Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi

Pamukkale University Journal of Engineering Sciences

Transportation of hazardous materials (hazmat) a literature survey

Tehlikeli maddelerin taşınması-bir literatür taraması

Zafer YILMAZ[1], Serpil EROL[2], Hakan Soner APLAK[1]*

[1] Defense Sciences Institute, Turkish Military Academy, Ankara, Turkey.
zyilmaz@kho.edu.tr, haplak@kho.edu.tr
[2]Industrial Engineering Department, Gazi University, Ankara, Turkey.
serpiller@gazi.edu.tr

Abstract

Transportation has a great role in logistics. Many researchers have studied on transportation and vehicle routing problems. Transportation of hazardous materials (hazmat) is a special subject for logistics. Causalities due to the accidents caused by trucks carrying hazardous materials will be intolerable. Many researchers have studied on risk assessment of hazmat transportation to find ways for reducing hazardous material transportation risks. Some researchers have studied routing of hazmat trucks. The emergency response models and network design problems for hazmat transportation were also studied by some researchers. The transportation of hazmats can also be classified according to the mode of transport. Mainly roads are used for hazmat transportation but some shipments are intermodal. There has been a great amount of effort spent to find convenient ways for hazmat transportation. In this study, a literature survey for the articles about hazmat transportation is prepared. After pointing out the importance of hazmat transportation by the example of US hazmat transportation data, the studies on hazmat transportation since 2005 have been examined. Totally 88 articles are classified as risk, routing, routing and scheduling, emergency response, network design and accident analysis. What can be studied in future researches is pointed out.

Keywords: Hazardous materials, Network design, Transportation, Routing, Risk assessment

Öz

Taşımacılık lojistik sektöründe çok büyük öneme sahiptir. Birçok araştırmacı taşıma ve araç rotalama problemleri üzerinde çalışmıştır. Tehlikeli maddelerin taşınması lojistik sektöründe özel bir konudur. Tehlikeli madde taşıyan araçların yaptıkları kazalara bağlı olarak meydana gelen ölümler tolere edilemez sonuçlara yol açar. Birçok araştırmacı, tehlikeli madde taşımacılığındaki taşımacılık riskini düşürmek için risk değerlendirme modelleri üzerinde çalışmışlardır. Bazı araştırmacılar ise tehlikeli madde taşıyan araçların rotalanmasını çalışmışlardır. Acil müdahale modelleri ve şebeke tasarım modelleri de bazı yazarlar tarafından çalışılmıştır. Tehlikeli madde taşımacılığı taşımacılık moduna göre de sınıflandırılabilir. Genellikle karayolları tehlikeli madde taşımacılığında en çok tercih edilir fakat bazen karma taşımacılık da kullanılabilir. Tehlikeli madde taşımacılığı için uygun yollar bulma konusunda önemli çabalar sarf edilmektedir. Bu çalışmada, tehlikeli madde taşımacılığı konusunda yazılmış makalelerin bir literatür araştırması yapılmıştır. Amerika Birleşik Devletleri örneği verilerek tehlikeli madde taşımacılığının önemi üzerinde durulduktan sonra tehlikeli madde taşımacılığı konusunda 2005 sonrası yapılan çalışmalar incelenmiştir. Toplam 88 makale risk, rotalama, rotalama ve çizelgeleme, acil yardım, şebeke tasarımı ve kaza analizi olarak sınıflandırılmıştır. Müteakip çalışmalarda nelerin üzerinde durulması konusu belirtilmiştir.

Anahtar kelimeler: Tehlikeli maddeler, Şebeke tasarımı, Taşımacılık, Rotalama, Risk değerlendirmesi

1 Introduction and general information

Hazardous materials are defined as any substance or material capable of causing harm to people, property and environment [1]. In some articles hazmat is also called as dangerous goods. United Nations sorts dangerous goods into nine classes according to their properties. These classes are [2]:

1 Explosive substances and articles,
2 Gases,
3 Flammable liquids,
4.1 Flammable solids, self-reactive substances and solid desensitized explosives,
4.2 Substances liable to spontaneous combustion,
4.3 Substances which, in contact with water, emit flammable gases,
5.1 Oxidizing substances,
5.2 Organic peroxides,
6.1 Toxic substances,
6.2 Infectious substances,
7 Radioactive material,
8 Corrosive substances,
9 Miscellaneous dangerous substances and articles.

The rulers in countries and the carriers must take a special care for transporting hazmats.

The difference between transportation of hazmats and transportation of other goods arises from an accident.

When an accident occurs then the harm to population and environment will be inevitable. Although it is vital to keep information of hazmats only few countries have special departments for transporting hazmats. These departments also keep a database for all hazmat incidents and their results. Figure 1 shows the distribution of accidents by hazmat class in 2013 in USA according to information of PHMSA-US Department of Transportation Pipeline and Hazardous Materials. The figure illustrates that the majority of the accidents/incidents are flammable-combustible liquids incidents.

In 2013, there were 15919 total incidents resulting 28 hospitalized and 132 Non-Hospitalized injuries. Unfortunately there were 12 fatalities and 81,365,866 dollars damages caused by these incidents [3].
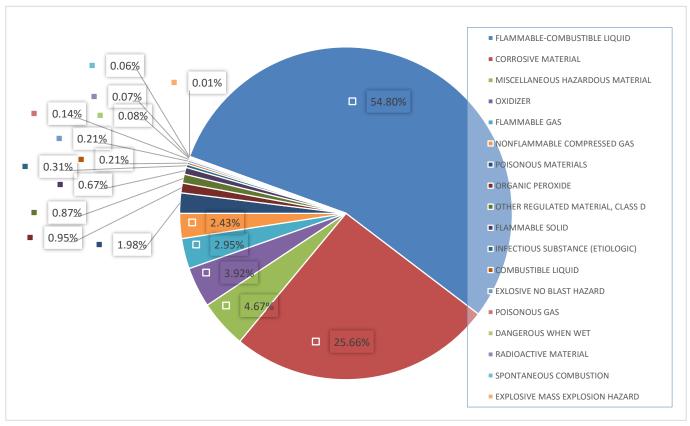
Figure 1: Accidents by hazmat class in 2013 [3].

Hazmat transportation is a special issue. Therefore the countries restrict the transportation of hazmats by some laws. The European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR) was done at Geneva on 30 September 1957 under the auspices of the United Nations Economic Commission for Europe, and it entered into force on 29 January 1968 [2].

The countries have adopted their hazmat transportation according to ADR.

Hazmat transportation is possible via all transportation modes (air, highway, railway, water and pipeline). Mainly hazmats are transported by road and most of the incidents caused by vehicles carrying hazmats resulting fatalities, injuries and environmental damage. If an accident cause hazmat release from the vehicle, then these accidents are called as incidents. Table 1 shows the number of incidents and fatalities by transportation mode in USA between the years 2007-2013.

Hazmat transportation is very important with respect to economic concerns. Incidents caused by hazmat transportation only in USA caused 548,698,727 dollars damage for last seven years. The damage amounts of last seven years in USA can be found in Table 2.

Hazmat incidents not only cause fatalities and environmental damage, they also cause explosions, fire, vapor dispersion etc. The emergency teams should pay special attention to decrease side effects of hazmat incidents. Sometimes, the need to evacuate the region also is required. Table3 shows hazmat incident results in 2013 in USA.

One can understand from the figures and tables above that, hazmat transportation is a special topic of countries in which hazmat transportation has vital effects. Vehicles carrying hazmat caused accidents resulting fatalities and environmental damage mainly. Hazmat transportation has many side effects when it is examined within the framework of economy. For all these reasons mentioned before, many researchers have published articles with the subject of hazmat transportation since early 1980s. The hazmat transportation did not lose its popularity as the years passed and many researchers still go on to study hazmat transportation.

In the following parts of this study, the hazmat literature review is explained and then details of the hazmat classification are given.

