Scheduling hazardous material shipments*

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Abstract

During the last years the analysis of the risks in transporting hazardous materials has completed remarkable steps ahead and begins to be an useful instrument of appraisal. This paper proposes an approach for the minimization of the risk based on the planning of the carriers schedule. In particular, the information coming from territorial databases make available the lowest risk routes according to opportune functions that hold account, simultaneously, of the risk factors for the carrier itself, for the surrounding areas and the respective populations and of the economic efficient characteristics of the transport (lengths and times). This allow us to represent a carrier scheduling problem as a graph optimization problem and to propose some fast heuristic algorithms, suitable for real time implementations. Finally, through the development of an appropriate software we have carried out many performance verifications and estimated the results.

Introduction

The problem to transport hazardous materials (hazmats) arises in industrial society due to the pervasiveness of these materials [5]. Hazmats include explosives, gases, flammable liquids and solids, poisonous and infectious substances, radioactive materials, corrosive substances, hazardous wastes and
any other dangerous goods. Unfortunately, most hazmats are not used where produced, but they are transported over considerable distances. What differentiates shipments of hazmats from other material shipments is the risk associated with an accidental release of these materials during transport. Hazmats can be extremely harmful to the environment and to human health, since exposure to their toxic chemical ingredients could lead to the injury or death of animals and humans and to the ruin of plants; this risk is recognized by the society and, in many cases, strict regulations govern their movements. Consequently, hazmat carriers have better accident records than others. In most transport planning models, the objective is to move products from their original places to destinations at a minimal cost. However, for hazmats shipments, a cost-minimizing objective is usually not suitable. In fact, the risk associated with them makes these problems more complicated than many other transport problems [4].

In this paper, we are going to consider the problem of scheduling a given set of hazmats transports on a set of given routes. We presume that the set of routes followed by the carriers are planned in order to minimize the overall risk for the community as a whole. There is already a considerable amount of literature about the hazmats routing problem so it is not our aim to define any solution that addresses to the difficulty of determining a route for a vehicle carrying hazmats, which, while minimizing total risk of travel, will also spread this risk equitably among the zones of a transport network [2].

Instead we propose a scheduling model in which global traveling risk over each link of the transport network is already computed based on some risk models (see for example [5, 6, 7]). This model will consider the risk factors and the economic efficient characteristics of the transport (lengths and times). In particular, the information coming from territorial databases allow us to assign to each link of the transport network a numeric value that expresses the maximum risk level that the link itself could support simultaneously. Moreover, to each carrier is associated a risk that depends on the substance transported and on the type of truck. To ensure that the level of risk on each link is not exceeded, it is necessary to determine shipments’ departure schedule; in particular, we have to determine each carrier starting times within a certain time window. Thus, we address the problem of having an equitable distribution of the risk to each area over time. Note that we do not consider that a shipment on a route can influence the shipments on its neighborhood.

Following paragraphs will describe the modelling process of the considered problem and the relative solution algorithm that we intend to propose with experimentations and results analysis.

The problem

Nowadays, in global markets fierce competitions have forced business enterprises to invest in, and focus attention on, their logistics networks. Managing their supply chain, enterprises need to produce and send the right quantity, to the right locations and at the right time in order to minimize system’s
wide costs while satisfying service’s level requirements. To achieve this objective it is necessary to improve the synchronization of the transport operations among the various entities of the system and to reduce the uncertainty in the delivery times so that departure and arrival delays will be contained within a threshold of acceptability. In particular, we focus our attention on hazmats shipments.

Our study intend to develop a tool that may be used by the authority to plan, manage and control transport activities of the enterprises involved in the problem. The authority’s main goal is related to contain the risk within acceptable limits. This would lead to restrictions on carrier’s routes selection and on their departure times. Obviously, the authority has to guarantee the maximum support for the necessities of the firms involved in the problem to the surrounding economic fabric so that they may be able to perform their activities in the highest efficient level. Therefore, main purpose is to provide the authority of a tool that allows to take decisions among conflicting needing. As already mentioned, there exist many routing models that can be used while dealing with the problem of hazmats to find low risk routes. Most of them are focused on containment of the costs, of the delivery delays or any other target function [5]. No matter of the target, for such routes, a scheduling process is required because the involved carriers have no cooperation among them and so they could determine an overcrowding of the transport network in given hours of the day and then produce situations at high risk. This paper deals with these last kinds of problems.

