ROUTING AND SCHEDULING OF HAZARDOUS MATERIAL: A CASE STUDY IN OSAKA, JAPAN

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1. Introduction

A huge quantity of Hazardous Materials (HAZMAT) is produced yearly as a consequence of industrial development of a country. Most of these are transported inland using trucks. More importantly, transportation of these materials imposes many risks to society and this is the reason that transportation of HAZMAT has been a key issue to both public and research community world wide since past few decades. Our objective here is to contribute to safety in transportation of HAZMAT through proper routing and scheduling of fleet of vehicles carrying these materials.

Logistic decision making is an important step for proper business planning and it can provide significant base to overcome such issues especially in urban areas. Large numbers of studies including those relating to routing and scheduling of HAZMAT has been carried out in the past. An extensive bibliography of these studies can be referred in Erkut et al.[1)]. An important fact to be considered while analyzing routing and scheduling option of HAZMAT transportation problem is that HAZMAT logistics unlike other logistic problems involve multiple parties with often conflicting priorities for decision making process. With regard to this fact, List et al.[2)] emphasized the need of movement towards multi-objective models in HAZMAT routing.

Numbers of multi-objective routing and scheduling models for HAZMAT transportation are available in literature and almost all of them either focused on path choice or routing issues of transportation. Path choice and routing are the two major processes in any vehicle routing problem with time window (VRPTW). In path choice process, shortest paths are determined for given origin destination pairs. The optimal order of customers to be visited by a fleet of vehicles is then determined utilizing these paths while satisfying capacity and time window constraints in routing process. VRPTW in general is formulated as a single objective function and result a single path for path choice. Such formulation allows VRPTW to be solved in two separate steps of path choice and routing. Literature for routing trucks carrying HAZMAT is very limited, and all those which exist carry out routing utilizing a single predetermined path (Tarantilis and Kiranoudis[3)], Zografos and Androutsopoulos[4)]). However, both path choice and routing in HAZMAT VRPTW are multi-objective. The path choice considering multiple numbers of objectives results into several non-dominated paths for each origin destination pairs. Using a single path for path choice process would cancel possibility of all other non-dominated paths to participate in routing process. Such typical characteristic of HAZMAT vehicle routing problems with time windows demands for requirement of carrying out both these processes as a single step process.

We present a multi-objective HAZMAT VRPTW model and an Ant Colony System (ACS) based metaheuristic algorithm that incorporates path choice and routing processes as a single step process. Application of the model and the algorithm to a small test network has been presented in our previous work Pradhananga et. al.[5)]. In this paper, we present an extension to it by showing its application to a practical road network in Osaka prefecture, Japan.

2. HAZMAT Vehicle Routing Problem with Time Windows (HVRPTW)

HAZMAT Vehicle Routing Problem with Time Windows (HVRPTW) is a typical case of VRPTW. VRPTW are topics of a great deal of ongoing research in the operations research community. Details on the topic including its variants, formulations and solution techniques can be referred from Desrosiers et al.[6)] and Taniguchi et al.[7)]. To facilitate prospective readers, attempts have been made to use standard notations used in Taniguchi et al.[7)] during

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formulation of HVRPTW in this study.

HVRPTW is defined in a network of nodes and arcs (V, A) similar to VRPTW. The vertex set $V=\{v_1, v_2, v_3, ..., v_{\hat{V}}\}$ includes the depot vertex, a set of customer vertices $N=\{n_1, n_2, n_3, ..., n_{\hat{N}}\}$ and/or some non customer vertices. The arc set $A=\{a_1, a_2, a_3, ..., a_{\hat{A}}\}$ includes all possible connections between vertices in V. To proceed path choice and routing processes simultaneously, a set $P=\{p_1, p_2, p_3, ..., p_{\hat{P}}\}$ that includes all non-dominated paths between all customer-customer and customer-depot node pairs based on travel time and risk values is defined in specific to HVRPTW in our study. Thus, HVRPTW is mathematically formulated as

$$Min \quad Z(X,Y) = \left[Z_1(X,Y) \quad Z_2(X,Y) \quad Z_3(X,Y)\right]^T \tag{1}$$

Subjected to

$$\sum_{n(i)\in x_l} D(n(i)) = W_l(x_l) \leq W_{c,l} \tag{2}$$

$$\sum_{l=1}^{m} \hat{N}_l = \hat{N} \tag{3}$$

$$t_{l,n(i)} \leq f_{n(i)} \tag{4}$$

Where,

$$Z_1(X,Y) = \sum_{l=1}^{m} \delta(x_l, y_l) \tag{5}$$

$$Z_2(X,Y) = \sum_{l=1}^{m} Z_{tl}(x_l, y_l)$$

$$= \sum_{l=1}^{m}\sum_{i=0}^{\hat{N}_l} (\overline{T}^{p(i)}_{n(i),n(i+1)} + t_{c,n(i+1)} + t_{w,n(i+1)}) \tag{6}$$

$$Z_3(X,Y) = \sum_{l=1}^{m} Z_{rl}(x_l, y_l)$$

$$= \sum_{l=1}^{m}\sum_{i=0}^{\hat{N}_l} R^{p(i)}_{n(i),n(i+1)}) \tag{7}$$

Notations:

