

Chapter 1

Introduction

Human civilizations have been striving to achieve a rapid and efficient mode of transport system for safe travel of people and economic transportation goods. Among various transportation modes that humans have invented so far, railways have acquired a critical role in the economical and societal development of a nation. So, the railroad has become one of the most important means of transportation and is a significant contributor to employment and productivity of a nation. This is especially true for a large and diverse country such as India, whose railroad network spans the entire country and measures over 67K kilometres (Lok sabha secretariat 2020). With ever increasing economic activities spread across different geographical spans the speed of transportation of goods and services becomes critical for national growth of any country. Therefore, railways world over have been focusing on technological upgrades to achieve higher speed of operation like other sectors of the economy. The increase in the speed, increasing rail network size and traffic density comes with a trade-off with other challenges to Indian Railways to honour its commitment of providing safe and reliable services to train users.

Indian Railways, the world's largest government railway system, operates 67,956 kilometres of track, carrying more than 23 million passengers and hauling nearly 2.77 million tons of freight daily (Indian railways annual report and accounts 2019-20 2020). Given the size and significance of this network, ensuring the safety of operations and the security of passengers is of paramount importance. The extensive nature of the railway

system also makes it vulnerable to accidents, derailments, natural calamities, and sabotage, which could disrupt its operations significantly.

Therefore, the safety of operations on the Railways and the safety and security of the millions availing the services of the Railways becomes of the primary principal of operation. The geographical span and diversity of the country makes the Indian Railways vulnerable, in different degrees, to various natural as well as man-made disasters. To meet any such eventuality affecting railway network, its operation or safety of passengers, railways have been evolving itself to arrest the possibility of avoidable occurrences. To mitigate the impact of unforeseen events beyond its control, railways have developed a dedicated fleet of rolling stock kept in preparedness to be deployed at a short notice. This rolling stock is popularly known as accident relief equipment. It is to be deployed to the site in emergency situations to provide quick relief and rescue to the passengers involved in the situation.

This research presents the optimization of the location of these vital assets over a railway network in order to minimize the overall impact of the eventuality, if it strikes the railway system.

The remainder of the chapter is organized as follows. Definition of Disaster and Disaster Management is elaborated in section 1.1. Section 1.2 elaborates the paradigm shift in disaster management (DM) in India. Section 1.3 introduces disaster management in Indian railways. The motivation of the research is presented in section 1.4 and section 1.5 describes the research problem. Section 1.6 defines the research objectives and scope of the thesis. Finally, section 1.7 presents the outline of the thesis.

1.1 Definition of Disaster and Disaster Management:-

Disaster, as defined by the United Nations, ‘is a serious disruption of the functioning of a community or society, which involve widespread human, material, economic or environmental impacts that exceed the ability of the affected community or society to cope using its own resources’(United Nations Office for Disaster Risk Reduction. Terminology).

“Disaster management is how we deal with the human, material, economic or environmental impacts of said disaster, it is the process of how we prepare for, respond to and learn from the effects of major failures” (Elliott 2014). Though often caused by nature, disasters can have human origins. According to the International Federation of Red Cross & Red Crescent Societies “A disaster occurs when a hazard impacts on vulnerable people. The combination of hazards, vulnerability and inability to reduce the potential negative consequences of risk results in disaster”.

1.2 Paradigm Shift in Disaster Management (DM) In India:

The Government of India (GoI) took a decisive step by enacting the Disaster Management Act, 2005 (DoWR 2013) on 23 December, 2005. This act envisaged the creation of the National Disaster Management Authority (NDMA), headed by the Prime Minister. Similarly on state level, the state Disaster Management Authorities (SDMAs) headed by the Chief Ministers, and District Disaster Management Authorities (DDMAs) headed by the Collector or District Magistrate. The aim and objective of this authority is to spearhead and adopt a holistic and integrated approach to DM. This act is a paradigm

shift, from the erstwhile relief-centric response to a proactive prevention, mitigation and preparedness-driven approach for conserving developmental gains and also to minimise losses of life, livelihoods and property as consequence of any eventual happening.