Let us consider the case of the Lazio region as a part of the Italian road network and the carriers who transport dangerous commodities cross this net. Every typology of commodity has his own level of risk that, when combined with the typology of the carrier (dimensions, safety systems, age etc.), determines the risk of every single shipment. This information can also be translated in a numerical attribute associated to the carrier itself. Every shipment has an assigned route that corresponds to the crossing sequence of roads with different attributes of risk. Each carrier’s journey can never be interrupted because of the lack of safe lay-buys. Knowing the route followed by every carrier and the relative departure and arrival times preferred, it is possible to foresee in advance the road and the times in which it will be in conditions of over-risk. In fact the sum of the carrier’s attributes of dangerousness contemporarily present on the same road overcomes the threshold of risk admitted for that road. In the hypothesis that such situations occur it becomes necessary a carrier’s departure scheduling that will carry to an admissible trip schedule. Therefore, the problem consists on finding a sequence of the trips that allows to get the best admissible results.

The model

The model we propose makes use of a graph $H(N,L)$ representing the network, where each element $l \in L$ stands for a link with homogenous characteristics of risk (expressed by a numerical attribute) between two nodes $n_1, n_2 \in N$. 
We intend to adopt an approach that makes use of the job-shop scheduling theory where we consider each shipment as a job and the link sequence of the shipment as the task sequence to be processed.

Let us consider the link set $L$. It corresponds, by a one to one relationship, to the set of processors $M$ of the correspondent scheduling model. Let $h_i$ be the risk joined to link $i$ that is the maximum risk tolerable by itself. Correspondingly, we have an attribute expressing the capability $s_i$ of the processor $i$. Let $k_i$ be the risk joined to the carrier $i$ and $t_i$ the corresponding volume joined to the related job. Assuming: $h_i = s_i$ and $k_i = t_i$ we have that, in each instant of time and for each processor, it never could be that the sum of the volumes simultaneously on a processor would be greater than the processor capability.

To every job $i$ are also assigned:

- the couple $(r_i, d_i)$ that denotes the preferred beginning $(r_i)$ and completion $(d_i)$ instants of the job $i$ and therefore, the preferred departure and arrival times of the corresponding carrier.
- the sequence of the visited processors $m_{ij}, \ldots, m_{ijn}$, i.e. the link sequence crossed by the carrier $i$, where $n_i$ is equal to the number of processors visited by the job $i$.
- the processing times $p_{ij}, \ldots, p_{ijn}$ on every processor of the sequence. They correspond to the time required to complete each link of the route.

According to the standard classification of the scheduling problems we are dealing with the following one: $J, m \mid prec, r_i, d_i, no\ wait \mid criteria$, where:

- $J, m$ stands for job shop problem with $m$ processors,
- $r_i$ and $d_i$ indicate the presence of ready-times and due-dates,
- no wait is the nonpreemption property of the jobs,
- criteria denotes the set of different objectives that we want to achieve.

Its representation in a graph simplifies the understanding of the problem and allows us to implement a solution algorithm.

Let $G(V,E)$ be the graph representing the network $H(N,L)$ where the set of vertices $V$ corresponds to the set $L$ of links and the set of edges $E$ corresponds to the set of nodes $N$ of the transport network. Clearly, to each node of $G$ corresponds a processor and to each route of $G$ corresponds a job of the job-shop system.

In the considered problem the maximum priority is guaranteed to hazmats transports to start only if it could "flow" from its original place to its destination without interruptions. This means that shipments would not have to interfere one with the other so that a carrier has to wait until the next link gets free for it. Assuming no-wait property allows us to translate this necessity in an explicit bound in the corresponding scheduling model. In this way a shipment will take place only when its journey will not be interrupted. Consequently a job could start and finish in a certain delay on his ready-time and due-dates and it means that a transport could leave and arrive to destination with a certain delay on his preferred starting-time and arrival-time.
The solution algorithm

Due to the complexity of the problem, finding an exact solution would require high power computers and yields the optimum results not so early as needed. Our purpose is to provide some techniques suitable for real time implementations. We designed some fast heuristic algorithms that do not guarantee to find an optimal solution, but instead of looking for reasonably good solutions in a relatively short time by a reasonable computational effort.