2 Hazmat literature review

The special importance of hazmat transportation forces the researchers to study on how to decrease risk or which route is the best for hazmat transportation. The researchers also searched the emergency response models and evacuation methodologies after hazmat accidents. From early 1980s, hazmat transportation is one of the main concerns of researchers. Hazmat transportation literature from 1982 to 2004 is studied by Erkut et al. [1]. Figure 2 shows the number of hazmat-transportation related papers published in refereed journals between 1982-2004 which are classified by Erkut et al. [1]

Table 1: Incidents and fatalities by transportation mode and incident year.

Number of Incidents / Fatalities	2007	2008	2009	2010	2011	2012	2013	TOTAL
AIR	1,556/0*	1,278/0	1,356/0	1,295/0	1,400/0	1,460/0	1,441/0	14,839/0
HIGHWAY	16,932/9	14,804/6	12,730/12	12,648/8	12,810/12	13,248/12	13,698/12	140,557/71
RAILWAY	753/0	748/0	642/1	749/0	745/1	662/0	663/0	7,175/2
WATER	61/0	100/3	90/0	105/0	71/0	70/0	63/0	714/3
TOTAL	19,302/9	16,9300/9	14,818/13	14,797/8	15,026/13	15,440/12	15,865/12	163,285/76

*: 1556 incidents resulting 0 fatalities.
Source: Hazmat Intelligence Portal, U.S. Department of Transportation [3].

Table 2: Damage amounts ($) by mode and incident year.

	2007	2008	2009	2010	2011	2012	2013	Total
AIR	88,030	191,434	707,939	20,267	171,467	41,089	143,105	1,363,331
HIGHWAY	47,279,979	42,889,714	50,628,781	63,672,251	112,515,635	60,175,059	44,746,385	421,907,804
RAILWAY	27,305,219	7,939,038	17,557,034	7,348,260	12,309,566	17,868,809	33,237,348	123,565,274
WATER	19,097	138,350	100,887	574,103	205,000	806,168	18,713	1,862,318
TOTAL	74,692,325	51,158,536	68,994,641	71,614,881	125,201,668	78,891,125	78,145,551	548,698,727

Source: Hazmat Intelligence Portal, U.S. Department of Transportation [3].

Table 3: 2013 Hazmat incident results in USA.

2013 Hazmat Incident Results					
Result	Incidents	Hospitalized	Non-Hospitalized	Fatalities	Damages ($)
Environmental Damage	76	2	1	2	36,893,716
Explosion	17	10	2	7	13,030,932
Fire	70	14	8	10	20,624,418
Material Entered Waterway/Sewer	62	1	1	0	32,148,280
None	913	0	0	0	1,645,411
Spillage	14644	12	110	7	70,192,689
Vapor (Gas) Dispersion	378	16	31	2	16,400,966
TOTAL	**16160**	**55**	**153**	**28**	**190,936,412**

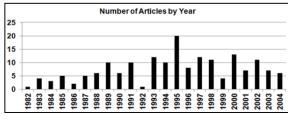Source: Hazmat Intelligence Portal, U.S. Department of Transportation [3].

Figure 2: Number of hazmat-transportation related papers published in refereed journals between 1982-2004.

The articles can be classified in many ways. One of the classifications made by Erkut et al. [1] is;

✓ Risk assessment,
✓ Routing,
✓ Combined facility location and routing,
✓ Network design.

In this study, 88 articles published in refereed journals between 2005-2014 (January-March) are examined. Figure 3 shows the number of articles with respect to publication years.
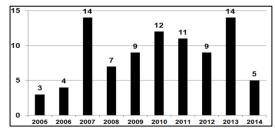

Figure 3: Number of hazmat-transportation related papers published in refereed journals between 2005-2014.

When we classify the articles according to hazmat class, most of the researchers did not take into consideration the type of hazmat carried by vehicles. Figure4 shows the classification of articles with respect to the type of hazmat carried. Mainly class-2 and class-3 hazmats are researched by the authors. In 59 articles, the authors did not mention the class of hazmat; therefore we named the hazmat type in these articles as "general hazmat". It can be understood from the Figure 4 that none of the researchers have studied on the hazmat type class-7, class-8 and class-9.
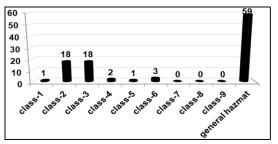

Figure 4: Number of papers related to hazmat class carried.

The classification of hazmat transportation may differ according to authors. If one goes deep into the articles published between 2005-2014, one of the classifications can be as follows;

✓ Risk (risk assessment, risk reduction, risk analysis etc.),
✓ Routing,
✓ Routing and Scheduling,
✓ Emergency Response,
✓ Network Design,
✓ Accident Analysis.

We added two new classification subject to Erkut et al. [1] since 2005, ''Emergency Response'' and ''Accident Analysis'' attracted the attention of researchers as new items.

2.1 Risk (Risk assessment, risk reduction, risk analysis etc.)

Hazmat transportation differs from normal transportation within the frame of risk. Risk can be explained in different ways according to point of view of the researchers. However, in almost all articles, the explanation made by US DOT (1994) is accepted as traditional risk and it is formulated as:

Rij=Pij*Cij where; Rij (transportation risk of link I, j), Pij (accident probability on the link) and Cij (accident consequences on link i,j).

Ang et al. (1989) explains the risk in three parts. [4]:

• Probability of accident involving release of hazmat,
• The level of potential exposure,
• The consequences (injuries, fatalities, property damage).

Erkut et al. [1] explained the risk in more detailed way and focused on Quantative Risk Assessment (QRA) which involves three key steps:

• Hazard and exposed receptor identification
• Frequency analysis
• Consequence modeling and risk calculation
   ✓ Modeling the impact area,
   ✓ Gaussian Plume Model,
   ✓ Risk Cost (injuries and fatalities, cleanup costs, property damage, evacuation, product loses, traffic incident delay, environmental damage).

Risk of a road was calculated by Erkut as edge risk and path risk. Risk has been main concern of articles about hazmat transportation.

Risk is the most popular item studied by majority of the authors dealing with hazmat transportation. For the recent studies; Toumazis and Kwon, [5] studied on minimizing the risk experienced by the hazmat shipment transportation in any given time-dependent; Chakrabarti and Parikh, [6] prepared a risk-based study of route evaluation, Saat et al. [7] proposed a quantitative analytical approach to estimate the risk cost of transporting hazardous materials by rail and Cappanera and Nonato, [8] focused on how to efficiently compute the Pareto frontier given by the non dominated solutions with respect to total risk and total cost on realistic instances taken from the literature.

2.2 Routing

Routing of vehicles carrying hazmat has been the second main concern of the articles about hazmat transportation. From early 1980s to 2014, the researchers have studied on routing the hazardous materials and they mainly focused on local-global routing, transportation mode, vehicle type, single-multi commodity, single-multi objective routing of hazmat transportation.

Traditionally, main consideration for hazmat transportation was about cost and safety [9]. Therefore for routing hazmat vehicles while carriers are trying to decrease their transport cost, local or global authorities should care about the safety of population.

For the recent studies on routing hazmat; Samanlioglu, [10] proposed a multi-objective mathematical model for the industrial hazardous waste location-routing problem, Desai and Lim, [11] focused on a stochastic dynamic programming approach for hazardous material route selection problem and Mahmoudabadi and Seyedhosseini, [12] dealt with the principle of hazmat routing problem and fundamental concerns of chaos theory for defining dynamic variables are combined to develop a mathematical model while risk and time are prioritized by corresponding coefficients.

2.3 Routing and Scheduling

The carriers and governments must have some strategies in order to reduce transport risk. Time of the transportation is important. Government and local authorities serve as supervisor to hazmat carriers and, they allocate road segments or available population zones within a time period [13]. The carriers should route and schedule their hazmat vehicles according to restrictions of the authorities to minimize transport risk.

