FINDING DISSIMILAR ROUTES FOR THE TRANSPORTATION OF HAZARDOUS MATERIALS

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1 INTRODUCTION

Routing Hazardous materials is an important issue in modern industrialized societies. Hazardous materials comprise explosive, flammable, poisonous gases and radioactive materials. Then, evaluating and designing safe routes is necessary for reducing the risk associated to an accident. However, the consequences of an injury strictly depend both on the network status and on the material being transported. In the literature there are several papers that consider how to assess the potential risk imposed by shipments traversing each link in a network [1,3,4,6,8]. In [6] the authors draw a band of fixed width around each link and use the population living within this band to assign to the link a weight representing the risk of the arc. In [8] the authors consider a Gaussian point-source pollution dispersion model to determine a measure of the risk of the links in a transportation network when after an accident the material becomes airborne. Basically, all these papers focus on the risk to be associated to the arcs of the network and, for instance in [6], in finding a route which minimizes the total transportation risk.

We focus our attention into the problem of finding a set of alternative paths between an origin and a destination site on which routing an hazardous or a set of hazardous materials. Finding a set of paths allows one to manage a fleet of vehicles and/or to equally distribute the total risk among the population exposed. Moreover, there may be instances where a decision maker is interested in developing back-up routes for a daily shipment in case the best route become infeasible due to road construction [2].

A similar approach is in [2] where the authors examined the problem of finding a set of spatially dissimilar paths between an origin and a destination. Indeed, they started from the consideration that in order to determine a set of alternative routes, efficient algorithms can be applied. This can be achieved, for instance, via a $K$-shortest path algorithm or by using an Iterative Penalty Method (IPM). The problem is that by using such algorithms the obtained routes may be spatially very similar to one another and in some instances this may be unacceptable. Seeking for a set of dissimilar paths is a mandatory requirement to ensure spatial risk equity for multiple shipments of hazardous materials. In order to find a set of spatially dissimilar paths, they used the two previous methods to generate a set of candidate
paths from which to extract the maximal dissimilar ones by applying a $p$-dispersion algorithm. Given a set of points, the $p$-dispersion method finds a subset of points so that the minimum \``distance\'' between pairs of selected points is maximized. As a measure of distance the authors introduced a dissimilarity index between each pair of routes found in the first phase. However, this dissimilarity index between two paths is computed by only considering the lengths of the arcs or of the set of arcs shared by the two routes.

There are two major drawbacks in their approach. Firstly, the methods employed for generating the set of initial paths consider only a single objective function, namely that of minimizing the risk or minimizing the cost or minimizing a linear combination between risk and cost. Indeed, by considering only one objective function or aggregating all the criteria in a single objective function (e.g. by linear combination) one can not necessarily capture the trade-off between two or more conflicting criteria (e.g. risk and cost) involved in the transportation of an hazardous material. The two methods employed have also several \``dimensions\'' in their implementation such as the structure of the penalty to be associated or the number $K$ of paths to be generated.

Secondly, the dissimilarity index computed by referring only to the lengths of the arcs of a pair of paths at a time, does not consider adequately the population exposure living near the paths.

## 2 OUR METHODOLOGY

In our approach we solve the problem in two phases too. We determine the set of initial paths by formulating it as a Multicriteria Shortest Path Problem (MSPP) and by solving it with an algorithm based on a Martins-like procedure [5]. In this way we can better distinguish the \``effects\'' of the conflicting criteria involved, thus avoiding the dependence of the solution from \``suitable\'' weights to be associated to the criteria in order to find a linear combination of them. The algorithm also does not involve any other decision in its implementation.

In a second phase, for finding the set of spatially dissimilar paths we refer to the notion of Buffer Zones of a path, that can be thought of as the zone determined by moving a circle along the path whose center is the vehicle on the path itself and whose radius is proportional to the impact area due to a possible accident. This definition is similar to the one used in [6]. The problem in considering such a zone is that we assume that all the persons within the band will be impacted equally and no one outside of the zone will be impacted at all. However, this can be realistic when the material being transported is not airborne when released like explosive or flammable materials. The Buffer Zones associated to each path are defined by using a Geographic Information System (GIS), this also allow to tailor the impact area to the topology of a path. After having defined the impact area, that is the Buffer Zones, of all the paths found in phase one, we compute an index representing the
dissimilarity between two paths referring to the areas shared by the two paths. This index is based on the one used in [2], namely:

\[ s(i,j) = \left( \frac{A(P_i \cap P_j)}{A(P_i)} + \frac{A(P_i \cap P_j)}{A(P_j)} \right) / 2 \]

where \( A(P_i \cap P_j) \) is the intersection area between two paths \( P_i \) and \( P_j \) with \( A(P_i) \) and \( A(P_j) \) the Buffer Zones of \( P_i \) and \( P_j \), respectively, determined by using a GIS. The corresponding dissimilarity index of \( P_i \) and \( P_j \) is therefore:

\[ D(i,j) = 1 - s(i,j) \]

In this way we can take into account the population exposure during a shipment. Then, by using a \( p \)-dispersion method we find the subset of maximal spatially dissimilar paths [2]. When we apply a \( p \)-dispersion method to the set of Pareto-Optimal paths, the final set of dissimilar paths is obviously not greater than the previous one. Then, our two phases method can also be seen as a method to reduce the set of routes in order to facilitate the decision maker choices. A similar approach was proposed in the paper of Mirchandani et al. [7] and is applied to a network when there are multiple uncertain measures. In particular, the authors proposed a method to routing problems for finding a set of non dominated paths from an origin to a destination where some of the link attributes are stochastic. This method uses a multiobjective algorithm which first finds the non dominated paths in deterministic networks. The central idea in their procedure is that they can reduce the set of Pareto-Optimal routes through the comparisons of two random paths attributes even in situations where the attributes does not satisfy the classical criterion of the stochastic dominance, as long as path attributes follow approximately a Normal distribution. This can then help to reduce the set of the Pareto-Optimal paths. However, in our application we suppose that the link attributes are all deterministic. In such a context our work can also be seen as a link of the methods proposed in [2] and in [7].

However, we compare our approach with the one that determines the set of candidate paths by means of an Iterative Penalty Method. Although the IPM is a suitable algorithm to generate a large set of alternative paths efficiently, the selected paths may not be in general desirable with respect to one of the two relevant criteria. Furthermore, if on one hand the IPM is easy to implement, on the other hand it has a lot of degrees of freedom, since several choices have to be made in its implementation.

We also provide some test problems on which we compare the effectiveness and efficiency of the two alternative methods proposed (MSP vs. IPM). We believe that this could stimulate other researches in defining other sets of test problems for further comparisons of alternative approaches applied to the transportation of Hazardous materials problem.
3 THE APPLICATION

As an example network we use the transportation road network of Rome, from which we have excluded the historical center, obtaining a subnetwork of 699 vertices and 1754. To each arc are associated two criteria, the length and a measure of risk as a function of the length of the arc itself and an index representing the average volume of traffic along the arc. A possible simple measure of risk for each arc may be obtained by the product of the arc length and the corresponding “traffic” index. It should be emphasized that this is only one of the possible measures of risk to be associated to the arcs of the network, and that it is presented only for the purpose of illustration. We also suppose that the material being transported is a flammable one as fuel or GPL (Liquid Propane Gas) for gas service stations. We assume that we have to transport the material only from one origin (depot) to one destination (station).

The Buffer Zones was determined by defining a band of fixed width of about 150 meters around each link of a path as in [6]. This follows by the hypothesis that the material being transported is not airborne.

Several results are presented.

REFERENCES


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