They all define a dispatching rule that could be useful to find a reasonably good schedule with regards to a single objective. In particular we can define an algorithm that tries to minimize the sum of the starting delay and another one that goes to the minimization of the number of late carriers. We could have been in need of the best global outcome and so we have to compare the results coming from the different techniques.

All the algorithms that we have implemented operate according to the same operational sequence: they produce a list of orderly jobs based on a certain ranking rule. One by one the jobs are selected form the list and assigned to the shop at the preferred departure time. If the assignment of a job determines an inadmissible condition the job itself is delayed for so many time unities as necessary to re-enter into admissibility conditions. Naturally the last jobs to be assigned are those that usually suffer the greatest delays. The general method can be summarized as follow:

Step 1:
Produce the list of the jobs according to the assigned rule.

Step 2:
If the list is not empty then select the first job from the list.
If the list is empty then END

Step 3:
Assign selected job to the shop starting from its ready time
Check the admissibility for the assignment
If it is not admissible then increase the ready time by 1 and repeat Step 3

Step 4:
Update the schedule
Eliminate the job from the list
Go to Step 2

In this work two different rules have been implemented to sort the jobs and each one pursues a specific objective. The former is the first in first served rule, which is equivalent to the earliest ready time first (ERT) rule. It attempts to equalize the waiting times of the jobs, that is, to minimize the starting delays. The latter could be named maximum priority first, in which the jobs are scheduled according to their priority attributes: the greater is the priority the smaller is the waiting time. Naturally this rule should guarantee the smallest weighed delays.
Preliminary results

We did preliminary experiments on a simplified real road net. As shown in Figure 1, we considered only the main roads of the Lazio region. Thanks to the results provided by [7] we divided the arcs composing those roads into three classes of risk: low, medium and high risk.

The net is composed by 242 links whose capacity depends, according to the following Table 1, on the risk class to which they belong.

![Figure 1: Risk Evaluation on Lazio Road Net](image)

<table>
<thead>
<tr>
<th>RISK</th>
<th>CAPACITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>3</td>
</tr>
<tr>
<td>Medium</td>
<td>2</td>
</tr>
<tr>
<td>High</td>
<td>1</td>
</tr>
</tbody>
</table>

In the first experimentation we considered eight different routes used to cross the region. Every route is crossed by two carriers in each direction, one with high and one with low priority so that we have thirty two carriers altogether. All of them have a volume that is equal to one so that we can have only a carrier at a
time on high risk arcs, two carriers at a time on medium risk arcs and three at a time on low risk ones. The preferred departure times are produced by a random number generation according to a normal distribution within a four-hour time window.

To keep into account of the operations required to manage the emergency that arises from an accident we settle a minimum safety distance among the carriers. It is equal to fifteen minutes. For this reason we keep the arcs still busy for fifteen minutes after the carrier has left them as if the processing time was longer. In this way the capacity of the arc is blocked and it is released fifteen minutes later.

In total ten tests have been done using every time a list of different ready times. The following charts in Figures 2, 3, 4 and 5 show the results of the experiments.

Figure 2

Figure 3
These results show as the method that executes the scheduling according to the decreasing priority rule not only gets the best results when the weighed delays are calculated, but also the results are better even if the priority factor is not kept in mind. Furthermore the number of late carriers and a single carrier’s maximum delay seems to be less when the maximum priority method is used.

**Conclusion**

In this paper we have considered the problem of sequencing the carriers transporting dangerous substances on a road net. Starting from previous studies that calculated the risk on every single arc of the road for every typology of substance and every mean of transport we have proposed a solution of the problem based on a job shop scheduling model in which the road arcs are the processors and the carrier’s journeys are the jobs. The central point of the model lies on the arcs capacity assignment, based on their riskiness, and on the carriers...
volumes assignment according to their dangerousness: a carrier can not cross an arc if this has not enough residual capacity to hold the incoming risk. The optimal solution of the problem requires long time and a great computational effort so that heuristic algorithms are more suitable for real situations. The experiments, conducted on a simplified network show the performances achieved by the proposed algorithms.

References