2.4 Emergency response

After a hazmat incident, it is obvious that emergency response is crucial in order to decrease or minimize the effect of incident. To establish a hazmat emergency response system constitutes a building block toward a comprehensive public and environmental safety infrastructure [14]. Emergency response departments are fire-fighting departments, first-aid teams and police stations [15]. The articles for emergency response are few when it is compared with risk and routing. One of the main concerns of emergency response researches is to locate response departments to best places in which the risk of the link is highest.

2.5 Network design

Network design is mostly popular in transportation and communication. Network design has different characteristics in the context of hazmat shipments. The transportation infrastructure is built mainly to connect heavily populated areas and not to avoid them. Therefore, the question becomes which road segments to close in an existing network rather than identifying the most appropriate ways to expand the infrastructure Erkut et al. [1]. Designing hazmat transportation is first introduced by Kara and Verter [16]. They proposed a bi-level integer programming model for network design. They considered the problem with two sides: government and carriers. The objective was minimizing risk while considering the carriers concern about minimizing cost. After Kara and Verter [16], Erkut and Alp [17] proposed an "optimum communication spanning tree problem" to design a network for hazmat shipments. Bianco et al. [18] introduced a bi-level network flow model, and Xu et al. [15] considered the network design with emergency response together under complex fuzzy environment.

2.6 Accident analysis

The accident analysis is a must in order to understand the effects of hazmat incidents. However, few articles are published about accident analysis of hazmat vehicles. Ronza et al. [19], used transportation accident databases to investigate ignition and explosion probabilities of flammable spills. Ghazinoory and Kheirkhah [20] was focused on transportation risk as the main parameter and they developed strategies for reaching the optimal condition and they laid out the impacts of these strategies on the reduction of accidents are analyzed. There are 13 articles published in refereed journals between 2005-2014 about accident analysis and main concentration of these articles is to analyze accidents in order to decrease the risk of hazmat transportation.

Figure 5 shows the number of articles published between 2005-2014 which are classified according to main subject studied in the articles.
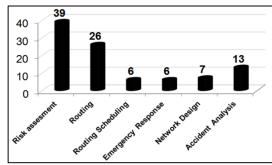

Figure 5: Number of papers according to main subject studied in the article.

To make a better understanding of the articles we prepared Table 4 which shows the publication year, author, and name of the article, topic and methodology used in the article. Table 4 provides the classification of articles using the above six main subjects. The 39 of articles over 88 articles deal mainly with risk of hazmat transportation. 26 of the articles take into consideration the routing of hazmat vehicles mainly. In 6 articles emergency response, in 6 of articles network design and in 13 articles accident analysis are studied. Since in some articles two subjects are studied at the same time, total numbers of the articles which are classified are not 88 in Figure 5. The methodologies which are used in each article are also shown in Table 4.

Table 4: A classification of hazmat transportation articles.

No.	Year	Author	Name of the Article	Topic	Methodology
1	2005	Fabiano et al [21].	Dangerous good transportation by road: from risk analysis to emergency planning	Risk (risk assessment, risk reduction, risk analysis, etc.)	An optimisation algorithm, based on the graph theory was developed to select optimal consistency and localisation
2	2005	Gheorghea et al [22].	Comprehensive risk assessment for rail transportation of dangerous goods: a validated platform for decision support	Risk (risk assessment, risk reduction, risk analysis, etc.)	The risk-related results are integrated on a software platform, structured as a decision support system using intelligent maps and a variety of GIS
3	2005	Ogle et al [23].	Emergency response to a non-collision hazmat release from a railcar	Emergency response	The technical challenges unique to rail transportation and railcar design greatly influenced the emergency response.
4	2006	Boulmakoul, A [24].	Fuzzy graphs modelling for Hazmat telegeo monitoring	Risk (risk assessment, risk reduction, risk analysis, etc.)	Path algebra for the K-best fuzzy shortest path Fuzzy graphs and object oriented modelling
5	2006	Bubbico et al [25].	Risk management of road and rail transport of hazardous materials in Sicily	Risk (risk assessment, risk reduction, risk analysis, etc.)	A Transportation Risk Analysis (TRA) tool has been used to accurately assess the risk associated to a variety of road and rail transportation
6	2006	Schweitzer, L [26].	Environmental justice and hazmat transport: A spatial analysis in southern California	Accident analysis	A combination of mapping and statistical methods.
7	2006	Huang, B [9].	GIS-Based Route Planning for Hazardous Material Transportation	Routing	A Geographic Information System (GIS) is used to quantify the factors on each link in the network

Table 4: A classification of hazmat transportation articles. (et seq.)

No.	Year	Author	Name of the Article	Topic	Methodology
8	2007	Carotenuto et al [27].	Finding minimum and equitable risk routes for hazmat shipments	Transportation planning	Lagrangean relaxation; Heuristics
9	2007	Akgün et al [28].	Routing of a hazmat truck in the presence of weather systems	Hazmat transportation on a network	Heuristics Time-dependent shortest path problem
10	2007	Cozzani et al [29].	Hazmat transport: A methodological framework for the risk analysis of marshalling yards	Quantitative risk analysis	Fault Tree analysis
11	2007	Carotenuto et al [30].	A tabu search approach for scheduling hazmat shipments	Vehicle routing and scheduling	Tabu search algorithm
12	2007	Glickman et al [31].	The cost and risk impacts of rerouting railroad shipments of hazardous materials	Routing	Network link risk assessment methodology
13	2007	Ronza et al [19].	Using transportation accident databases to investigate ignition and explosion probabilities of flammable spills	Accident analysis	The results of the survey of two vast US federal spill databases (HMIRS, by the Department of Transportation, and MINMOD, by the US Coast Guard) are reported and commented on.
14	2007	Verma and Verter [32].	Railroad transportation of dangerous goods: Population exposure to airborne toxins	Risk (risk assessment, risk reduction, risk analysis, etc.)	Risk approximation approach,(Gaussian plume model)
15	2007	Berman et al[14].	Designing emergency response networks for hazardous materials transportation	Emergency response	Two formulations for the maximal arc-covering problem, a known one and a new one.
16	2007	Erkut and Alp [17].	Designing a road network for hazardous materials shipments	Network design	Tree design problem as an integer programming problem and a path-addition heuristic
17	2007	Godoy et al [33].	STRRAP system—A software for hazardous materials risk assessment and safe distances calculation	Risk (risk assessment, risk reduction, risk analysis, etc.)	Computational tool (Stochastic Toxic Release Risk Assessment Package, STRRAP)
18	2007	Zhang and Zhao [34].	Risk Analysis of Dangerous Chemicals Transportation	Risk (risk assessment, risk reduction, risk analysis, etc.)	Simulation analysis on accident aftermath on the GIS platform
19	2007	Alumur and Kara [35].	A new model for the hazardous waste location-routing problem	Routing	A new multi-objective location-routing model is proposed
20	2007	Bell M [36].	Mixed Routing Strategies for Hazardous Materials: Decision-Making Under Complete Uncertainty	Routing	A minmax problem is formulated. Connections to game theory provide useful insights into the nature of the solution. The properties of the optimality conditions are explored leading to the formulation of an equivalent linear programming problem.
21	2007	Erkut and Alp [37].	Integrated routing and scheduling of hazmat trucks with stops en route	Routing and scheduling	Four versions of the problem with increasingly more realistic constraints on driving and waiting periods, and propose pseudo polynomial dynamic programming algorithms for each version.
22	2008	Erkut and Gzara [38].	Solving the hazmat transport network design problem	Network design	Bilevel programming; Heuristic solution method

Table 4: A classification of hazmat transportation articles. (et seq.)

