Multi-Objective Optimization of Hazardous Material Transportation

By:
R. Pradhananga, E. Taniguchi & T. Yamada
Department of Urban Management
Kyoto University

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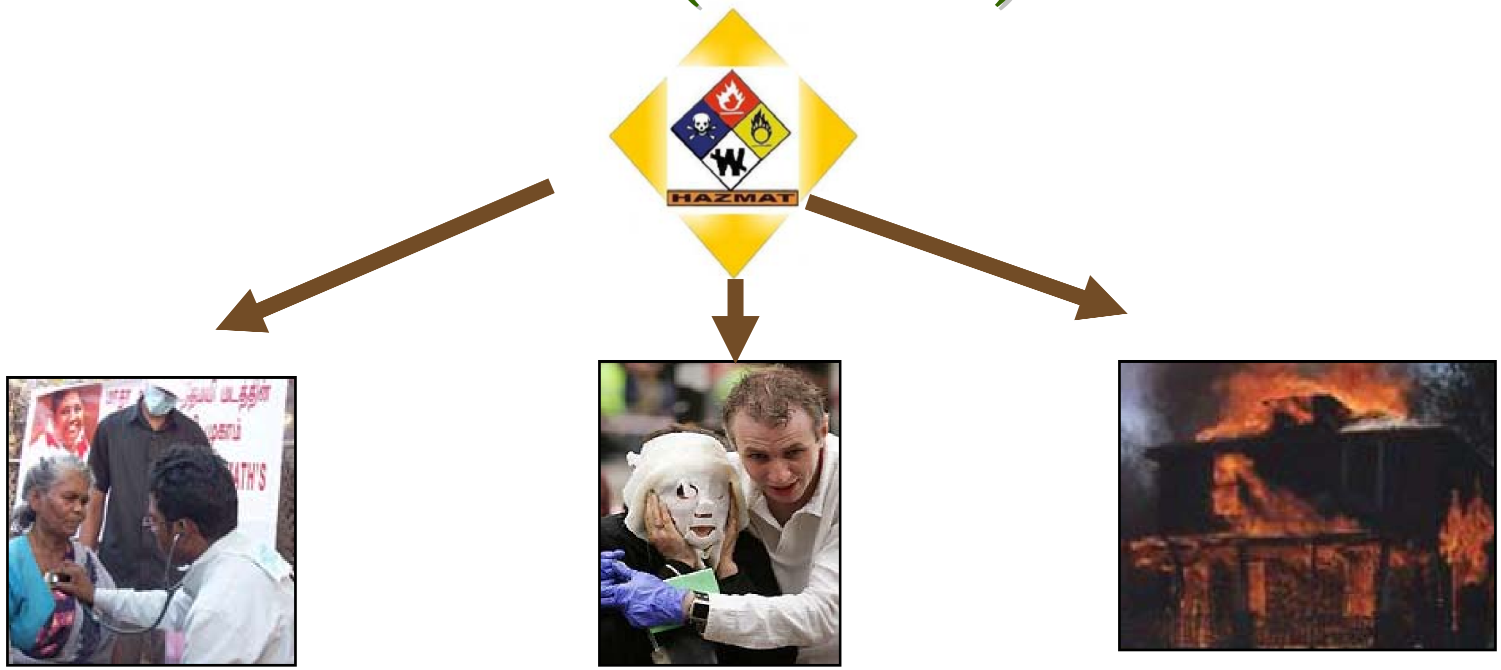
Hazardous material (Hazmat)



US Department of Transportation (2004):

"Hazardous material is a substance or material which has been determined by the Secretary of Transportation to be capable of posing an unreasonable Risk to Health, Safety, and Property when transported in commerce, and which has been so designated."

Hazmat Transportation

- **Cause**

  Advance Technology

- **Main Problems**
  - High volume shipments
  - Potential adverse condition

- **Hazmat transport accidents**
  - Relatively less number
  - High severity

Some Major Hazmat Accidents

- Wagon carrying fuel oil explosion in North Korea (2004)

  161 killed, 1300 injured

- Truck carrying gasoline explosion in Iran (2004)

  90 deaths, 114 injured & 6 vehicles crushed

(Source: UNEP-APELL Program)

- Truck carrying gasoline and diesel accident in Tokyo (3rd August 2008)

Source: The Japan Times Online

Objectives of the Study

To determine a set of pareto-optimal paths in which both the cost of transportation and associated risk are minimized with equal consideration.