1.3 Disaster Management in Indian Railways: -

Indian Railway is one of the ministries of the Government having its presence across the vast expanse of the country. The mammoth size of the railways and the uniqueness of nature of possible disasters, and its susceptibility towards varied calamitous events make it a pivotal player in the scheme of disaster management. By virtue of its importance and centrality in the scheme of disaster management, it has acquired a role at the forefront of the aspiration expressed through the ‘Disaster Management Act’.

Until 2005, the accepted concept of a Disaster was inadequately and not comprehensively defined on Indian Railways. It was commonly accepted that a Disaster situation implies to cover only cases of serious rail/train accidents on the railways.

The Government of India vide gazette notification dated 26 December 2005 defined “Disaster” as, ‘a catastrophe, mishap, calamity or grave occurrence in any area, arising from natural or manmade causes, or by accident or negligence which results in substantial loss of life or human suffering or damage to and destruction of property or damage to degradation of environment and is of such a nature or magnitude as to be beyond the coping capacity of the community of the affected area’ (Govt. of India 2020). Based on the definition of the ‘Disaster’ in the Disaster Management Act 2005, the Ministry of Railways adopted the following definition of ‘Railway Disaster’ in the “Disaster Management Plan of Indian Railways 2009 and 2014”.

“Railway Disaster is a serious train accident or an untoward event of grave nature, either on railway premises or arising out of railway activity, due to natural or man-made causes, that may lead to loss of many lives and/or grievous injuries to a large number of people , and/or severe disruption of traffic etc., necessitating large scale help from other Government/Non-government and private organization.” (Book and Equipment 2015)

Disasters can cause injuries, fatalities and widespread infrastructure and property destruction. The associated economic and environmental costs can be devastating but it can be contained if the management systems are in place to plan for, respond to or recover them from failure.

Disaster in the Railway context was traditionally confined to include ‘a serious train accident, caused by human/equipment failure, which may affect normal movement of train services with loss of human life or property or both’.

The definition of the disaster is now extended to encompass the natural and other man-made disasters. Different types of disasters are described along with a few examples, below:

- a) Natural Disaster includes Earthquakes, Floods, Cyclones, Landslides, Snow Avalanches and Tsunami etc.
- b) Train Accident-related Disaster includes Collisions (with a huge number of casualties), Train marooned (flash floods), derailments of a train on a bridge over a river and coaches falling down, derailment of a train carrying explosives or highly inflammable material causing explosion or other environmental hazards, tunnel collapse trapping a train with passengers, fire or explosion in trains etc.

c) The definition of the Manmade Disasters encompasses the acts of Terrorism and Sabotage, i.e. causing deliberate loss of life and/or damage to property. This includes Setting a Train on fire, Railway installations etc., bomb blast at Railway Station/Train, Chemical (Terrorism) Disaster, Biological, Radiological and Nuclear Disaster targeting train, passengers and railway establishments.

Enactment of the Disaster Management Act, 2005 and subsequent developments on the national level, the disaster Management Philosophy has also changed to adopt the latest concepts enshrined in the current philosophy of disaster management.

New Philosophy gives more Emphasis on Prevention and Mitigation as under:

- Prevent the eventuality from happening and mitigate the impact of disasters in case it happened.
- Consolidate the system by infusing Disaster Resistance, Disaster Prevention and Mitigation on the basis of National Disaster Management Authority and self-prepared guidelines. Audit the existing systems for finding shortcomings and focused attention on desired points for continual improvement.
- Disaster Management in Developmental Planning – Expertise based response from all stakeholders; and Pooling of resources of all agencies, e.g. local administration, community, defence, hospitals and other Government organizations. Continual honing of talent and expertise to make dedicated resources available to handle any critical situation.

Disaster Management Act 2005

“The Disaster Management Act, 2005 stipulates that Ministries of Government of India shall be responsible for taking measures necessary for prevention, mitigation, capacity building and to respond effectively to any threatening disaster situation or a disaster in accordance with the guidelines of the National Disaster Management”.



