

Improvement/ Remedies for the Efficiency of Railways Transportation in Times of Natural Calamities

Alok Saxena¹, B.K.Singh²

Assistant Professor, Department of Mathematics, Moradabad Institute of Technology, Moradabad, Uttar Pradesh, India¹

Professor & Head, Department of Mathematics, IFTM University, Moradabad, Uttar Pradesh, India²

Abstract—Today a number of options are available for transportation like roadways, railways, subway etc. Among these available options, a railway is the most complicated system to study because of the problems that the railway management has to face due to the sudden occurrence of any accident or natural calamity etc. that may lead to the delay of entire network of railways. In this paper we have designed a model to improve the efficiency of railways transportation especially in the times of emergency like any natural calamity.

Keywords— railways, calamities, nodes, transportation

I. INTRODUCTION

In the present scenario, railways are the largest system to transport the passengers as well as the goods. The purpose of this research is to improve the efficiency of transportation and to make the safest form of transportation in the worst situations like natural calamities etc. At the time of a sudden natural calamity, reaction and response time act like major and important variables. During natural calamities, a transportation system generally makes a random route diversion plan to overcome the problem but sometimes nodes are formed and affect the exit points for all the vehicles. Therefore, the most complicated situation is formed. Many transportation engineers prefer a route guidance map as a key to divert traffic from the natural calamity affected area. During a natural calamity, uncertainty in the network makes the System efficiency crucial. As, vehicles entering the system during external influence or natural disaster add load to the road network which is to be minimized to improve the system efficiency.

II. RELATED LITERATURE

Research studies of route choices and user behaviour during a natural calamity have seen noticeable in recent years. Banverket(2009) discussed the two most traffic-intensive hours per day, 34% of the entire Swedish railway network is considered saturated with a low average speed and high sensitivity to

disturbances. Cordera et al.(2009) presented a model where multi-criteria evaluation is applied to possible zones for introducing a bike lane in Cantabria. Corman, F., D'Ariano, A., Pacciaarelli, D., Pranzo, M.(2010) introduced a centralized versus distributed systems to reschedule trains in two dispatching areas. Fang, Z., Q. Li, L. D. Han, and D. Wang.(2011) proposed pedestrian waiting –time model for improving space-time use efficiency in stadium evacuation scenarios. Pel, A. J., M. C. J. Bliemer, and S.P. Hoogen doorn (2012) provided a review on travel behaviour modelling in dynamic traffic simulation models for evacuations. Mishra, et al. (2012) modeled intermodal connectivity as a measure to gauge the effectiveness of an intermodal transportation system. In this work, the focus was to compare connectivity of transit system performance at line, transfer facility, local and regional levels. Bish, D R, H D Sherali, and A G Hobeika(2013) discussed an optimal evacuation planning using staging and routing. Roberto, S., Jose, L. M., Angle, I.(2014) presented a decision making system for stopping high speed trains during emergency situations.

III. PROBLEM FORMULATION

In case of a railway network the natural calamity affected area gets distributed into three zones/levels: affected area, restricted area and safe area (see figure 1). When the natural calamity takes place in a railway network, all the trains get diverted immediately from the first level i.e. affected area and no backward movement is allowed in this level. When the trains of the affected area enter into the second level (restricted area), there are too many possible restrictions like route diversion and no railway lines etc. In the last level of network known as safe area no restriction occurs and all the trains can move according to the pre decided planes. Inman (1978), Chen et al (2001) Mathew et al (2006) Haung et al (2010) and Bish et al

(2012) also presented a literature on congestion theories for highway networks.