No.	Year	Author	Name of the Article	Topic	Methodology
23	2008	Dadkar et al [39].	Identifying geographically diverse routes for the transportation of hazardous materials	Routing	Genetic algorithm
24	2008	Zografos and Androutsopoulos [40].	A decision support system for integrated hazardous materials routing and emergency response decisions	Routing and Emergency response	Heuristic algorithm and A new Lagrangean relaxation heuristic algorithm
25	2008	Planas et al [41].	Results of the MITRA project: Monitoring and intervention for the transportation of dangerous goods	Emergency response	A prototype of a new operational system for monitoring the transportation of dangerous goods in Europe based on regional responsibilities
26	2008	Bonvicini and Spadoni [42]	A hazmat multi-commodity routing model satisfying risk criteria: A case study	Routing	A new model named OPTIPATH has been developed, offering a wide set of different optimisation strategies. The OPTIPATH methodology has been integrated in the TRAT4-GIS software.
27	2008	Ghazinoory and Kheirkhah [20].	Transportation of hazardous materials in Iran: A strategic approach for decreasing accidents	Accident analysis	Strategies for reaching the optimal condition are laid out and the impacts of these strategies on the reduction of accidents are analysed.
28	2008	Verter and Kara [43].	A path-based approach for Hazmat transport network design	Network design	The main modelling construct in this paper is a set of alternative paths for each shipment that is mutually acceptable to the government and the hazmat carriers involved. We discussed the use of the maximum cardinality of alternative path sets K and the maximum allowable percent detour from the shortest path D as possible means of constructing the alternative path sets
29	2009	Trépaniera et al [44].	Cross-analysis of hazmat road accidents using multiple databases	Accident analysis	Cross-analysis of databases
30	2009	Qiaoa et al[45].	Utilization of accident databases and fuzzy sets to estimate frequency of HazMat transport accidents	Accident analysis	Negative binomial regression
31	2009	Verma, M [46].	A cost and expected consequence approach to planning and managing railroad transportation of hazardous materials	Risk assessment	Bi-objective optimization model
32	2009	Bianco et al [18].	A bilevel flow model for hazmat transportation network design	Network design	Integer linear program- heuristic algorithm
33	2009	Paltrinieri et al [47].	Risk reduction in road and rail LPG transportation by passive fire protection	Risk (risk assessment, risk reduction, risk analysis, etc.)	Quantitative risk analysis and Simulation
34	2009	Samuel et al [48].	Frequency analysis of hazardous material transportation incidents as a function of distance from origin to incident location	Accident analysis	A temporal trend study (1995–2004) of 2145 HazMat incidents

Table 4: A classification of hazmat transportation articles. (et seq.)

No.	Year	Author	Name of the Article	Topic	Methodology
35	2009	Welles et al [49].	New York Hazardous Substances Emergency Events Surveillance (HSEES) data support emergency response, promote safety and protect public health	Accident analysis	The HSEES program is one of 14 state-based programs funded by the US Centers for Disease Control and Prevention that collects data on acute releases of non-petroleum hazardous substances and their public health impacts.
36	2009	Kheirkhah et al.,2009 [50].	Developing strategies to reduce the risk of hazardous materials transportation in Iran using the method of fuzzy swot analysis	Risk (risk assessment, risk reduction, risk analysis, etc.)	Fuzzy SWOT analysis
37	2009	Clark et al [51].	A New Approach to Hazardous Materials Transportation Risk Analysis: Decision Modelling to Identify Critical Variables	Risk (risk assessment, risk reduction, risk analysis, etc.)	A decision model empirically identifies the critical variables using an exploratory methodology for a large, highly categorical database involving latent class analysis (LCA), loglinear modelling, and Bayesian networking.
38	2010	Guo and Verma [52].	Choosing vehicle capacity to minimize risk for transporting flammable materials	Risk (risk assessment, risk reduction, risk analysis, etc.)	The proposed methodology makes use of the TNT equivalent approach, which is at best an approximation and not useful for analyzing toxic-materials.
39	2010	Verma and Verter [53].	A lead-time based approach for planning rail–truck intermodal transportation of dangerous goods	Routing Risk (risk assessment, risk reduction, risk analysis, etc.)	An iterative decomposition based solution methodology
40	2010	Lozanoa et al [54].	Analysis of hazmat transportation accidents in congested urban areas, based on actual accidents in Mexico	Accident analysis	An analysis of exposure to a hazmat accident during transportation within an urban environment
41	2010	Reniers et al [55].	Transportation Risk ANalysis tool for hazardous Substances (TRANS) – A user-friendly, semi-quantitative multi-mode hazmat transport route safety risk estimation methodology for Flanders	Risk (risk assessment, risk reduction, risk analysis, etc.)	Transportation Risk ANalysis tool for hazardous Substances (TRANS)
42	2010	Pradhanang et al [56].	Ant colony system based routing and scheduling for hazardous material transportation	Routing and scheduling	Ant colony system
43	2010	Androutsopoulos and Zografos [57].	Solving the bicriterion routing and scheduling problem for hazardous materials distribution	Routing and scheduling	An algorithm for determining the non-dominated scheduled route-paths. Alternatively a label setting algorithm is proposed for determining the k-shortest non-equivalent scheduled route-paths
44	2010	Dadkar et al [58].	Optimizing facility use restrictions for the movement of hazardous materials	Routing	A heuristic procedure that integrates Tabu Search and gradient based non-convex optimization was developed
45	2010	Yang et al [59].	A survey on hazardous materials accidents during road transport in China from 2000 to 2008	Accident analysis	The spatial distribution, the causes and consequences of the accidents related to the population (e.g., number of people killed, injured, evacuated, or poisoned), and environment elements were analysed
46	2010	Milazzo et al [60].	A study of land transport of dangerous substances in Eastern Sicily	Risk (risk assessment, risk reduction, risk analysis, etc.)	The application of TRAT-GIS code to the land transport of hazardous materials

Table 4: A classification of hazmat transportation articles. (et seq.)

No.	Year	Author	Name of the Article	Topic	Methodology
47	2010	Caramia et al [61].	On the selection of k routes in multi-objective hazmat route planning	Routing	The proposed approach first exploits the Martins' algorithm to find the set of efficient paths, and the k-means algorithm to partition the latter set into k classes of paths. Next, one path from each one of the k classes is chosen by heuristically solving the problem of selecting paths maximizing the total spatial dissimilarity.
48	2010	Dzemydiené and Dzindzalieta [62].	Development of Architecture of Embedded Decision Support Systems for Risk Evaluation of Transportation of Dangerous Goods	Risk (risk assessment, risk reduction, risk analysis, etc.)	An approach of designing the architecture of the system that uses wireless technologies for monitoring dynamic objects with implementation of probabilistic methods for evaluation of risk of possible types of scenarios of accident events which can occur in transportation of dangerous goods.
49	2010	Fabiano and Palazzi [63].	HazMat transportation by heavy vehicles and road tunnels: a simplified modelling procedure to risk assessment and mitigation applied to an Italian case study	Risk (risk assessment, risk reduction, risk analysis, etc.)	A novel analytical model for solving the ventilation design for both plane and sloping tunnels is presented.
50	2011	Jiaa et al [64].	A fuzzy-stochastic Constraint Programming Model for Hazmat Road Transportation Considering Terrorism Attacking	Risk (risk assessment, risk reduction, risk analysis, etc.)	A fuzzy-stochastic constraint programming-heuristic algorithm
51	2011	Chakrabarti and Parikh [65].	Route risk evaluation on class-2 hazmat transportation	Risk (risk assessment, risk reduction, risk analysis, etc.) Routing	HAMS-GPS QRA-Model Fault-tree analysis
52	2011	Kazantzi et al [66].	Risk informed optimization of a hazardous material multi-periodic transportation model	Network design	Monte Carlo Simulation Minimum cost transportation network
53	2011	Lozano et al [67].	Hazardous materials transportation in Mexico City: Chlorine and gasoline cases	Risk (risk assessment, risk reduction, risk analysis, etc.)	Estimation of accumulated population exposure
54	2011	Verma, M [68].	Railroad transportation of dangerous goods: A conditional exposure approach to minimize transport risk	Risk (risk assessment, risk reduction, risk analysis, etc.)	The assessment methodology, which includes Bayes Theorem and Logical Diagrams.
55	2011	Chakrabarti and Parikh [69].	Route evaluation for hazmat transportation based on total risk e A case of Indian State Highways	Risk (risk assessment, risk reduction, risk analysis, etc.)	Loss of Containment (LOC) probabilities and spillage probabilities for different route segments have been computed and compared
56	2011	Chakrabarti and Parikh [70].	Class-2 hazmat transportation consequence assessment on surrounding population	Risk (risk assessment, risk reduction, risk analysis, etc.)	ALOHA software
57	2011	Ellis,J [71].	Analysis of accidents and incidents occurring during transport of packaged dangerous goods by sea	Accident analysis	Records of dangerous goods releases from a US and a UK database for an 11-year period covering 1998–2008 were analyzed
58	2011	Pesic et al [72].	The model of air pollution generated by fire chemical accident in an urban street canyon	Accident analysis	Simulation

