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# Bi-objective decision support system for routing and scheduling of hazardous materials

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ABSTRACT

This paper presents a Pareto-based bi-objective optimization of hazardous materials vehicle routing and scheduling problem with time windows and shows its application to a realistic hazardous material logistics instance. A meta-heuristic solution algorithm is also proposed, which returns a set of routing solutions that approximate the frontier of the Pareto optimal solutions based on total scheduled travel time and total risk of whole transportation process. It works in a single-step fashion simultaneously constructing the vehicle route and selecting the optimal paths connecting the routed locations from a set of non-dominated paths obtained in terms of travel time and risk value.


## 1. Introduction

The nature of Hazardous Material (HazMat) is such that its production, storage, and transportation activity inherit many risks to both society and environment. Of the various modes of the HazMat transportation, large proportion of the HazMat shipment is carried out in-land by trucks. About 94% of total HazMat shipments in US are reported to be carried out by means of truck [17]. Despite of the efforts to mitigate the adverse effects of HazMat, accidents do happen [18] and the consequences in most cases are severe. Amount of HazMat transported by all transport modes is increasing year after year [24]. Without doubt, the HazMat incidents in highways are the most tremendous in number than in any other modes. Of the 15,007 HazMat incidents that occurred in US in 2011, 12,795 occurred in-land in highways causing an estimated damage of 64 million USD [43]. In regard to this fact, land based transportation of the HazMat is the main concern in this paper.

At beginning, the line haul transport of HazMats is basically a shortest path problem involving large shipments between two defined points, for example from a refinery to the central depot. Once it reaches to the depot, it must be distributed to the end users. The problem therefore is to determine efficient routes for a fleet of vehicles transporting the HazMats from depot to a set of customers. A similar problem to the latter case is commonly known as Vehicle Routing and scheduling Problem with Time Windows (VRPTW) [12,42]. The VRPTW is a complex problem than the shortest path problem. In HazMat transportation context, the VRPTW is extend to the Hazardous materials Vehicle Routing and scheduling Problem with Time Windows (HVRPTW) with additional objective of minimizing risk in addition to the conventional objective of minimizing the cost. Such multi-objective nature further increases the complexity of the HVRPTW. Therefore, despite of the practical significance, the HVRPTW-related research is very scant. Present study is an effort to fill in the gap of the literature and aims for development of an efficient optimization model for the HVRPTW addressing the practical aspects of HazMat transportation:

a Presenting an optimization model that explicitly considers the multi-objective characteristics of the HazMat distribution problem.
b Demonstrating the model's application to a realistic Intelligent Transportation System (ITS) data-based HazMat logistics instance. Travel time data used for the HazMat logistics instance is the average of the historical data accumulated through Vehicle Information and Communication System (VICS), an ITS application in Japan.

The HVRPTW involves a wide variety of stakeholders with often conflicting objectives. While the primary objective for the carrier is to minimize the transportation cost by optimizing the vehicle

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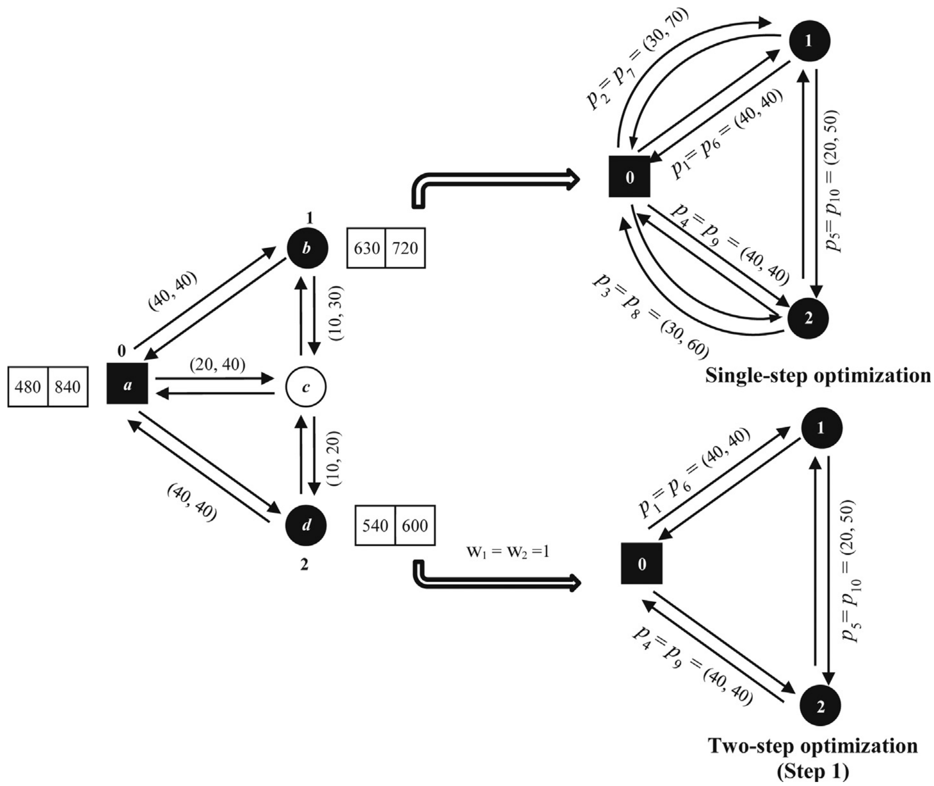