Solution Techniques for Normal Vehicle Routing Problems with Time Windows (VRPTW)

Route Choice:

Shortest Path Techniques

- Dijkstra Method
- Adapted least path method
- Ant routing method

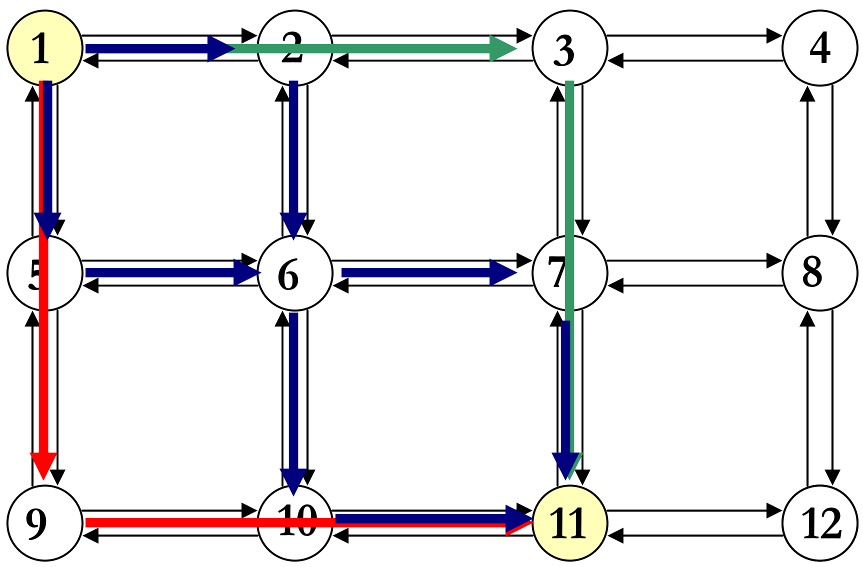
Routing:

Order of customer to be visited

- Exact Algorithm
- Meta-heuristic Algorithms

Genetic Algorithm, Simulated Annealing, Tabu Search, Ant Algorithm

Normal VRPTW vs. Hazmat VRPTW



Route Choice:

Shortest travel time path or Lowest risk path ???

Route choice and routing process should be carried out simultaneously as a single process.

Mathematical Model

Objective Function

Minimize

$$Z(X,Y) = [Z_1(X,Y) \quad Z_2(X,Y) \quad Z_3(X,Y)]^T$$

$Z_1 =$ Total number of Vehicles in Use

$Z_2 =$ Total Travel Time

$Z_3 =$ Total Risk Exposure

$X =$ Order of Customers to be visited

$Y =$ Order of Paths to be followed

Travel Time Calculation

$$Z_2(X,Y) = \sum_{l=1}^{m} C_t(x_l, y^p_{n(i),n(i+1)}) \quad \text{for} \quad n(i) \in x_l$$

Average Travel Time from *n(i)* to *n(j)* using path p

Unloading Time

$$C_t(x_l, y^p_{n(i),n(i+1)}) = \sum_{\substack{i=0 \\ j=i+1}}^{N_l} (\overline{T}^p_{n(i),n(j)} + t_{c,n(j)} + t_{w,n(j)}) \quad \text{where} \quad p \in P$$

Waiting Time

$$t_{w,n(j)} = (e_{n(j)} - t_{l,n(j)}) \quad \textbf{\textit{if}} \quad t_{l,n(j)} < e_{n(j)}$$

$$0 \quad \textbf{\textit{otherwise}}$$

Risk Exposure Calculation

$$Z_3(X,Y) = \sum_{l=1}^{m} R_l(x_l, y^p_{n(i),n(i+1)}) \quad \text{for} \quad n(i) \in x_l$$

$$R_l(x_l, y^p_{n(i),n(i+1)}) = \sum_{\substack{i=0\\ j=i+1}}^{N_l} R^p_{n(i),n(j)} \quad \text{where} \quad p \in P$$