Table 4: A classification of hazmat transportation articles. (et seq.)

No.	Year	Author	Name of the Article	Topic	Methodology
59	2011	Ĺopez-Atamoros et al [73].	Development of a Relative Ranking Risk Index forRisk Assessment in the Transportation of LiquefiedPetroleum Gas in Mexico City's Metropolitan Area	Risk (risk assessment, risk reduction, risk analysis, etc.)	A relative ranking methodology was developed basedon a systematic study to elucidate the main causes of accidents in Mexico.
60	2011	Li and Leung [74].	Multi-objective route planning for dangerous goods using compromise programming	Routing	A novel methodology for the determination of optimal routes for DG transportation under conflicting objectives by means of the compromise programming approach. With the support of geographical information system (GIS).
61	2012	Xie et al [75].	A multimodal location and routing model for hazardous materials transportation	Routing	Mixed integer programming
62	2012	Verma et al [76].	A bi-objective model for planning and managing rail-truck intermodal transportation of hazardous materials	Routing	Tabu search
63	2012	Das et al [77].	Pareto frontier analyses based decision making tool for transportation of hazardous waste	Routing	Multi-objective optimization
64	2012	Reilly et al [78].	Game theory-based identification of facility use restrictions for the movement of hazardous materials under terrorist threat	Routing	Game theory
65	2012	Das et al [79].	A comprehensive risk assessment framework for offsite transportation of inflammable hazardous waste	Risk (risk assessment, risk reduction, risk analysis, etc.)	Computation of the impacts due to a volatile cloud explosion estimates the vulnerable population in terms of disability adjusted life years
66	2012	Chakrabarti and Parikh [80].	Applying HAZAN methodology to hazmat transportation risk assessment	Risk (risk assessment, risk reduction, risk analysis, etc.)	The method of hazard analysis technique, advocated by Kletz, can be usefully applied to hazmat transportation
67	2012	Ren et al [81].	Study on emergency response rank mode of flammable and explosive hazardous materials road transportation	Emergency response	A quantitative approach to determine the emergency response rank for hazmat road accidents
68	2012	Zhao et al [82].	Analysis of factors that influence hazardous material transportation accidents based on Bayesian networks: A case study in China	Accident analysis	The Bayesian network structure was built based on expert knowledge using Dempster–Shafer evidence theory, and the structure was modified based on a test for conditional independence.
69	2012	Wang et al [83].	Dual Toll Pricing for Hazardous Materials Transport with Linear Delay	Risk (risk assessment, risk reduction, risk analysis, etc.)	A Mathematical Program with Equilibrium Constraints (MPEC). Then we decompose the MPEC formulation into first-stage and second-stage problems. Separate methods are developed to solve each stage.
70	2013	Chakrabarti and Parikh [6].	Risk-based route evaluation against country-specific criteria of risk tolerability for hazmat transportation through Indian State Highways	Risk (risk assessment, risk reduction, risk analysis, etc.)	HAMS-GPS QRA-Model Fault-tree analysis

Table 4: A classification of hazmat transportation articles. (et seq.)

No.	Year	Author	Name of the Article	Topic	Methodology
71	2013	Chakrabarti and Parikh [84].	Using consequence e based hazard zone assessment for effective evacuation planning of vulnerable settlements along hazmat transport corridors through industrial city of Surat in western India	Emergency response	Gaussian dispersion model A software called ALOHA (Areal Locations of Hazardous Atmospheres)
72	2013	Reniers and Dullaert [85].	A method to assess multi-modal Hazmat transport security vulnerabilities: Hazmat transport SVA	Risk (risk assessment, risk reduction, risk analysis, etc.)	Multi-criteria analysis
73	2013	Tena-Chollet et al [86].	Development of a spatial risk assessment tool for the transportation of hydrocarbons: Methodology and implementation in a geographical information system	Risk (risk assessment, risk reduction, risk analysis, etc.)	GIS, Decision-making
74	2013	Gzara, F [87] .	A cutting plane approach for bilevel hazardous material transport network design	Network design	Bilevel programming, Cutting plane algorithm
75	2013	Samanlioglu, F [10].	A multi-objective mathematical model for the industrial hazardous waste location-routing problem	Routing	Multiple objective programming
76	2013	Desai and Lim [11].	Solution Time Reduction Techniques of a Stochastic Dynamic Programming Approach for Hazardous Material Route Selection Problem	Routing	Stochastic dynamic programming, Markov Decision
77	2013	Raemdonck et al [88].	Risk analysis system for the transport of hazardous materials	Risk (risk assessment, risk reduction, risk analysis, etc.)	An adapted approach which used historical accident data to calculate the risks of multi-modal hazmat transport in Flanders
78	2013	Liu et al [89].	Integrated risk reduction framework to improve railway hazardous materials transportation safety	Risk (risk assessment, risk reduction, risk analysis, etc.)	A Pareto-optimality technique is used to maximize risk reduction at a given level of investment
79	2013	Toumazis and Kwon [5].	Routing hazardous materials on time-dependent networks using conditional value-at-risk	Routing	A numerical method to determine an optimal departure time and an optimal route for a given origin–destination pair
80	2013	Desai and Lim [90].	Solution time reduction techniques of a stochastic dynamic programming approach for hazardous material route selection problem	Routing	Stochastic dynamic programming
81	2013	Chakrabarti and Parikh [91]	A societal risk study for transportation of class-3 hazmats – A case of Indian state highways	Risk (risk assessment, risk reduction, risk analysis, etc.)	A comparative evaluation of study routes was undertaken based on their societal risks presented in terms of F–N curves
82	2013	Shen et al [92].	Analysis on tank truck accidents involved in road hazardous materials transportation in China	Analysis on tank truck accidents	Detailed descriptions of 708 tanker accidents associated with hazmat transportation in China from 2004 to 2011 were analysed.
83	2013	Szeto, W.Y [93].	Routing and scheduling hazardous material shipments: Nash game approach	Routing and scheduling	A route-based maxmin problem over the space–time expanded network proposed in this paper. This route-based problem is decomposed into a link-based linear problem so that linear programming solution methods can be adopted.

Table 4: A classification of hazmat transportation articles. (et seq.)