Fig. 1.1 Stages of Disaster Management.(picture source internet)

Disaster management is a larger concept encompassing many vital decisions post and pre-disaster taken to prevent the disaster or calamity from occurring and to mitigate the impact of it. Railways have made huge investment in adoption and technology to prevent the possibility of such occurrences. It is noted that preparedness is the best strategy for both the aspects of the management. The philosophy of ever preparedness is adopted in practice to mitigate the impact of any disastrous event. To meet these challenges the Indian Railway maintains a dedicated fleet of rolling stock designated for housing re-railing and rescue equipment. They are designated as Accident Relief Train (ART). Similarly, there are dedicated rakes for extending medical assistance to the passengers in the case of an accident involving passenger trains. These rolling stocks have extensive medical facilities for immediate medical assistance to the injured. This includes a small operation theatre with

trained doctors nominated for emergency service. They are called Accident relief medical vans (ARMV) or Accident medical Equipment (ARME). In addition to above to tackle accidents involving heavy infrastructure or capsized rolling stock like a locomotive or a loaded wagon, the Indian railway has heavy capacity cranes (140T cranes). It is a unique equipment capable of handling heavy loads. It is normally deployed to remove the heavy obstruction from the track or to restore the position of an asset in case of an accident involving heavy infrastructure or a train. At present, the Indian railway has 175 ART and 162 ARMV located at important junctions throughout the country (Indian railways annual report and accounts 2019-20 2020). These rolling stocks are kept in preparedness to move at a short notice.

The location of these accident relief equipment is vital from the preparedness point of view. It becomes more critical to keep and maintain these assets in good fettle. The location of these assets becomes of primary importance for it needs to be moved to the site of requirement within minimum possible time for effective utilization.

1.4 Research Motivation.

We note from the discussion above, that the siting these assets (relief equipment) at strategic places is an extremely vital decision to be made by the railway authorities. As the location of specific type of facility at a location which has maximum possibility of having demand of that type of equipment with repeated demand not only governs the system's ability to effectively respond to the call, but also governs the number of each type of assets needed to make the system reliable and self-sufficient for every type of unforeseen situation. Therefore, the amount of investment required to be made on these equipment is also a vital decision to be taken by the railway authorities.

The aim of this study is to propose a sophisticated optimization framework that could be used to make location and allocation decisions given the uncertainty of the accident and demand for different combinations of them at the accident site.

Primarily, the location decision in regards to these facilities should be made in such a manner that it ensures the availability of relief at the accident site with quickest response time. The actual deployment of the relief equipment following an accident or disruption is an important decision because the intensity of disruption dictates the number and type of equipment required. Thus, locating relief equipment across the vast network appropriately acquires prominence considering the interaction amongst multiple decisions, and is challenging because of several reasons. *First*, the demand for relief equipment is difficult to predict because of the uncertainty around the time, location, and intensity of an accident (or disruption). *Second*, for a commercial organization, utilization of assets and the cost to maintain them could play a role in the purchase and installation decisions. *Third*, siting of relief facilities should consider the actual utilization and effectiveness of the asset keeping the actual possibility of occurrence of an accident over the network. *Fourth*, the data collection and identification of data for decision-making is a herculean task for an organization which is managed in traditional old ways. The current practice of deciding the location of these assets on the railway network is based only on the ability of a relief facility to provide radial coverage. Radial coverage means the ability of the equipment to travel to a certain point from its stable location which is normally a junction node on the network, within stipulated time.

The demand pattern of the relief is influenced by the traffic pattern of the section. However, as per current practice the distinction between two sections regarding possibility of the

accident, which ultimately requires deployment of the relief equipment is not taken in consideration while deciding the siting of these facilities. Importance of a section is considered based on the managerial parameters like through-put of the section, GTKM (Gross Ton Kilometres), NTKM (Net Ton kilometres) etc. These parameters though decide the basic character and capacity of the section and are taken in consideration while deciding on augmentation of the capacity of the section for smooth operation and decongestion of the section, but they don't govern the accident pattern and possible combination of the assets needed to be deployed at the accident site.

To identify the factors influencing the importance of a section from accident attention or disaster management point of view, we have conducted a detailed survey amongst the railway professionals dealing with disaster management and train operation in railways.