Probability of explosive accident

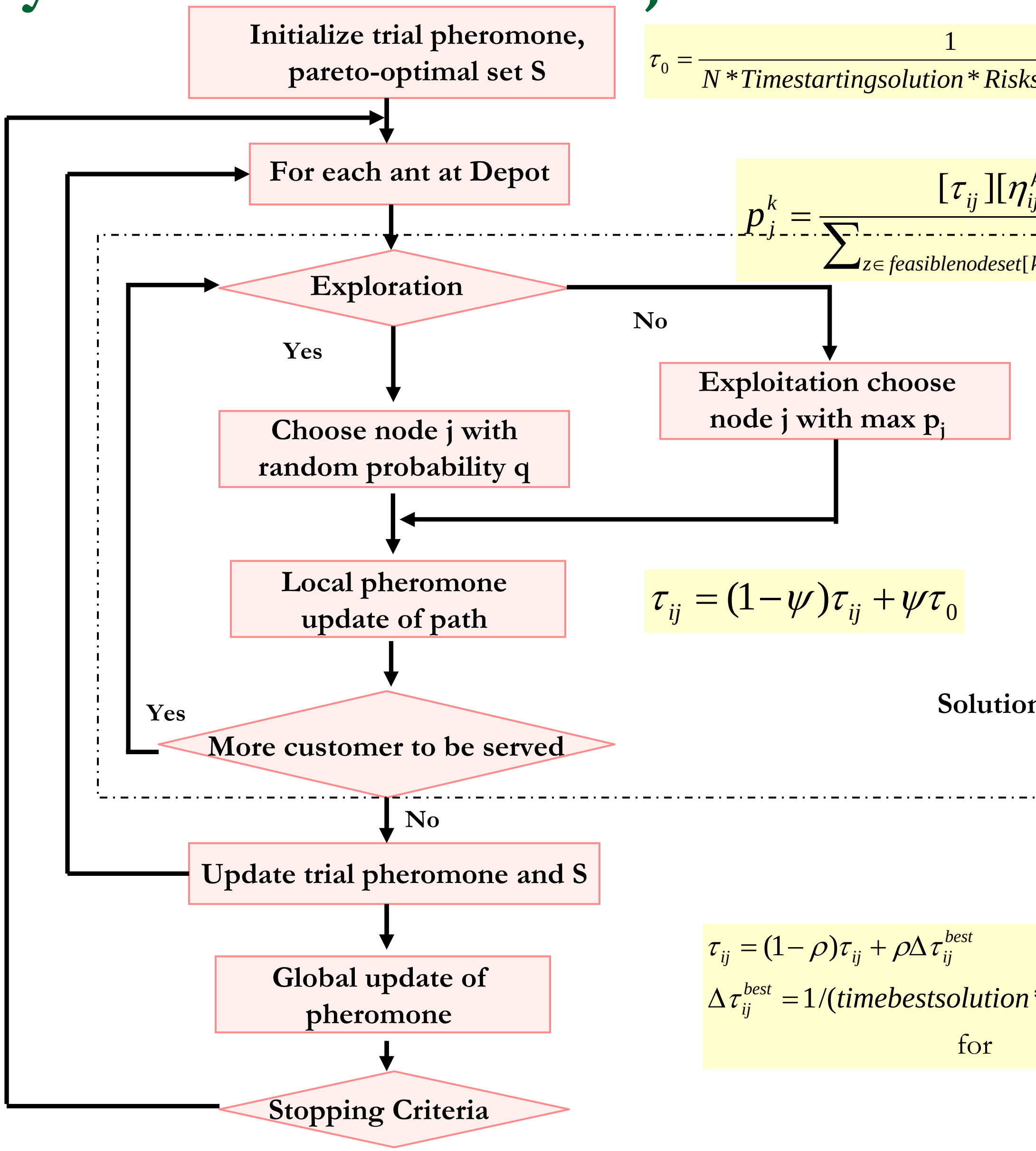
Exposure Population

$$R^p_{n(i),n(j)} = \sum_{v(i)v(j)\in p} AR_{v(i)v(j)} \, EP_{v(i)v(j)}$$

Ant Colony System for Multi-Objective VRPTW

- **MACS-VRPTW Gambardella et.al, 1999**
  2Ant colonies , ACS-VEI, ACS-TIME

- **Baran et.al, 2003**
  Single Ant colony



$$\tau_0 = \frac{1}{N * Timestartingsolution * Riskstartingsolution}$$

$$p_j^k = \frac{[\tau_{ij}][\eta_{ij}^{\beta}][\nu_{ij}^{\mu}]}{\sum_{z \in feasiblenodeset[k]} [\tau_{iz}][\eta_{iz}^{\beta}][\nu_{iz}^{\mu}]}$$