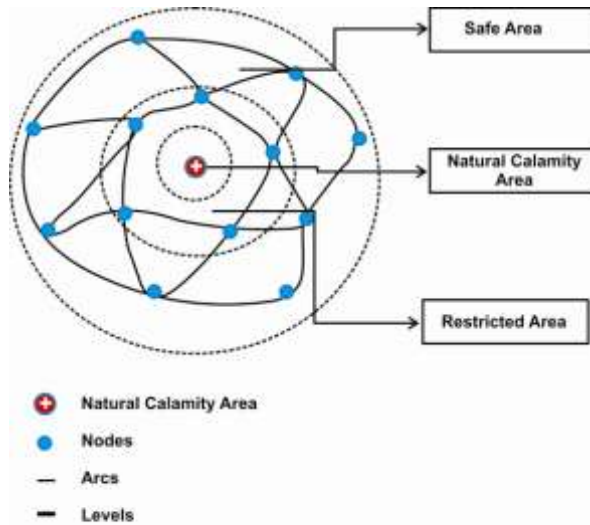


Figure 1 – Typical levels in a Natural Calamity

In this paper we present a model for more quick and efficient movement from affected area to safe area through restricted area. Sometimes in the restricted area all the trains meet at a single point is called choke point or node. These points are not fixed for a network and have a dynamic property according to the diversion. This paper presents a mathematical model for identifying choke points. If a link flow f_a , over the time interval t_0 is to pass through a node N , the arrival rate b_a over that time interval is given by,

$$f_a = \sum_{a=1}^m b_a * t_0 \quad (1)$$

$$f_a = f_0 + \Delta f_t \quad (2)$$

Where, f_0 = Initial link free flow per unit time, Δf_t = incidental change in flow of link due to surplus system loading within interval t_0 .

If the ratio of link flow to total outflow (β) is known, we can calculate the loading characteristics of the succeeding links by computing the departure rates from the node. Now from equation (1) -

$$f_a = \sum_{i=1}^m b_a * t_0 \quad (3)$$

$$a \forall m; \text{ and } a \neq 0$$

$$\beta_a = \frac{f_a}{\sum_{i=1}^m f_a} \quad (4)$$

The term β_a will change due to the state of the network: free flow versus jammed condition. Under the conditions of free flow, the outflow split to succeeding arcs is somewhat stable as user choices are unconstrained. This matches with increasing values of β_a beyond the stability state and as departure rate, d_N from node approaches zero. We suppose this link's desirability index as its values approach 1, the more the likelihood of user to choose an alternate way. Desirability index is an indicator of potential choke points. Thus, if flow conservation is maintained through any given node N , Equation (5) below can show that inflow to node $\sum b_a$ must equal to outflow from node.

Consider a directed network with origin, O close to natural calamity affected area as shown in figure 2. Let A represent the total links in the networks with $N = \{N_1, N_2, N_3, \dots, N_n\}$ number of nodes. In the event of a natural calamity, the movement goes towards major evacuation exit nodes E, F and G . The exit paths from O to E are $O \rightarrow N_1 \rightarrow N_5 \rightarrow N_7 \rightarrow E$ or $O \rightarrow N_3 \rightarrow N_{10} \rightarrow E$. We have chosen two O-D pair network for simplicity. O- D pair in this problem consists of $O \rightarrow E$ and $O \rightarrow F$ which indicate the path between the O and the exit nodes. Let a be any arc (where $a \in A$) with flow, X_a and travel time $t_a = \{t_1, t_2, t_3, \dots, t_A\}$.

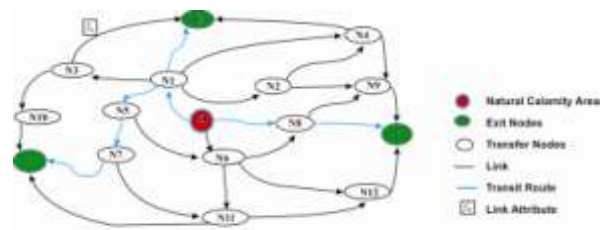


Figure 2 – A Typical Railway network

For free flow conditions $O \rightarrow E$,

$O \rightarrow N_1 \rightarrow N_3 \rightarrow N_{10} \rightarrow E > O \rightarrow N_1 \rightarrow N_5 \rightarrow N_7 \rightarrow E$ if and only if

$$t_{0-1} + t_{1-3} + t_{3-10} + t_{10-E} > t_{0-1} + t_{1-5} + t_{5-7} + t_{7-E}$$