**Fig. 1.** The hypothetical urban road network and its transformed HVRPTW instance.

number (fixed cost of vehicle) and the total scheduled travel time (operation cost of vehicle), that of the local government and the people in the area is to reduce the risk. It is quite difficult to exactly determine how important the particular objective to the particular group is. Therefore, multi-objective analysis is an important tool in HazMat planning. It serves stakeholders of various needs for decision making in the HazMat transportation [17,25] and more importantly, it provides a basis for evaluation of various city planning policies. Although there exist some literature on multi-objective HVRPTW [27,46,47], the problem was solved using weight-based scalar approach. Scalar approaches are easier but major drawback with these approaches is that the optimal routing is highly influenced by the assigned weight values. Therefore, it requires precise determination of weight values which needs extreme analysis of the field data. More importantly, the approach results a single optimal solution and to examine trade-off among the objectives, the problem must be solved several times, which on the whole takes longer computation time. This paper takes an initiative to solve HVRPTW applying concept of Pareto optimization. Pareto optimization works simultaneously to determine a set of non-dominated solutions applying conditions of Pareto dominance, and is the best approach to deal with multi-objective problems.

Typically, path choice and routing are two separate steps in any classical VRPTW. During the path choice, shortest paths from each customer to all other customers including the depot are determined. The pre-determined paths are then used in routing step to determine the optimal order of customers to be visited by the fleet of vehicles satisfying the demand and time windows constraints. Risk and time (cost) are the two indispensable objective functions of the HVRPTW that governs both path choice and routing. Scalar approach such as weighted sum approach combines the multiple objectives of path choice into a single objective and result a single path between the customers. Therefore, it allows the two steps to be processed separately, similar to the case in the classical VRPTW. Pareto optimization, in HVRPTW results in a set of non-dominated paths for path choice between each customer pair. Therefore, the final non-dominated set of routing solutions must be based on all these sets of shortest paths. Consequently, it becomes necessary to process the two steps together as a single-step process.

Fig. 1 along with Table 1 illustrates the necessity of single-step procedure in Pareto-based optimization of HVRPTW. Route optimization is shown comparing the classical two-step approach with the proposed single-step approach on a small hypothetical HVRPTW instance derived from an urban road network with 4 nodes and 10 links. Nodes *b* and *d* are customers 1 and 2 in the network and have demand values of 200 units each. Node *a* is a depot (customer 0) and node 3 is a non-customer node. Capacity of vehicle is 1000 units. Time windows at the depot and the customer nodes are given in the boxes. The first and the second values in the parenthesis represent the travel time and the risk value associated with the links, respectively. These values are same for the links in both directions connecting same pair of nodes. The travel time and the time windows are in the same units. Unloading time of 10 in the

**Table 1**
Routing results in single-step and two-step optimization.

| Optimal routing | Customer order | Arc order | Total scheduled travel time | Total risk |
|---|---|---|---|---|
| **Single-step optimization** | | | | |
| 1 | $0 \to 2 \to 1 \to 0$ | $p_4 \to p_{10} \to p_6$ | 120 | 130 |
| 2 | $0 \to 2 \to 1 \to 0$ | $p_3 \to p_{10} \to p_6$ | 110 | 150 |
| 3 | $0 \to 2 \to 1 \to 0$ | $p_3 \to p_{10} \to p_7$ | 100 | 180 |
| **Two-step optimization (Step 2)** | | | | |
| 1 | $0 \to 2 \to 1 \to 0$ | $p_4 \to p_{10} \to p_6$ | 120 | 130 |