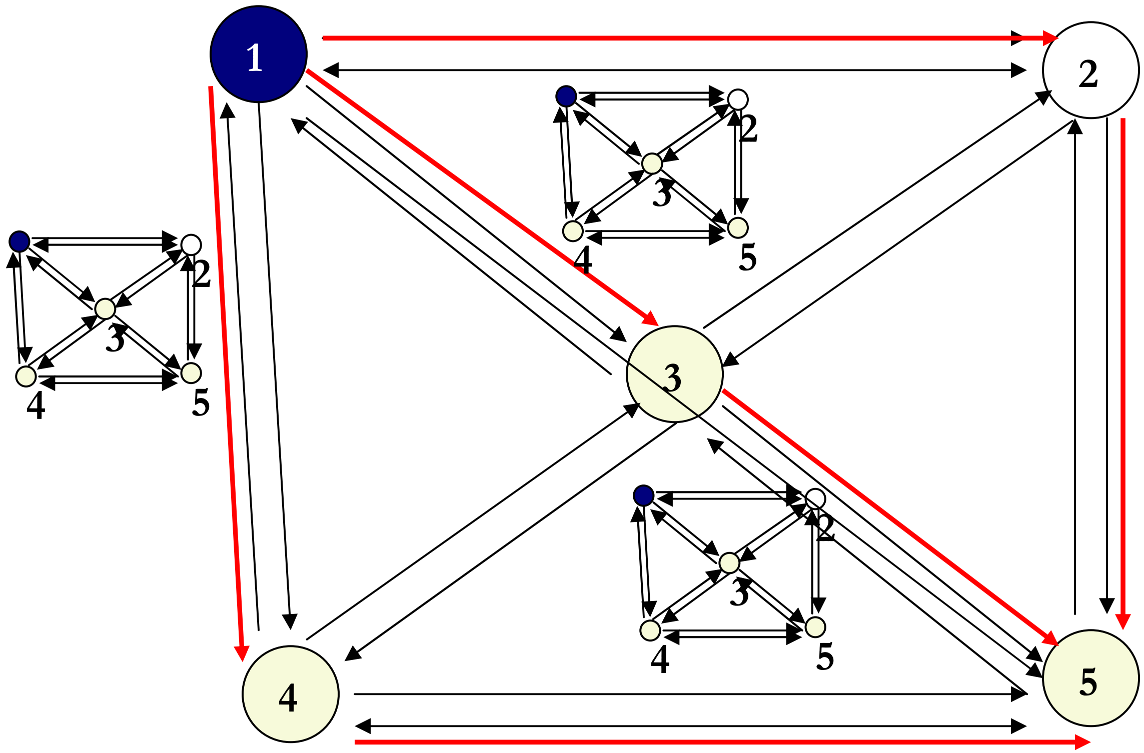
$$\tau_{ij} = (1-\psi)\tau_{ij} + \psi\tau_0$$

$$\tau_{ij} = (1-\rho)\tau_{ij} + \rho\Delta\tau_{ij}^{best}$$

$$\Delta\tau_{ij}^{best} = 1/(timebestsolution * riskbestsolution)$$

$$\text{for} \quad ij \in bestsolution$$

Proposed Ant Colony System



1 - Depot

3,4,5 – Customer nodes

2 – Non customer node

- **Previous ACS**

Shortest path is already known. One path for one node to be considered.