$Z(X,Y)$	: three dimensional objective vector
$Z_1(X,Y)$	: total numbers of vehicle in use
$Z_2(X,Y)$	: total scheduling time of all the vehicles in operation
$Z_3(X,Y)$	: total risk exposure associated with transportation process
X	: order of visiting customers for all vehicles $X=\{x_l \mid l=1, m\}$
x_l	: order of visiting customers for vehicle l $x_l=\{n(i) \mid i=0, \hat{N}_l\}$
$n(i)$	: i^{th} customer visited by a vehicle with $n(0)$ as depot node
$\hat{N}_l$	: total number of customers visited by vehicle l with $\hat{N}_l$+1 being 0
m	: maximum number of vehicles available
Y	: order of visiting paths for all vehicles $Y=\{y_l \mid l=1, m\}$
y_l	: order of using paths for vehicle l $y_l=\{p(i) \mid i=0, \hat{N}_l\}$
$p(i)$	: i^{th} path used by a vehicle at customer $n(i)$ while visiting next customer $n(i+1)$
$D_{n(i)}$	: demand at customer $n(i)$
$W_l(x_l)$	: load of vehicle l

$W_{c,l}$: capacity of vehicle l

$\delta(x_l, y_l)$:=1; if vehicle l is used

=0; otherwise

$Z_{tl}(x_l, y_l)$: total scheduling time incurred by vehicle l

$\overline{T}^{p(i)}_{n(i)n(i+1)}$: average travel time of a vehicle at customer $n(i)$ while visiting next customer $n(i+1)$ using path $p(i)$

$t_{c,n(i)}$: service time at customer $n(i)$

$t_{w,n(i)}$: waiting time at customer $n(i)$

$=(e_{n(i)} - t_{l,n(i)})$; if $t_{l,n(i)} < e_{n(i)}$

= 0; otherwise

$e_{n(i)}$: start time window at customer $n(i)$

$f_{n(i)}$: end time window at customer $n(i)$

$t_{l,n(i)}$: service start time of vehicle l at customer $n(i)$

$Z_{rl}(x_l, y_l)$: risk associated with vehicle l during transportation process

$R^{p(i)}_{n(i),n(i+1)}$: risk associated with a vehicle at customer $n(i)$ during use of path $p(i)$ for visiting customer $n(i+1)$

$$= \sum_{v(j)v(j+1)\in p(i)} AR_{v(j)v(j+1)} . EP_{v(j)v(j+1)}$$

$AR_{v(j)v(j+1)}$: Probability of HAZMAT accident for arc connecting vertices $v(j)$ and $v(j+1)$

$EP_{v(j)v(j+1)}$: Exposure population for arc connecting vertices $v(j)$ and $v(j+1)$

3. Ant Colony System for HVRPTW

An ACS based metaheuristic solution algorithm has been proposed for solving HVRPTW. ACS has been already applied for routing multi-objective VRPTW by Gambardella et al.[8] and Baran and Schaerer[9] for normal case. The proposed ACS for Hazmat VRPTW is based on ACS presented by later for multi-objective case and use insertion neighborhood as a local search process. Unlike in previous ACS, ants in proposed ACS are responsible for finding optimal order of paths in addition to finding optimal order of customers. Carrying out path choice and routing simultaneously tends to increase size of the problem tremendously due to need of consideration of whole network for each feasible node during node addition phase in construction of solution for each ant. This problem has been overcome to certain extent by using only non-dominated paths from each node to all its feasible nodes that are obtained using Labeling Algorithm. Details on the algorithm can be referred from Pradhananga et al.[5].

4. Area of Study

The model and the proposed solution technique is expected to be applied for routing of Liquefied Petroleum Gas (LPG) in a road network consisting of 225 nodes and 781 links in Osaka prefecture in Japan. Of the 225 nodes in the network 24 nodes are customer nodes. Circles in Figure 1 show the locations of the customer nodes in the network. The depot node has been represented by rectangle in the network. Average travel time values for week day period obtained based on Vehicle Information and Communication System (VICS) data for these links over a period of one month will be used for determining total scheduling time. While the network is mainly spread over 24 wards of Osaka city, few of the links are located in 5 other cities in Osaka prefecture. The population density and the normal accident numbers in these areas will be used for risk calculation purpose. An impact area of 275m based on tests performed for calculation of threat zone for LPG material in Osaka area using USEPA[10] will be used.

The final routing solutions are expected to obtain sets of pareto-optimal solutions based on various objectives considered in the model.

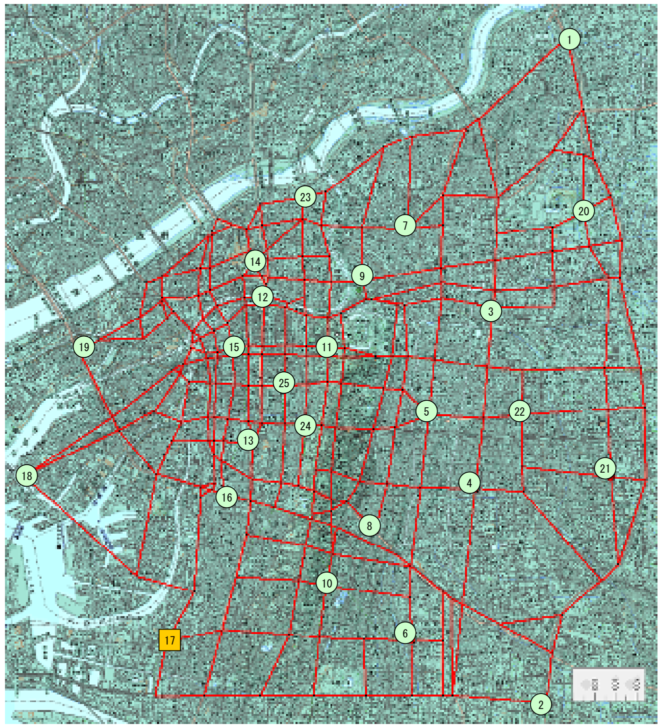

Figure 1 Customers location in Osaka network

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