No.	Year	Author	Name of the Article	Topic	Methodology
84	2014	Mahmoudabadi and Seyedhosseini [12].	Developing a chaotic pattern of dynamic Hazmat routing problem	Routing	The principle of Hazmat routing problem and fundamental concerns of chaos theory for defining dynamic variables are combined to develop a mathematical model.
85	2014	Saat et al [7].	Environmental risk analysis of hazardous material rail transportation	Risk (risk assessment, risk reduction, risk analysis, etc.)	A quantitative analytical approach to estimate the risk cost of transporting hazardous materials by rail
86	2014	Pradhanang et al [94].	Bi-objective decision support system for routing and scheduling of hazardous materials	Routing and scheduling	A meta-heuristic solution algorithm (a Pareto-based bi-objective optimization of hazardous materials vehicle routing and scheduling problem with time windows)
87	2014	Cappanera and Nonato [8]	The Gateway Location Problem: a cost oriented analysis of a new risk mitigation strategy in Hazmat Transportation	Risk (risk assessment, risk reduction, risk analysis, etc.)	Computation of the Pareto frontier given by the non-dominated solutions with respect to total risk and total cost on realistic instances taken from the literature
88	2014	Kang et al [95].	Generalized route planning model for hazardous material transportation with VaRand equity considerations	Routing	A Lagrangian relaxation framework to obtain an efficient solution method

3 Conclusion

Hazmat transportation is a crucial subject since the incidents caused by vehicles carrying hazmat resulted in huge amount of fatalities and environmental damage. Despite its importance, few countries take serious steps towards hazmat transportation risk and only these few countries have special departments about hazmat transportation.

Hazmat transportation has attracted the attention of researchers since early 1980s and it did not lose its popularity since then. Erkut et al. [1] prepared a chapter about hazmat transportation and one can found the hazmat transportation related articles literature review between 1982-2004 in that chapter.

In first part of our study, we figured out the importance of hazmat transportation with respect to fatalities and economical concerns. In second part, we prepared a literature survey about the hazmat transportation articles since 2005. 88 articles are examined in details, and the articles are classified according to publication year, hazmat class and the main concern of the article. Short briefs about risk, routing, routing and scheduling, network design, emergency response and accident analysis were given. We add two different subjects (emergency response and accident analysis) to Erkut et al.'s [1] classification since these two subjects have begun to be popular among authors who study hazmat transportation. At the end of our study, all the articles are given in a table according to 6 classification subject.

For the future works, the articles can be classified according to new study areas of the authors dealing with hazmat transportation. We also propose that every classification can be a unique subject to the researchers. Thus, authors can explain the subject in detail which helps to understand methodologies in the articles deeply. The articles which are published in journals are examined in this study. Future researchers can study on the books, websites, and conferences regarding hazmat transportation.

4 References

[1] Erkut E, Tjandra AS, Verter V. "Hazardous Materials Transportation". *Handbooks in Operations Research and Management Science*, 14, 539-621, 2007.

[2] The United Nations Economic Commission for Europe. "Part2 Classification". http://www.unece.org/fileadmin/DAM/trans/danger/publi/adr/adr2011/English/Part2.pdf (25.03.2014).

[3] U.S. Department of Transportation. "Hazmat Intelligence Portal". https://hip.phmsa.dot.gov/analytics/saw.dll?Dashboard (27.03.2014).

[4] Zhang JJ, Hodgson J, Erkut E. "Using GIS to Assess the Risks of Hazardous Materials Transport in Networks". *European Journal of Operational Research*, 121(2), 316-329, 2000.

[5] Toumazis I, Kwon C. "Routing Hazardous Materials on Time-Dependent Networks Using Conditional Value-at-Risk". *Transportation Research Part C*, (37), 73-92, 2013.

[6] Chakrabarti UK, Parikh JK. "Risk-Based Route Evaluation Against Country-Specific Criteria of Risk Tolerability for Hazmat Transportation Through Indian State Highways". *Journal of Loss Prevention in the Process Industries,* 26(4), 723-736, 2013.

[7] Saat MR, Werth CJ, Schaeffer D, Yoon H, Barkan CPL. "Environmental Risk Analysis of Hazardous Material Rail Transportation". *Journal of Hazardous Materials*, 264, 560-569, 2014.

[8] Cappanera P, Nonato M. "The Gateway Location Problem: a Cost Oriented Analysis of a New Risk Mitigation Strategy in Hazmat Transportation". *Procedia-Social and Behavioral Sciences*, 111, 918-926, 2014.

[9] Huang B. "GIS-Based Route Planning for Hazardous Material Transportation". *Journal of Environmental Informatics*, 8(1), 49-57, 2006.

[10] Samanlioglu F. "A Multi-Objective Mathematical Model for the Industrial Hazardous waste Location-Routing Problem". *European Journal of Operational Research*, 226(2), 332-340, 2013.

[11] Desai S, Lim G. "Solution Time Reduction Techniques of a Stochastic Dynamic Programming Approach for Hazardous Material Route Selection Problem". *Computers & Industrial Engineering*, 65(4), 634-645, 2013.

[12] Mahmoudabadi A, Seyedhosseini SM. "Developing a Chaotic Pattern of Dynamic Hazmat Routing Problem". *IATSS Research,* 37(2), 110–118, 2014.

[13] Shen X, Xie C, Liu H, Qui Z. "Model and Algorithm for Routing and Scheduling Problem in Hazardous Materials Transportation Network". *Journal of Networks*, 8(5), 1027-1034, 2013.

[14] Berman O, Verter V, Kara BY. "Designing Emergency Response Networks for Hazardous Materials Transportation". *Computers & Operations Research*, 34(5), 1374-1388, 2007.

[15] Juiping Xu, Jun Gang, Xiao Lei. "Hazmat Transportation Network Design Model with Emergency Response under Complex Fuzzy Environment". *Hindawi Publishing Cooperation Mathematical Problems in Engineering*, 2013, 1-22, 2013.

[16] Kara BY, Verter V. "Designing a Road Network for Hazardous Materials Transportation". *Transportation Science*, 38(2), 188–196, 2004.

[17] Erkut E, Alp O. "Designing a Road Network for Hazardous Materials Shipments". *Computers & Operations Research*, 34, 1389-1405, 2007.

[18] Lucio Bianco L, Caramia M, Giordani S. "A Bilevel Flow Model for Hazmat Transportation Network Design". *Transportation Research Part C*, 17(2), 175-196, 2009.

[19] Ronza A, V´ılchez JA, Casal J. "Using Transportation Accident Databases to Investigate Ignition and Explosion Probabilities of Flammable Spills". *Journal of Hazardous Materials*, 146(1-2), 106-123, 2007.

[20] Ghazinoory S, Kheirkhah AS. "Transportation of Hazardous Materials in Iran: A Strategic Approach for Decreasing Accidents". *Transport*, 23(2), 104-111, 2008.

[21] Fabiano B, Curro` F, Reverberi, AP, Pastorino R. "Dangerous Good Transportation by Road: From Risk Analysis". *Journal of Loss Prevention in the Process Industries*, 18(4-6), 403-413, 2005.

[22] Gheorghea AV, Birchmeier J, Vamanu D. "Comprehensive Risk Assessment for Rail Transportation of Dangerous Goods: A Validated Platform for Decision Support". *Reliability Engineering & System Safety,* 88(3), 247-272, 2005.

[23] Ogle RA, Morrison,DR, Viz MJ. "Emergency Response to a Noncollision Hazmat Release from a Railcar". *Process Safety Progress*, 24(2), 81-85, 2005.

[24] Boulmakoul A. "Fuzzy Graphs Modelling for HazMat Telegeomonitoring". *European Journal of Operational Research,* 175(3), 1514-1525, 2006.

[25] Bubbico R, Maschio G, Mazzarotta B. "Risk Management of Road and Rail Transport of Hazardous Materials in Sicily". *Journal of Loss Prevention in the Process Industries*, 19(1), 32-38, 2006.

[26] Schweitzer L. "Environmental Justice and Hazmat Transport: A Spatial Analysis in Southern California". *Transportation Research Part D: Transport and Environment*, 11(6), 408-421, 2006.

[27] Carotenuto P, Giordanib S, Ricciardelli S. "Finding Minimum and Equitable Risk Routes for Hazmat Shipments". *Computers & Operations Research*, 34(5), 1304-1327, 2007.

