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Environmental Analysis of Pareto Optimal Routes in Hazardous Material Transportation

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Abstract

This paper presents environmental analysis of the Pareto optimal solutions of a bi-objective Hazardous material Vehicle Routing and Scheduling Problem with Time Windows (HVRPTW) logistics instance derived from road network of Osaka city, Japan. Environmental emissions of CO_2, NO_x and SPM corresponding to the Pareto optimal solutions were determined and compared in terms of the total emission values and the intensities of emissions on various links used in the solutions.

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Keywords: Hazardous material; multi-objective optimization; vehicle routing and scheduling problem with time windows; environmental impacts

1. Introduction

Transportation of Hazardous Material (HazMat) involves multiple parties such as shippers, carriers, manufacturers, residents, insurers, governments, and emergency responders. Various parties usually have different priorities for cost and risk objectives. A single objective model of minimizing the transportation cost tends to produce economic advantages and benefits for carriers and shippers. However, this lowest cost route may pass through highly populated areas and can in danger social security in case the vehicle carrying hazardous materials

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is subjected to an incident along the route. Similarly, a single objective model minimizing the risk can favor the government objective of enhancing social security but is likely to be very expensive because of their possible longer lengths. Single objective models are unable to represents the conflicts in HazMat transportation, arising when more than one criterion is taken into account. Hence, multi-objective models provide realistic alternatives (List, Mirchandani, Turnquist & Zografos, 1991; Erkut, Tjandra & Verter, 2007).

Decision making in multi-objective problems involves two primary steps: generating the option space which is the accumulation of all potential solutions, and select the best option (Hazelrigg, 1996). There are two primary approaches to finding solutions of multi-objective optimization problems. The first one is a scalar approach widely known as weighted sum approach which involves determining beforehand the relative importance (weight value) of the objectives and then use it to combine the multiple objectives into a single overall objective. The problem is then solved for an optimal solution for a given set of weight values. The second approach undergoes Pareto optimization of all the objectives and involves obtaining a set of non-dominated solutions that approximate the frontier of the Pareto optimal solutions. The most suitable one among the solutions is then selected.

A major drawback with the scalar approach is that the final optimal solution 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-offs among the objectives, the problem must be solved several times which on the whole takes longer computation time.

Pareto optimization overcomes this drawback working simultaneously to obtain a set of Pareto-optimal solutions and providing the decision maker with a clear picture of the trade-offs occurring between the objectives. Therefore, the Hazardous material Vehicle Routing and scheduling Problem with Time Windows (HVRPTW) in this paper is described as a cost and risk based bi-objective model and has been solved using Pareto-based approaches.

Selecting the final solution from a set of Pareto optimal solutions may seem a straightforward process. But in reality, it is a decision of significant importance and is the function of the trade-offs and compromises. A detailed environmental analysis as presented in this paper can be carried out in the case of realistic HazMat logistics instances, which can provide significant additional insights for decision making in HazMat transportation. Selection of the final HazMat routing solution can be made much easier and meaningful comparing the resulting information of the probable environmental impacts of the Pareto optimal solutions.

2. Literature Review

Routing studies in HazMat transportation can be categorized into two groups: a) full truck load shipments and, b) less than full truck load shipments. Substantial research effort has been seen in the former type (Erkut, Tjandra & Verter, 2007; Androutsopolos & Zografos, 2012) while less has been studied on the latter. Routing problems in the first category are simplified to a shortest path problem between two defined points: the origin and destination. However, HazMat distribution in urban areas is a day to day planning problem where the customer demands are much smaller than a full truck load. This gives rise to the second category of problems to which this paper is mainly related. A single vehicle here can service a sequence of customers. Therefore the problem is to find efficient routes for a fleet of vehicles carrying HazMat to service a set of customers with pre-defined demands and time windows. It is an extension of the Vehicle Routing and scheduling Problem with Time Windows (VRPTW) (Desrosiers, Dumas, Solomon & Sournis, 1995; Taniguchi, Thompson, Yamada & van Duin, 2001) and will be referred as Hazardous material Vehicle Routing and scheduling Problem with Time Windows (HVRPTW) hereafter.

Zografos and Androutsopoulos (2004; 2008), Androutsopoulos & Zografos (2010), Pradhananga, Taniguchi & Yamada (2010) and Androutsopoulos & Zografos (2012) are previous studies on multi-objective HVRPTW. A bi-objective risk and time based static HVRPTW was formulated in Zografos & Androutsopoulos (2004). Using weight values for the two objectives, the problem was transformed to a single objective problem similar to in single objective study presented by Pradhananga, Hanaoka & Sattayaprasert (2011) where cost values are used instead. An insertion-based heuristic approach was then used to solve the resulting HVRPTW. The model and the heuristic algorithm are extended to develop a GIS-based decision support system for the integrated HazMat routing

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