Through this study the first attempt to fill this important gap and provides a tool to decision-maker. The basic aim of the study is to provide a decision support system for location and allocation of relief equipment for possible accidents on a rail network. This is done in order to cover any point in the network from more than one facility i.e., redundancy of the coverage. The coverage of the sections of the network is done in the order of the priority of the section. The ultimate aim of the study is to provide facilities at such locations from where the deployment can be done in minimum possible time to save precious lives of passengers and restoration of the operation in the fastest possible time. The historic data of the accidents on a test case network is studied to find out the appropriate location of the assets and actual number of the equipment required to attend all the occurrences in the past, taking various possibilities over a long period of time.

The complex problem is solved for the best solution adopting two approaches first by treating it as a multi-objective optimization program with conflicting objectives. Second the same problem is addressed through two stochastic modelling approach. North Central zone of Indian railways has been considered for the experimental purpose and to demonstrate the applicability of the research in the field.

To solve this problem, we have used decision support tools like AHP and Topsis to evaluate the importance of a link and have used interactive Augmecon for optimum solution. The study is further extended and a two stage stochastic model is proposed and solved with introduction of the concept of the disutility factor.

1.5. Research Problems :-

The following problems are worth investigating with respect to location and allocation of the relief equipment on a railway network. Following problem is addressed in the present research work.

- (i) The vulnerability and the importance of a link in the network depends on many parameters e.g. operational traffic pattern and network profile etc. The vulnerability of the network is defined in terms of the importance of the links from an accident relief point of view.
- (ii) The demand of the relief equipment depends on the nature and intensity of the accident which is highly unpredictable in nature. The location of the accident is also not known. This calls for the multi-objective approach with conflicting objectives.
- (iii) Rather than the current method of radial coverage, which needs more assets to be maintained and still coverage of the network cannot be assured in absence of a

mathematical verification, a mathematical modelling-based decision support needs to be developed for such a critical decision.

- (iv) Due to the huge cost of these assets, it becomes more vital to have a holistic approach and a mathematical logic-based solution for optimum utilization.
- (v) The uncertainty related to demand (regarding frequency location and intensity of the event) is very high which needs to be accounted for while planning for location of the accident relief and subsequent deployment during actual occurrence of the event.

1.6 Research Objectives and Scope of the Thesis:

Motivated by the pivotal role of accident relief equipment, the criticality of their location over a railway network and on the research-gaps identified, we consider a network design for location of these vital assets over a railway network. A network where the location of the equipment is decided in an optimal manner to attend every possible accident on the network in minimum possible time to mitigate the consequential impact on train operation, and to save human life by providing relief and rescue in the golden hour. These equipment being capital incentive assets need to be located at strategic locations where facilities needed to maintain and operate them from these locations is available with lowest investment. Consequently, it is necessary to decide the set of equipment to be procured or current equipment to be relocated in order to meet the demand during an emergency.

To capture the research theme sequentially, we set the objectives for study as, to minimize the overall time taken to meet any combination of the equipment demand at any given point in the network. To maximize the coverage of any point by maximum number of the equipment to cater the demand of multiple combinations in case of a large accident and in

case of availability of limited equipment to ensure the coverage of important sections of the network on priority. Following are methods offered through this research to solve the problem considered in this work:-

- (i) The existing quantity of various types of the equipment which are sited at current locations decided by the competent authority is evaluated and the objectives are formulated by consultative mechanism and solved the multi-objective problem with iterative δ -Augmecon method.
- (ii) To determine an optimal number of different types of equipment required to attend all types of historical occurrences of the event seen by a representative network, a two-stage stochastic model is solved, and robustness of the solution is achieved by introducing the concept of disutility.
- (iii) To evaluate the solution obtained through various methods a simulation framework proposed. The demand is simulated based on the historic record and Monte-Carlo techniques of simulation. A transportation model is proposed and demand supply scenarios for various combinations are repeated many times to simulate real-life events.