[28] Akgün V, Parekh A, Batta R, Rump CM. "Routing of a Hazmat Truck in the Presence of Weather Systems". *Computers & Operations Research*, 34(5), 1351-1373, 2007.

[29] Cozzani V, Bonvicini S, Spadoni G, Zanelli S. "Hazmat Transport: A Methodological Framework for the Risk Analysis of Marshalling Yards". *Journal of Hazardous Materials,* 147(1-2), 412-423, 2007.

[30] Carotenuto P, Giordani S, Ricciardelli S, Rismondo S. "A Tabu Search Approach for Scheduling Hazmat Shipments". *Computers & Operations Research,* 34(5), 1328-1350, 2007.

[31] Glickman TS, Erkut E, Zschocke MS. "The Cost and Risk Impacts of Rerouting Railroad Shipments of Hazardous Materials". *Accident Analysis and Prevention*, 39(5), 1015-1025, 2007.

[32] Verma M, Verter V. "Railroad Transportation of Dangerous Goods: Population Exposure to Airborne Toxins". *Computers & Operations Research,* 34(5), 1287-1303, 2007.

[33] Godoy, SM, Santa Cruz ASM, Scenna, NJ. "STRRAP System-A Software for Hazardous Materials Risk Assessment". *Reliability Engineering and System Safety,* 92(7), 847-857, 2007.

[34] Zhang J, Zhao L. "Risk Analysis of Dangerous Chemicals Transportation". *Systems Engineering-Theory & Practice*, 27(12), 117-122, 2007.

[35] Alumur S, Kara BY. "A New Model for the Hazardous Waste Location-Routing Problem". *Computers & Operations Research,* 34(5), 1406-1423, 2007.

[36] Michael G, Bell H. "Mixed Routing Strategies for Hazardous Materials: Decision-Making Under Complete Uncertainty". *International Journal of Sustainable Transportation*, 1(2), 133-142, 2007.

[37] Erkut E, Alp O. "Integrated Routing and Scheduling of Hazmat Trucks with Stops En Route". *Transportation Science,* 41(1), 107-122, 2007.

[38] Erkut E, Gzara F. "Solving the Hazmat Transport Network Design Problem". *Computers & Operations Research,* 35, 2234-2247, 2008.

[39] Dadkar Y, Jones D, Nozick L. "Identifying Geographically Diverse Routes for the Transportation of Hazardous Materials". *Transportation Research Part E, Logistics and Transportation Review*, 44(3), 333-349, 2008.

[40] Zografos KG, Androutsopoulos KN. "A Decision Support System for Integrated Hazardous Materials Routing and Emergency Response Decisions". *Transportation Research Part C: Emerging Technologies*, 16(6), 684-703, 2008.

[41] Planas E, Pastor E, Presutto F, Tixier J. "Results of the MITRA Project: Monitoring and Intervention for the Transportation of Dangerous Goods". *Journal of Hazardous Materials,* 152(2), 516-526, 2008.

[42] Bonvicin S, Spadoni G. "A Hazmat Multi-Commodity Routing Model Satisfying Risk Criteria: A Case Study". *Journal of Loss Prevention in the Process Industries,* 21(4), 345-358, 2008.

[43] Verter V, Kara BY. "A Path-Based Approach for Hazmat Transport Network Design". *Management Science,* 54(1), 29-40, 2008.

[44] Trépaniera M, Lerouxa M, Warina NM. "Cross-Analysis of Hazmat Road Accidents using Multiple Databases". *Accident Analysis and Prevention,* 41(6), 1192-1198, 2009.

[45] Qiaoa Y, Kerenb N, Mannana MS. "Utilization of Accident Databases and Fuzzy Sets to Estimate Frequency of HazMat Transport Accidents". *Journal of Hazardous Materials,* 167(1-3), 374-382, 2009.

[46] Verma M. "A Cost and Expected Consequence Approach to Planning and Managing Railroad Transportation of Hazardous Materials". *Transportation Research Part D: Transport and Environment,* 14(5), 300-308, 2009.

[47] Paltrinieri N, Landucci G, Molag M, Bonvicini S, Spadonia G. "Risk Reduction in Road and Rail LPG Transportation by Passive Fire Protection". *Journal of Hazardous Materials*, 167(1-3), 332-344, 2009.

[48] Samuel C, Keren N, Shelley MC, Freeman SA. "Frequency Analysis of Hazardous Material Transportation Incidents as a Function of Distance From Origin to Incident Location". *Journal of Loss Prevention in the Process Industries*, 22(6), 783-790, 2009.

[49] Welles WL, Wilburn RE, Ehrlich JK, Kamara JM. "New York Hazardous Substances Emergency Events Surveillance (HSEES) data Support Emergency Response, Promote Safety and Protect Public Health". *Journal of Loss Prevention in the Process Industries,* 22(6), 728-734, 2009.

[50] Kheirkhah AS, Esmailzadeh A, Ghazinoory S. "Developing Strategies to Reduce the Risk of Hazardous Materials Transportation in Iran Using the Method of Fuzzy Swot Analysis". *Transport*, 24(4), 325-332, 2009.

[51] Clark Renee M, Besterfield-Sacre, Mary E. "A New Approach to Hazardous Materials Transportation Risk Analysis: Decision Modeling to Identify Critical Variables". *Risk Analysis*, 29(3), 344-354, 2009.

[52] Guo X, Verma M. "Choosing Vehicle Capacity to Minimize Risk for Transporting Flammable Materials". *Journal of Loss Prevention in the Process Industries,* 23(2), 220-225, 2010.

[53] Verma M Verter V. "A Lead-Time Based Approach for Planning Rail–Truck Intermodal Transportation of Dangerous Goods". *European Journal of Operational Research*, 202(3), 696-706, 2010.

[54] Lozanoa A, Muñoza A, Antúna JP, Granadosa F, Guarnerosa L. "Analysis of Hazmat Transportation Accidents in Congested Urban Areas, Based on Actual Accidents in Mexico". *Procedia Social and Behavioral Sciences* 2(3), 6053-6064, 2010.

[55] Genserik L, Reniers L, Jongh K, Bob Gorrens, Dirk Lauwers, Maarten Van Leest, & Frank Witlox. "Transportation Risk Analysis tool for hazardous Substances (TRANS)-A User-Friendly, Semi-Quantitative Multi-Mode Hazmat Transport Route Safety Risk Estimation Methodology for Flanders". *Transportation Research Part D: Transport and Environment,* 15(8), 489-496, 2010.

[56] Pradhanang R, Taniguchi E, Yamada T. "Ant Colony System Based Routing and Scheduling for Hazardous Material Transportation". *Procedia Social and Behavioral Sciences*, 2(3), 6097-6108, 2010.

[57] Androutsopoulos KN, Zografos KG. "Solving the Bicriterion Routing and Scheduling Problem for Hazardous Materials Distribution". *Transportation Research Part C: Emerging Technologies*, 18(5), 713-726, 2010.

[58] Dadkar Y, Nozick L, Jones D. "Optimizing Facility Use Restrictions for the Movement of Hazardous Materials". *Transportation Research Part B: Methodological*, 44(2), 267-281, 2010.

[59] Yang J, Li F, Zhou L, Zhang L, Huang L, Bia J. "A Survey on Hazardous Materials Accidents During Road Transport in China From 2000 to 2008". *Journal of Hazardous Materials,* 184(1-3), 647-653, 2010.

[60] Milazzo MF, Lisi R, Maschio G, Antonioni G, Spadoni G. "A Study of Land Transport of Dangerous Substances in Eastern Sicily". *Journal of Loss Prevention in the Process Industries,* 23(3), 393-403, 2010.

[61] Caramıa M, Gıordan S, Iovanella A. "On the Selection of k Routes in Multiobjective Hazmat Route Planning". *IMA Journal of Management Mathematics*, 21(3), 239-251, 2010.

