALLY MINIMIZED.

	$Minf_{1(x)}$		$Minf_{2(x)}$	$Minf_{3(x)}$	$Minf_{4(x)}$
	1	2	3	4	5
$\lambda_1 f_{1(x)}$	0.2480.7	0.7	80880.0.3	1514126.1	430.6
$\lambda_2 f_{2(x)}$	0.2754.6	0.1	63867.0.1	4202029.7	475.05
$\lambda_3 f_{3(x)}$	0.2358.44	0.1	92475.0.6	2403300.1	109.95
$\lambda_4 f_{4(x)}$	0.2561.5	0.1	98366.0.1	6009490.1	112.3

TABLE 2
5 DISPERSED WEIGHT VECTORS.

TABLE 3
5 REPRESENTATIVE EFFICIENT SOLUTIONS FROM THE PARETO FRONTIER

Solution number	Treatment centers	Disposal centers	Recycling centers
1	3,4	1,4	3,4
2	1	1	2
3	3	2	1,4
4	3,4	3,4	3,4
5	3,4	3,4	1,4

5. CONCLUSIONS AND FUTURE RESEARCH

In this study a new multi-objective collection-routing mathematical model is proposed for designing of the industrial hazmat management problem considering of human and environmental risks as well as cost. In contrast to previous models we consider more real-life aspects of hazardous waste management problem than existing models in hazmat. Considering of the problem with special treatment vehicles in hazmat problem can be as a future study.

6. REFERENCES

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