The scope of this thesis is limited to study the location of these assets over a railway network in order to mitigate the impact of the accident by providing quick relief and rescue. We consider a railway network having connections with the arc and station as nodes of the network. There are few stations having certain prerequisite facilities for siting these vital equipment. We have defined the vulnerability of the network and rated the relative importance of the sections of the network keeping possibility of an accident in view. We have considered the cooperative coverage of a point on the network, i.e. a station (node),

which may be covered by more than one facility provided it is located at a certain distance from the point of location of the facility. The coverage of important sections is given priority over others in case the equipment is limited.

Further we have explored the possibility of complete coverage of the network and optimized the number of total equipment of each type is required for the complete coverage and decide the optimum location for siting the equipment in order to minimize the total time of arrival at any point on the network.

The study further explores the solution of the problem by considering the historical data of accidents and proposing a two-stage stochastic model with the aim to know the maximum number of individual equipment required to cover every event that occurred in the last 10 years.

1.7. Outline of the Thesis

The remainder of the thesis is presented as follows. In chapter 2, we present a survey of the contemporary literature on the problems studied in this thesis: Optimal location of accident relief facilities for a resilient railway network. We review the contributions in disaster management and location of various facilities for mitigation of consequences by quick response particularly for the railway network. We also present important contributions from the perspective of solution methodologies adopted to solve these problems. The chapter is concluded by identifying the literature gaps which have been addressed in the thesis.

In chapter 3, we examine the network's susceptibility to specific types of accidents and underscore the significance of individual links concerning the likelihood of particular types of accident occurrences. The analysis of vulnerability focuses on the repercussions stemming from system failures when estimating relief demand probabilities becomes impracticable.

These repercussions typically pertain to human life, public health, and environmental integrity. When monetized, these consequences can further be articulated as operational costs, network disruptions, and broader impacts on the interconnected system.

The factors influencing the vulnerability of a network are identified and their weightage is calculated with the use of concepts of MCDM. After wide calculation of the weightage through survey and application of AHP these factors are used to calculate the relative vulnerability by use of TOPSIS.

In chapter 4, we apply the concept of network vulnerability and link importance presented in chapter 3 for formulating a mathematical model for decision making on location of the relief facilities over a railway network.

Strategically, the location of these facilities should be chosen to ensure the availability of relief at the accident site within the least response time. A model with a multi-objective optimization program is presented with conflicting objectives to address the complex problem in hand. The complex problem is solved for the best solution through use of iterative Augmecon (Mavrotas and Florios 2013). Finally, the data from the North Central Railway zone of Indian Railways has been used to demonstrate the practicality of the research. It is also illustrated through the experiments that the proposed plan of reconfiguring location of the relief facilities would help increase the coverage of the nodes and coverage of the links of the considered network.

In chapter 5, The problem is reformulated with new insights received from the study conducted in chapter 4, a two-stage stochastic programming modelling framework is proposed for the problem where the optimal location of relief equipment is the first stage decision and the deployment of the same in case of an accident on a network link is a second stage decision. The objective is to minimize the total cost including the cost of purchase, installation and

maintenance of relief equipment, the cost of deploying relief equipment in case of an accident and the cost of not responding to an accident. Various accident profiles are defined to understand the actual demand for the relief equipment after the occurrence of a specific type of accident that is the type of train that meets with an accident and the demand for the number of specific types of equipment deployed for the rescue, restoration exercise. The probability of occurrence of an accident profile is estimated from the past data of accidents in a rail network.

In chapter 6, a significant gap in academic research has been tackled by presenting a method for the comparative evaluation of solutions for location of relief equipment on railway networks- a domain that has been notably neglected in scholarly exploration. The research presented in this chapter endeavours to fill the gap by introducing a comprehensive simulation framework that utilizes mathematical modelling and optimization techniques to evaluate the performance of the location solution in different real time circumstances over a long-time horizon. In this study a transportation model is proposed to solve the demand-supply problem for each instance of accident on a railway network. The model integrates constraints mirroring the practical and operational restrictions associated with moving relief equipment within the network. Application of this transportation model is demonstrated with historical data of accidents and the demand of equipment during each scenario, presenting a practical case study to validate the proposed methodology.

Finally, in Chapter 7, the main contributions of the thesis are summarized along with some potential research directions.
