OPTIMALTRAFFIC PLANNING FOR EFFICIENT EVACUATION

S. R. Khadka

Central Department of Mathematics,

Institute of Science and Technology,

Tribhuvan University, Kathmandu, Nepal

Email Address: shreeramkhadka@gmail.com

Abstract

Efficient traffic planning during evacuation in emergency has been important issue. The planning based on research significantly improves the quality of the emergency management. In this paper, we discuss on both optimization and simulation approaches of the traffic planning. Both approaches have been extensively studied in the literature with efficient softwares.

Keywords: *Traffic planning, evacuation planning, emergency management*

1. Introduction

Emergency management deals with natural and man-made disasters with the goal of saving lives and protecting property during emergencies and disasters. The management based on research upgrades the quality. Nepal has been a vulnerable place for disasters such as earthquake, flood, land slide, explosion of glacial lakes, fire etc. The country has been suffering from such disasters like flood, land slide, fire every year and has been losing a good number of lives and property. Emergency management does not avert or eliminate the threats themselves. However, the study and prediction of the threats based on research substantially reduce the risk.

One of the most important issues in the emergency management is to plan effective transportation mode which can evacuates within a reasonable time. The traffic planning during the response phase of the emergency management has been extensively studied in the literature on both optimization as well as simulation approaches, see [6].

In this paper, we describe both optimization and simulation approaches in brief that exist in the literature.

The organization of the paper is as follows. We describe about emergency management in Section 2, evacuation planning in Section 3, traffic planning in Section 4. We give a brief report of the optimization and simulation approaches for the traffic planning. The last section concludes the paper.

2. Emergency Management

Emergency management includes prevention, planning, response and recovery (PPRR) in order to lessen the impact of disasters.

Prevention is designed to provide permanent protection from disasters though not all disasters can be prevented. The risk of loss can be lessened. It is not worthy that the Hyogo Framework has been adopted on 2005 by 168 Governments as a 10-year global plan for natural disaster risk reduction.

Preventative measures (local or international levels) are to be taken into account during the construction e.g. houses, road, hydro power etc.

Planning or mitigation focuses on preparing equipment and procedures for use when a disaster occurs. Planning measures can take many forms including the construction of shelters, efficient transportation, implementation of an emergency communication system, installation of warning devices, supply of necessary logistics, creation of back-up life-line services (e.g., power, water, sewage), and rehearsing evacuation plans.

The response phase focuses on search and rescue quickly by national or international agencies and organizations with fulfilling the basic needs of the affected population. The objective of response is to save lives and to protect property as soon as possible in an efficient manner. This takes place either of a shelter in place or an evacuation. In a shelter-in-place scenario, a population would be prepared to fend for themselves in their shelter for many days without any form of outside support. In an evacuation, a population is evacuated to a safety zone using efficient and available mode of transportation with necessary logistics. Large disasters that overwhelm local capacity require an effective coordination with efficient communication system among the local emergency management agency, national and or international organizations, volunteers and several donors.

The recovery phase starts after the immediate threat to bring the affected area and or population back to some degree of normalcy.

In this paper, we consider the planning phase focused on efficient traffic planning. This is an emerging field of research as well as implementation of developed evacuation planning procedures to a particular location. The efficient planning procedures and their effective implementation to a particular location demand a sincere and continuous group effort. We require a number of case studies, awareness program, rehearsals and implementation of an efficient and suitable procedure.

3. Evacuation Planning

Evacuation is defined as the removal of lives and/or property from the disaster zone to the safety zone as quickly as possible. Evacuation planning includes the estimation of the evacuation time, propagation time of the disaster, the potential risk, and location of the safety zone and the reorganization of the traffic routes from the disaster zone to the safety zone.

Evacuation planning depends on the disaster source (flood, explosion, hurricane, land slide etc.),the disaster zone (building, city, region or vehicle), distribution (age, gender, disability) and behavior of evacuees, safety zone and emergency facilities. The time evacuation completes is called the evacuation time. The evacuation time consists of the recognition of emergency situation time, decision time and exit time. The exit time of all the evacuees is called the clearance time of the evacuees.