- **Proposed ACS**

Network addition for each feasible node-> Complicate problem size

Labeling Algorithm

- Obtain a set of dominant paths P that can only contribute for optimal routing for each node pair.

- Steps:

❖ Label Initialization

-Define Set of Unprocessed labels->L and Useful labels ->U

L_{N1}={res(L), t(L), r(L), {vis(L)}, pre(L), clabel}

{ 2	56	20.46	{0 2 0 1 1 2 1 1 1 2 2 2}	13	26}

res(L)-> resident vertex node

t(L)-> Travel time at label L

r(L)-> Risk at label L

{vis(L)}-> A vector showing possibility of visit from resident vertex to all nodes

pre(L)- >Preceding label of label L

clabel -> Current label

Labeling Algorithm (Contd….)

❖ Label Selection

- Select label L_i with minimum time among set L to process

❖ Dominance Rule

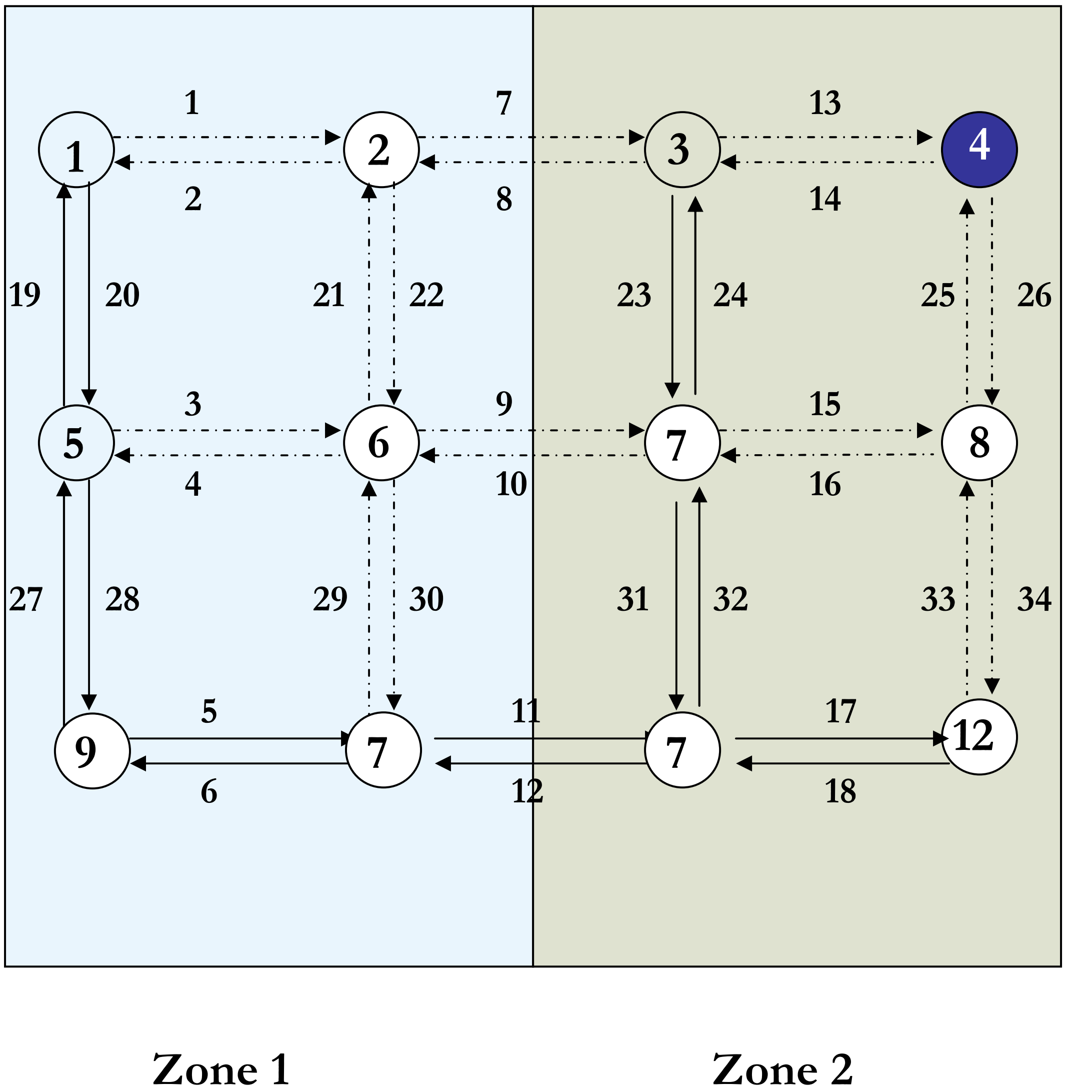
- For labels with same resident nodes related with L_i
- If $t(L_2) \geq t(L_1)$ & $r(L_2) > r(L_1)$ OR