For all arcs, the best solution to minimize arc flow is at the point where additional delay due to transit activities, Δt_a equates to nothing significant. In other word evacuation is optimal and efficient at $\Delta t_a = 0$ or $t'_a = t_a$ which also satisfies the condition of free flow. The best solution for an O-D pair may not be optimal for achieving the desired system efficiency for evacuation. So, further iterations to find the optimal values for the travel time that is acceptable to the users (like acceptable system delay due to evacuation) as well as satisfies system requirements (such as evacuation time goals). In order to estimate travel time considering user choices, we must find a reliable way to predict the user choices in a given combination of evacuation paths, k . According to Jha et al (2008), the travel cost C associated with user choices can be estimated using-

$$C_k^{OD} = \sum_a t'_a \delta_{a,k}^{OD} \quad (5)$$

Where,

C_k^{OD} = the total travel time (sum of individual link travel time, t'_a) on k^{th} path connecting to origin O and the destination D .

Therefore along a path, k^{th} objective functions are two-fold: (1) minimize total travel time, T_k required to traverse all the three neighborhoods to safety and in the process enhance time of evacuation throughout network; and (2) minimize link flow to reduce the likelihood of potential choke points from developing earlier user choices and better distribution of load throughout the network. This can be expressed as

$$\min Z = \sum_a x_a * t_a \quad x_a \quad (6)$$

Subject to

$$\sum_{k=1}^m f_k^{OD}, \sum_{k=1}^m \beta_{ak}^{OD} \quad O, D \quad \text{path limit constraints} \quad (7)$$

$$\sum_{i=1}^m \beta_{ak}^{OD} \leq 1 \quad \text{Desirability constraint} \quad (8)$$

$$f_k^{OD}, \beta_{ak}^{OD} \geq 0 \quad \text{Non negative constraint} \quad (9)$$

$$x_a = \sum_O \sum_D \sum_k f_k^{OD} * \delta_{ak}^{OD} \quad (10)$$

$$d_N = \sum_{i=1}^m b_a \quad \text{Node integrity} \quad (11)$$

Where,

t'_a = travel time of link $a(t_a)$ plus differential travel time due to transit activities, Δt_a .

f_k^{OD} = the flow on k^{th} path connecting the origin O and destination D

f_{kT}^{OD} = the flow on path k connecting transit origin O and the destination D pair

x_a = the link flow

r_a = the link reliability, a which defines t_a (link performance function, $t'_a(x_a) * r_a$)

$$\delta_{a,k}^{OD} = \begin{cases} 1 & \text{if link is part of path k of } O-D \text{ Pair} \\ 0 & \text{Otherwise} \end{cases}$$

$$\tau_{a,k}^{OD} = \begin{cases} 1 & \text{if link is part of transit route within an } O-D \text{ Pair} \\ 0 & \text{Otherwise} \end{cases}$$

Similarly we denote a parallel set of parameters to account for non-drivers who must also evacuate. As defined previously, the terms f_{ak}^{OD} , α_{ak}^{OD} and δ_{ak}^{OD} are flow per unit time along the connectable transit route (i.e. transit line plus transfer station); desirability function that calculate user choice along the given path; and binary function that determine if user path tends to transit access point respectively. Transit loads are defined by normal transit loads plus surplus loads due to user choices and influx demand caused by desire to leave at the same time. The later element also contributes to the total time needed to evacuate all units from disaster area. The base flow for

this concept is the ridership for each transit mode. This denotes the normal number of users per unit time.