The time that a lot of evacuees take from the disaster zone to the safety zone is called the exit time. The exit time depends on the availability of traffic routes, efficient traffic planning and behavior of evacuees during evacuation.

The recognition of emergency situation time and the decision time depend on behaviors and organization of the evacuators and evacuees. Thus, the exit and the clearance time have been focused for many evacuation models. Traffic planning substantially influences the exit and the clearance time.

4. Traffic Planning

The tendency of people clustering in the cities and their metropolitan areas is increasing in developing countries also. The metropolitan areas are facing serious congestion problems due to the increasing number of vehicles, which threaten to deteriorate the quality of life and increase air pollution. Rapid increase of unavoidable travel demand and less construction of new transportation facilities worsen the traffic conditions unless some innovative congestion-relief methods can be developed and implemented in time. Efficient traffic planning are concerned with the prediction of the way in which vehicles use an existing or proposed infrastructure, or with the determination of the way in which such a utilization should be done. An efficient traffic planning is seriously required when disasters occur.

The traffic planning is the reorganization of the traffic routes so that all the evacuees can reach the safety zone as soon as possible. Efficient traffic planning is required for effective evacuation of evacuees during disasters. Only the effective and efficient planning achieves the goal of saving lives and protecting property during emergencies and disasters. If no such traffic planning has been assessed in prior time basically in urban places like Kathmandu where about 4 million people live with no adequate planning, we face a great loss during the disaster due to long evacuation time and unidentified potential transportation modes and shelters. Hard real time occurs in emergency. So delay evacuation is fatal. The efficient emergency traffic planning produces high quality emergency management. The planning significantly reduces the clearance and exit time and also increases the amount of flow of evacuees during emergency response situations. The planning should be scalable for the number of evacuees being moved and the size of the transportation network. The planning should reduce risk by identifying critical locations with unusually high evacuation times through sector evaluations.

There always exists a traffic network with finite nodes and finite edges between a disaster zone and a safety zone. Usually Urban areas have complex road networks with several lanes and intersections. The population is high enough. In Urban area like Kathmandu has high population density. Evacuees extremely capacity of the street during emergency. So, high congestion occurs. The basic idea is to reorganize the traffic routing from the disaster zone to the safety zone. The disaster zone and/or safety zone may have multiple nodes. The disaster zone may be buildings, vehicles, stadiums, cities or a region. The main objective of traffic planning is prior selection of scalable traffic routes for all evacuees within a desired time.

Since disasters may occur in different places and situations there exist several evacuation models. If the evacuees be considered as homogenous flow objects, the planning is based on optimization approaches. If behavior of an evacuee is taken as a separate flow object, the planning is based on simulation.

4.1. Optimization approach

The network that exists between the disaster zone and the safety zone can be considered as a graph network with finite nodes and finite edges. A static network, in which time is not considered as an attribute, can be useful to find the shortest path i.e. a path between the disaster zone and the safety zone with minimum weight, [7] .

Dynamic network, in which time is an attribute issued in each edge, has been widely used to investigate a suitable evacuation model. The seminal work of Ford and Fulkerson has begun the dynamic network for such investigations. Static network is a basis of a dynamic network. A maximum flow of evacuees is obtained converting a maximal dynamic flow network into a time expanded static flow network [8]. The dynamic flow problem sends maximum flow, based on temporally repeated flows computed by the minimum cost flow problem, of evacuees from the disaster zone to the safety zone[22,34]. The minimum cost flow problem finds the cheapest way of sending an amount of evacuees from the disaster zone to the safety zone. A constraint in which travel time depends on the inflow of a certain point extends the dynamic network flow problem. The problem is studied with an alternative time expanded network. A pseudo polynomial solution procedure exists with the assumption of constant capacity and constant travel time in each edge. Continuous time is attributed in this case[8,19].