[62] Dzemydiené D, Dzindzalieta R. "Development of Architecture of Embedded Decision Support Systems for Risk Evaluation of Transportation of Dangerous Goods". *Technological and Economic Development of Economy*, 16(4), 654-671, 2010.

[63] Fabiano B, Palazzi E. "Hazmat Transportation by Heavy Vehicles and Road Tunnels: A Simplified Modeling Procedure to Risk Assessment and Mitigation Applied to an Italian Case study". *International Journal of Heavy Vehicle Systems*, 17(3-4), 216-236, 2010.

[64] Jiaa H, Zhanga L, Loua X, Cao H. "A Fuzzy-Stochastic Constraint Programming Model for Hazmat Road Transportation Considering Terrorism Attacking". *Systems Engineering Procedia,* 1, 130-136, 2011.

[65] Chakrabarti UK, Parikh JK. "Route Risk Evaluation on Class-2 Hazmat Transportation". *Process Safety and Environmental Protection,* 89(4), 248-260, 2011.

[66] Kazantzi V, Kazantzis N, Gerogiannis VC. "Risk Informed Optimization of a Hazardous Material Multi-Periodic Transportation Model". *Journal of Loss Prevention in the Process Industries,* 24(6), 767-773, 2011.

[67] Lozano A, Muñoz A, Macías L, Antún JP. "Hazardous Materials Transportation in Mexico City: Chlorine and Gasoline Cases". *Transportation Research Part C: Emerging Technologies,* 19(5), 779-789, 2011.

[68] Verma M. "Railroad Transportation of Dangerous Goods: A Conditional Exposure Approach to Minimize Transport Risk". *Transportation Research Part C: Emerging Technologies,* 19(5), 790-802, 2011.

[69] Chakrabarti UK, Parikh JK. "Route Evaluation for Hazmat Transportation Based on Total Risk e A Case of Indian State Highways". *Journal of Loss Prevention in the Process Industries,* 24, 524-530, 2011.

[70] Chakrabarti UK. Parikh JK., "Class-2 Hazmat Transportation Consequence Assessment on Surrounding Population". *Journal of Loss Prevention in the Process Industries,* 24(6), 758-766, 2011.

[71] Ellis J. "Analysis of Accidents and Incidents Occurring During Transport of Packaged Dangerous Goods by Sea". *Safety Science,* 49(8-9), 1231-1237, 2011.

[72] Pesic DJ, Blagojevic MD, Glisovic SM. "The Model of Air Pollution Generated by Fire Chemical Accident in an Urban Street Canyon". *Transportation Research Part D: Transport and Environment,* 16(4), 321-326, 2011.

[73] L´opez-Atamoros LG, Villag ´omez GF. "Development of a Relative Ranking Risk Index for Risk Assessment in the Transportation of Liquefied Petroleum Gas in Mexico City's Metropolitan Area". *Human and Ecological Risk Assessment*, 17(6), 1193-1209, 2011.

[74] Li R, Leung Y. "Multi-Objective Route Planning for Dangerous Goods Using Compromise Programming".*Journal of Geographical Systems,* 13(3), 249-271, 2011.

[75] Xie Y, Lu W, Wang W, Quadrifoglio L. "A Multimodal Location and Routing Model for Hazardous Materials Transportation". *Journal of Hazardous Materials,* 227-228, 135-141, 2012.

[76] Verma M, Verter V, Zufferey N. "A Bi-Objective Model for Planning and Managing Rail-Truck Intermodal Transportation of Hazardous Materials". *Transportation Research Part E: Logistics and Transportation Review*, 48(1), 132-149, 2012.

[77] Das A, Mazumder TN, Gupta AK. "Pareto Frontier Analyses Based Decision Making Tool for Transportation of Hazardous Waste". *Journal of Hazardous Materials*, 227-228, 341-352, 2012.

[78] Reilly A, Nozick L, Xu N, Jones D. "Game Theory-Based Identification of Facility Use Restrictions for the Movement of Hazardous Materials under Terrorist Threat". *Transportation Research Part E: Logistics and Transportation Review*, 48(1), 115-131, 2012.

[79] Das A, Gupta AK, Mazumder TN. "A Comprehensive Risk Assessment Framework for Offsite Transportation of Inflammable Hazardous Waste". *Journal of Hazardous Materials,* 227-228, 88-96, 2012.

[80] Chakrabarti UK, Parikh JK. "Applying Hazan Methodology to Hazmat Transportation Risk Assessment". *Process Safety and Environmental Protection*, 90(5), 368-375, 2012.

[81] Ren C, Yuan X, Wang J, Zhang X, Li Jin. "Study on Emergency Response Rank Mode of Flammable and Explosive Hazardous Materials Road Transportation". *Procedia Engineering*, 45, 830-835, 2012.

[82] Laijun Zhao, Xulei Wanga, Ying Qian. "Analysis of Factors That Influence Hazardous Material Transportation Accidents Based on Bayesian Networks: A Case Study in China", *Safety Science*, 50(4), 1049-1055, 2012.

[83] Wang J, Kang Y, Kwon C, Batta R. "Dual Toll Pricing for Hazardous Materials Transport with Linear Delay". *Networks and Spatial Economics*, 12, 147-165, 2012.

[84] Chakrabarti UK, Parikh JK. "Using Consequence-Based Hazard Zone Assessment for Effective Evacuation Planning of Vulnerable Settlements Along Hazmat Transport Corridors Through Industrial City of SURAT in Western India". *Journal of Loss Prevention in the Process Industries*, 26(5) 941-947, 2013.

[85] Reniers GLL, Dullaert W. "A Method to Assess Multi-Modal Hazmat Transport Security Vulnerabilities: Hazmat transport SVA". *Transport Policy*, 28, 103-113, 2013.

[86] Tena-Chollet, F, Tixier J, Dusserre G, Mangin JF. "Development of a Spatial Risk Assessment Tool for the Transportation of Hydrocarbons: Methodology and Implementation in a Geographical Information System". *Environmental Modelling & Software*, 46, 61-74, 2013.

[87] Gzara F. "A Cutting Plane Approach for Bilevel Hazardous Material Transport Network Design". *Operations Research Letters,* 41(1), 40-46, 2013.

[88] Raemdonck KV, Macharis C, Mairesse O."Risk Analysis System for the Transport of Hazardous Materials". *Journal of Safety Research*, 45, 55-63, 2013.

[89] Liu X, Saat MR, Barkan CP."Integrated Risk Reduction Framework to Improve Railway Hazardous Materials Transportation Safety". *Journal of Hazardous Materials,* 260, 131-140, 2013.

[90] Desai S, Lim GJ. "Solution Time Reduction Techniques of a Stochastic Dynamic Programming Approach for Hazardous Material Route Selection Problem". *Computers & Industrial Engineering,* 65(4), 634-645, 2013.

[91] Chakrabarti UK, Parikh JK. "A Societal Risk Study for Transportation of Class-3 Hazmats-A Case of Indian State Highways". *Process Safety and Environmental Protection,* 91(4), 275-284, 2013.

[92] Szeto WY. "Routing and Scheduling Hazardous Material Shipments: Nash Game Approach". *Transportmetrica B: Transport Dynamics,* 1(3), 237-260, 2013.

[93] Shen X, Yan Y, Li X, Xie C, Wang L. "Analysis on Tank Truck Accidents Involved in Road Hazardous Materials Transportation in China". *Traffic Injury Prevention*, 15(7), 762-768, 2014.

[94] Pradhananga R, Taniguchi E, Yamada T, Qureshi AG. "Bi-Objective Decision Support System for Routing and Scheduling of Hazardous Materials". *Socio-Economic Planning Sciences*, 48(2), 135-148, 2014.

[95] Kang Y, Batta R, Kwon C. "Generalized Route Planning Model for Hazardous Material Transportation with VaR and Equity Considerations". *Computers & Operations Research*, (43), 237-247, 2014.