The difference between vehicular and transit modes is that vehicular mode goes through a defined path (the roadway), the transit mode has at least three distinct stages of movement to define a full path; user path, access points and transfer point. User path is unpredictable and not easy to define. However, it is a assumption to expect that the user will be attracted to the nearest 'known' transit access point. Therefore, a true account of all transit users at transit access points could be an onerous proposition. Even though capturing exact quantities of flow will improve the accuracy of the formulation of this problem, we are fairly confident that there are sufficient pattern of user path to validate the outcomes of this analysis.

We can express the objective function as,

$$\min Z = \sum_a x_a * t_a + \Delta t_a x_a * \tau_{a,k}^{OD} \quad (12)$$

Subject to the condition,

$$\sum_a f_k^{OD} = O, D \quad \forall O, D \quad (13)$$

$$f_k^{OD} \geq 0 \quad \forall k, O, D \quad (14)$$

$$x_a = \sum_O \sum_D \sum_k f_k^{OD} * \delta_{ak}^{OD} \quad (15)$$

To Expand equation (6) to include transit elements of the network, we have

$$x_a = \sum_O \sum_D \sum_k f_k^{OD} \delta_{ak}^{OD} + f_{kT}^{OD} \tau_{ak}^{OD} \quad (16)$$

IV. CONCLUSION

The above presented model helps us not only to solve the complex problems present in the hypothetical cases but the formulation given in this paper can also solve an additional capacity constraint for the exit node. Though large scale data collection and computing systems are required in applying this model to real life network problems yet we are sure enough that this model will help the railway management in calculating where to allocate resources during a natural calamity for more quick and efficient

movement from affected area to safe area through restricted area.

REFERENCES

- [1] Schöbel, A. (2009). Capacity constraints in delay management. *Public Transport*, 1(2), 135-154.
- [2] Corman, F., D'Ariano, A., Pacciarelli, D., Pranzo, M. (2009). Evaluation of green wave policy in real-time railway traffic management. *Transportation Research: Part C* 17 (6), 607-616.
- [3] Budai, G., Maróti, G., Dekker, R., Huisman, D., Kroon, L. (2010). Rescheduling in passenger railways: the rolling stock rebalancing problem. *Journal of Scheduling* 13, 281-297.
- [4] Corman, F., D'Ariano, A., Pacciarelli, D., Pranzo, M. (2010). A tabu search algorithm for rerouting trains during rail operations. *Transportation Research Part B* 44 (1), 175-192.
- [5] Xie, M. Q., Ho, T. K., & Mao, B. H. (2010). Modeling circulation of train-set with multiple routing. *Journal of Transportation Systems Engineering and Information Technology*, 10(3), 50-57.
- [6] Vasirani & Ossowski (2011) A computational market for distributed control of urban road traffic systems. *IEEE*, 12(2).
- [7] Min, Y.-H., Park, M.-J., Hong, S.-P., Hong, S.-H. (2011). An appraisal of a column- generation based algorithm for centralized train-conflict resolution on a metropolitan railway network. *Transportation Research Part B* 45 (2), 409-429.
- [8] Mishra, S., T. Welch, and M.K. Jha (2012). Performance Indicators for Public Transit Connectivity in Multi-Modal Transportation Networks, *Transportation Research, Part A*, 46(7), 1066-1085.
- [9] Dollevoet, T., Huisman, D., Schmidt, M., & Schöbel, A. (2012). Delay management with rerouting of passengers. *Transportation Science*, 46(1), 74-89.
- [10] Apivatanagul, P., R.A. Davidson, and L.K. Nozick. (2012) Bi-level optimization for risk- based regional hurricane evacuation planning. *Natural Hazards* 60:2, 567-588
- [11] Bish D. R., E.P. Chamberlayne, and H.A. Rakha. (2012) Optimizing Network Flows with Congestion-Based Flow Reductions. *Networks and Spatial Economics* Networks and Spatial Economics, 1-24.
- [12] Bish, D. R., H. D. Sherali, and A. G. Hobeika. (2013) Optimal evacuation planning using staging and routing. *Journal of the Operational Research Society*.