The network may have multiple nodes in the disaster zone and in the safety zone as well. The multiple nodes are specified in an order from high to low priority. Then the dynamic network flow problem with multiple nodes of the disaster zone is called the lexicographic maximum dynamic flow problem. There exists an approximate polynomial algorithm based on chain decomposable flow to this problem. The flow is permitted to flow along the reversed direction of the edge[22]. Chain decomposable flow means the flow decomposed into flow units with discretised travel time. The lexicographic maximum dynamic flow problem is the multi-terminal extension of the maximum dynamic flow problem. All algorithms forlex max static flow can be applied for the lex max dynamic flow converting the dynamic network into exponentially large time expanded network[14].

The minimum cost dynamic network flow problem minimizes the total cost as well as the average evacuation time. This evacuation model is investigated for building evacuation in which waiting time node is allowed[12]. The model may be useful for the case with no waiting time also. The problem can be extended to the problem with multiple nodes in the disaster and the safety zones with no waiting time[9] .A pseudo polynomial time solution exists for the problem with time dependent attributes having single node disaster and safety zone. The attributes transit time, transit cost, transit capacities, storage cost and capacities can be taken into account for the time dependent case.

The earliest arrival flow problem sends the evacuees as early as possible together with a maximum evacuees in every time period to the safety zone[11]. Such flow always exists if there is only one node of the safety zone. There may not be a maximum dynamic flow with earliest arrival case if more than one node in the safety zone occurs[9]. However, Earliest arrival owes from multiple sources to a single sink do always exist [10].An additional constraint of flow for each node in the disaster and the safety zone is taken for the problem with more than one node in the disasters and the safety zones. Basically such a problem is modified into a dynamic flow problem with a super disaster node and a super safety node connected with each disaster node and safety node having null transit time, respectively. There exist several pseudo polynomial algorithms and an approximate polynomial algorithm for the problem. It still remains unresolved whether an exact solution procedure with polynomial time exists or not. The problem in which transit time, inflow capacity and cost depend on time has more practical importance.

The problem that minimizes the time horizon of the clearance time is another variant of the maximum dynamic network flow problem. The problem is called the quickest transshipment problem that minimizes the clearance time. The problem with a single disaster node and a single safety node case is called the quickest flow problem[5]. The quickest flow problem has been solved by polynomial and strongly polynomial solution procedures based on parametric search. The problem can be extended to the case in which the travel time depends on inflow. Several variants of the problem for example the problem with null transit time, the problem that considers rate-dependent flow and the problem with multi nodal case have been solved[23]. The problems with flow dependent travel time and load dependent travel time have been studied also[18]. The problem that allows single path with minimum clearance time is called the quickest path problem. The multi objective problem can yield an optimal solution if the evacuation time is high enough. The result holds true for the problem with multiple nodes for given evacuee capacities.

Evacuation for pedestrians from buildings based on dynamic network flow has also been extensively studied. The problem maximizes number of evacuees and evacuation time[1]. A variant of the problem avoids unnecessary obstacle during evacuation has been investigated[13]. The disaster zone may have multiple nodes. Another variant with time dependent flow uses tree structure network to evacuate from common buildings. Moreover, time dependent case updates the evacuation routes in every time period[2]. A variant of the problem evacuates through a single route. Another variant studies for the disaster caused by the flood with water depth that varies over time[4]. This minimizes the evacuation time. A cell transmission based dynamic traffic assignment model also exists in the literature [3].

The traffic planning for the disaster that occurs in a region exists in the literature. The shortest path with a minimal cost can be found[37]. A heuristic for the problem with flow that depends on travel time has been developed and improved[21]. The quickest flow with a single node of the safety zone and traffic assignment problems has solution[16]. Stochastic programming network with all possible scenarios designs a two stage programming[24]. First stage extends the capacity to the region to be evacuated and the second stage find the traffic tanssipment model. A linear dynamic traffic assignment problem with a single node of the safety zone is a basis for the regional evacuation. The upgraded model is useful for mass evacuation. The model addresses maximum flow with traffic assignment on a static network. Since the road capacity may be uncertain during evacuation due to unavoidable hurdles, the model incorporates uncertainty also. Uncertainty in road capacity as well as the number of evacuees can be incorporated.