  $t(L_2) > t(L_1)$ & $r(L_2) = r(L_1)$ -> L_1 dominates L_2
- Remove all dominated labels from U

❖ Path Extension

-Create new labels from all labels with resident node as of L_i to all nodes that are feasible for visit (vis value 1)

Test Network



Distribution of Gasoline

4 Depot

2 Customer

Type-1 Link (20Km/hr)

Type-2 Link (15Km/hr)

Potential Impact Area :

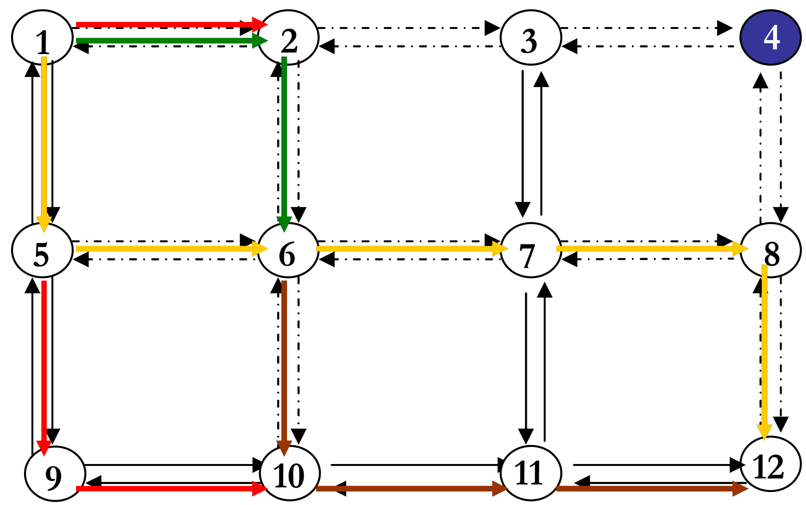
0.5Km in all direction

2006 Accident data from :

http://www.unescap.org/ttdw/roadsafety/Reports2007/Japan_RSpresentation

Paths by Labeling Algorithm vs. Other Shortest Path Approach

From	To	Algorithm	Path	Travel time (min)	Risk (in 1000)
1	2	Dijkstra for time	1->2	16	4.52
1	2	Dijkstra for risk	1->2	16	4.52
1	2	Labeling	1->2	16	4.52
1	12	Dijkstra for time	1->5->9->10->11->12	60	26.92
1	12	Dijkstra for risk	1->2->6->7->8->12	80	24.24
1	12	Labeling	1->5->9->10->11->12	60	26.92
			1->5->6->10->11->12	68	25.63
			1->2->6->10->11->12	72	24.99
			1->5->6->7->8->12	76	24.88
			1->2->6->7->8->12	80	24.24



Dominant set of Paths from node to node-> P small for nearby nodes but increased for farther nodes.

Approach	Dijkstra	Labeling Alg.
No. of Paths	144	250

73.61% increase

What Next?

- **Ant Colony System** with simultaneous route choice and routing for minimizing both time and risk.

- Set of **pareto-optimal paths** with equal consideration of multiple objectives involved.

- Results-> Expected to provide more precise alternative solutions.

Thank You