In order to increase the road capacity during the evacuation, consideration of lane reversal or contra flow is highly applicable. The problem with more than one node in either disaster and/or safety zone that allows each edge is reversed at the initial time and the total cost is to be minimized with a given time bound is NP-complete[17,30]. Establishment of the contra flow particularly for the solution from bottle necks is useful. A heuristic based on tabu search that includes the capability of reversal of lanes has been established for a linear model based on cell transmission. Another cell transmission based model includes the level of danger of different parts in the network. Its extension includes different cell sizes. This avoids crossing conflicts. A mixed integer programming based on the cell transmission incorporates lane reversal and line addition on certain street segments but not the crossing conflicts[26]. A tabu search heuristic with Lagrangian relaxation is the solution approach for the problem with a bi-level model with capability of lane-reversal[35,36].

The traffic planning with evacuation response can be formulated in a mixed integer location routing model that incorporates the logistics[25]. The evacuation planning in a location allocation model has a genetic algorithm solution procedure. Some facilities may be damaged during the response. Such consideration has also been performed[15].

Since forecast of disaster may not always be certain, evacuation decision may be costly if disaster does not occur. A decision support model exists[31].

4.2. Simulation

Simulation approach is useful to evaluate given traffic network under different conditions. Microscopic model considers each evacuee as a separate flow object. Each evacuee is exposed to select a route step by step. The choice of route may be deterministic or random or modified random depending on the different situations. The movement pattern depends either on deterministic or probabilistic rules. There exists cellular automata simulation as well. The cellular automata study the behavior of the evacuee under various and uncertain conditions. It is particularly useful for the situations where rapid and/or random changes should occur[27].

The microscopic model simulation softwares that are widely used not only in the disaster but in the normal traffic planning situation are for example PARAMICS, CORSIM, VISSIM, EGRESS and FlightSim [20,28].CORSIM that combines two micro-simulators NETSIM and FRESIM includes some features such as altering signals, traffic diversions, access restrictions and roadway clearance. This simulator that considers speed, queuing time and length is less effective for real world problems. However, this is effective to test the effectiveness of the contra flow. VISSIM is implemented for the comparison between the results with and without contra flow. PARAMICS simulates high risk evacuation areas. It is used for the comparison between the simultaneous and staged evacuation strategies. EGRESS and FlightSim make use of cellular automata. DOSIMIS-3 predicts the traffic evolution. The micro simulations model is expensive when the size of evacuees is large enough.

Macroscopic models have been developed for the large size case. The model is useful to analyse and simplify the situation so that one can improve the accuracy. The simulators MASSVAC for structured rural networks and NETVAC for radial evacuation from the disaster zone are popular simulators[29,32]. Other simulators for example OREMS, DYNEV and ETIS additionally incorporate advanced features.

There exist mesosimulator softwares CEMPS, Smart CAP, Smart AHS, DYNEMO that keep advantage over disadvantages of the macro and micro simulators. However, macro and micro simulators are still useful, see [28].

Simulation approach can be useful for the review of traffic generation, traffic departure times, safety zone selection, traffic route selection with clearance time and capacities and the potential hurdles along the routes. Simulation identifies the bottlenecks in the networks and estimates the evacuation time so that evacuation can be followed. The simulation models have been developed for various disasters like nuclear accidents, hurricanes, floods, wild-fires etc. Likewise, the models exist for complex buildings, cities, regions, moving vehicles too.

5. Concluding Remarks

One of the most important issues on emergency management is to plan the transportation mode during evacuation. The traffic planning can be made efficient if it is based either on optimization approach or on the simulation one. There have been several procedures depending on the situation of the evacuation. Study of the traffic network with appropriate traffic planning in populated area in Nepal like Kathmandu would be better area of research in the future.

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