

## Chapter 6

### Optimizing Strategic Placement of Railroad Accident Relief Equipment: A Simulation-Based Decision Tool

---

#### 6.1. Introduction :

In this chapter, 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.

Current research 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 chapter 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.

Computational experiments are conducted to compare three existing location solutions available in the literature. These solutions are critically examined to assess their efficacy in addressing the challenges of relief facility placement within a railway network. Through in-depth analysis, this study provides valuable insights into the strengths and weaknesses of different location solutions. The incorporation of real-life scenarios, use of simulation techniques, and comparative analysis of existing solutions contribute to the

development of a robust decision-making tool for relief facility location. This work not only addresses the current gap in academic research but also sets the stage for further advancements in the optimization of relief operations within complex railway networks, which is the unique contribution and novelty of the research presented in this chapter.

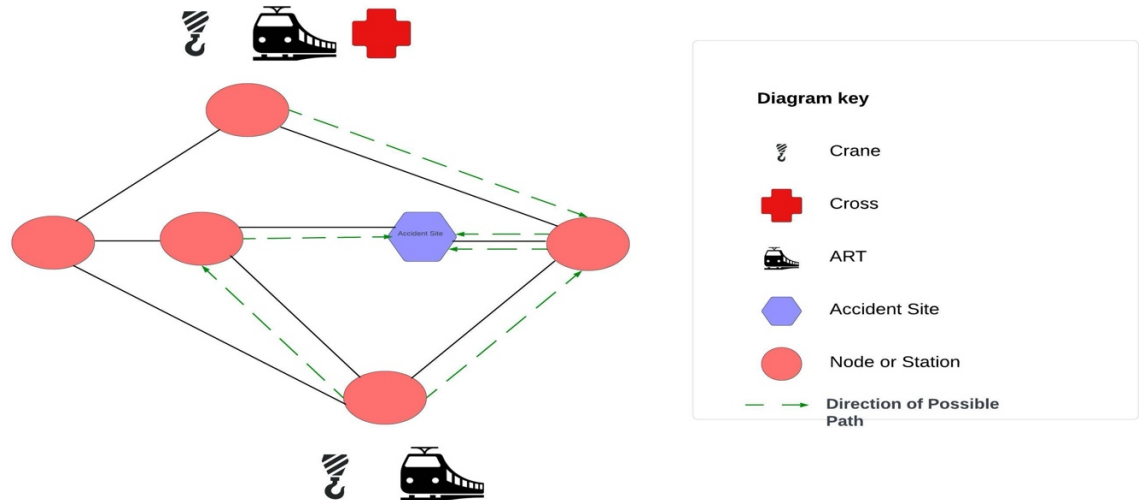
In the rest of the chapter section 6.2 presents the description of the problem. Section 6.3 describes the methodology for the study. The “Trans-Sim Optimization Program (TSOP)” proposed in this study is explained in section 6.4. Section 6.5 covers the application of the TSOP. The Equipment and Experiment are explained in section 6.6. Section 6.7 covers the Results and Discussion of the experiment. Finally, section 6.8 concludes the chapter.

## **6.2 The Problem Description :**

### **Problem Statement :**

The problem pertains to locating facilities over a network of Indian Railways, which consists of a series of continuous arcs connecting the two possible nodes in the set  $N$  and such a combination of arcs are termed as 'links' in this work. Each link represents a set of stations connected by continuous arcs, with unique characteristics such as track specifications, flow of passenger and freight traffic, and vulnerability. Any point on the network's links can potentially experience an accident and require accident relief facilities. There are certain locations on a network where an accident relief facility or a combination of these facilities can be located. Due to the unpredictability of the location, frequency and intensity of the accident, the location of these relief equipment becomes critical in the overall scheme of disaster management in Railways. The representative

diagram in Fig. 6.1 depicts the possibility of various locations and a representative combination of the possible paths for deployment of the equipment during an emergency.



**Fig. 6.1 Schematic Presentation of Network [Nodes, Arcs], Location of Equipment and Possible Path**

The railway network considered in our problem can be represented as an undirected Graph where  $G = (N, A)$ ,  $N$  represents the set of all nodes (i.e., stations) in the network and  $A$  represents the set of all arcs connecting the stations. Let  $N$  represent the set of stations that are normal stations or junctions in the network.

The relief facilities considered in this study include Accident Relief Train (ART), Accident Relief Medical Equipment (ARME), and Crane, each providing specific services for accidents of varying magnitudes.

The locational decisions already obtained through three different studies have been considered for the purpose of comparison and evaluation of effectiveness of the results. The results obtained by these studies are presented in table 6.3.

A comparative analysis is made between the above three sets of solutions. The first solution being the one explained in the literature review section for multi-objective problem and second being the current practice of locating the accident relief equipment over NCR at present. The third solution for demonstration purposes has been taken as a set covering model solved for the coverage of the entire network. By this way the results of three use cases are evaluated and a comparative analysis is done through simulation study in this work. Following is the definition of concept of coverage used in the chapter.

### **6.2.1 Definition of Coverage :**

Each equipment type, considered in this chapter, namely ART, ARME, and Crane, possesses distinct capabilities, utility, and cost implications. Practical considerations, coupled with validation, lead us to presume that if a Crane reaches an accident site within 4 hours of ordering, all points/stations within that radius are considered covered. Correspondingly, the time frames for ART and ARME are 3 hours and 2 hours, respectively. The demand generated through simulation at each node must be covered by at least one relief facility within predefined time or distance constraints else the node is considered uncovered. Multiple facilities can cover a single demand node. The equipment available at the nearest facility is used in order to reach the site in the quickest possible time. The uncovered node incurs a proportional penalty, thereby increasing the cost of accident response.

### **6.3 The Methodology of the Study :**

The primary objective of our study revolves around validating solutions for a facility location problem. This entails comparing solutions derived from various scenario

combinations within the problem. Historical data from a specific zone is harnessed for simulating scenarios, considering the distribution of demand across the network. The accident relief equipment's placement is pre-defined, and resource supply during crises is simulated, adhering to real-life constraints.

Scenario generation involves random selection of accident locations from the network's list of stations, with demand simulated using the Monte Carlo simulation method proposed by Christopher Z. Mooney. Demand for various scenarios is generated by randomly selecting locations across the entire network. The demand generated by the simulation method at every instance should be attended by at least one facility as already described above. The problem is formulated as a transportation optimization program to ensure coverage of demand with given constraints.

The unavailability of an asset at the time of demand may arise out of a strategic decision of not locating the equipment at that location or the equipment despite being located is not available at that instance due to either being down or engaged in other activity. In both the cases a suitable penalty is assumed to understand the cost repercussions of these situations and make a comparative assessment of the same. The process flow is elucidated through a flow chart in Fig. 6. 2

#### **Algorithm for Scenario Simulation :**

##### **Input:**

1. Network parameters nodes and links  $(N, A)$  and distance  $d_{ij}$  between them.  $C_{ij}$  cost of transportation etc.

2. Set of potential locations (stations) for siting relief facilities indexed by  $j$ .
3. The historic data of past accidents and their demand for different accidents.

Step 1. Chose a random location  $i$  form the list  $I$  of nodes of the network  $(N, A)$

Step 2. Monte Carlo Simulation for demand generation.

Step 3. Solve the transportation problem for supply of relief equipment from optimal locations to meet the demand generated through step 2 at a location in step 1.

Step 4. Impose the penalty on cost as applicable on the scenario stipulated.

**Output.** Print the results and compare

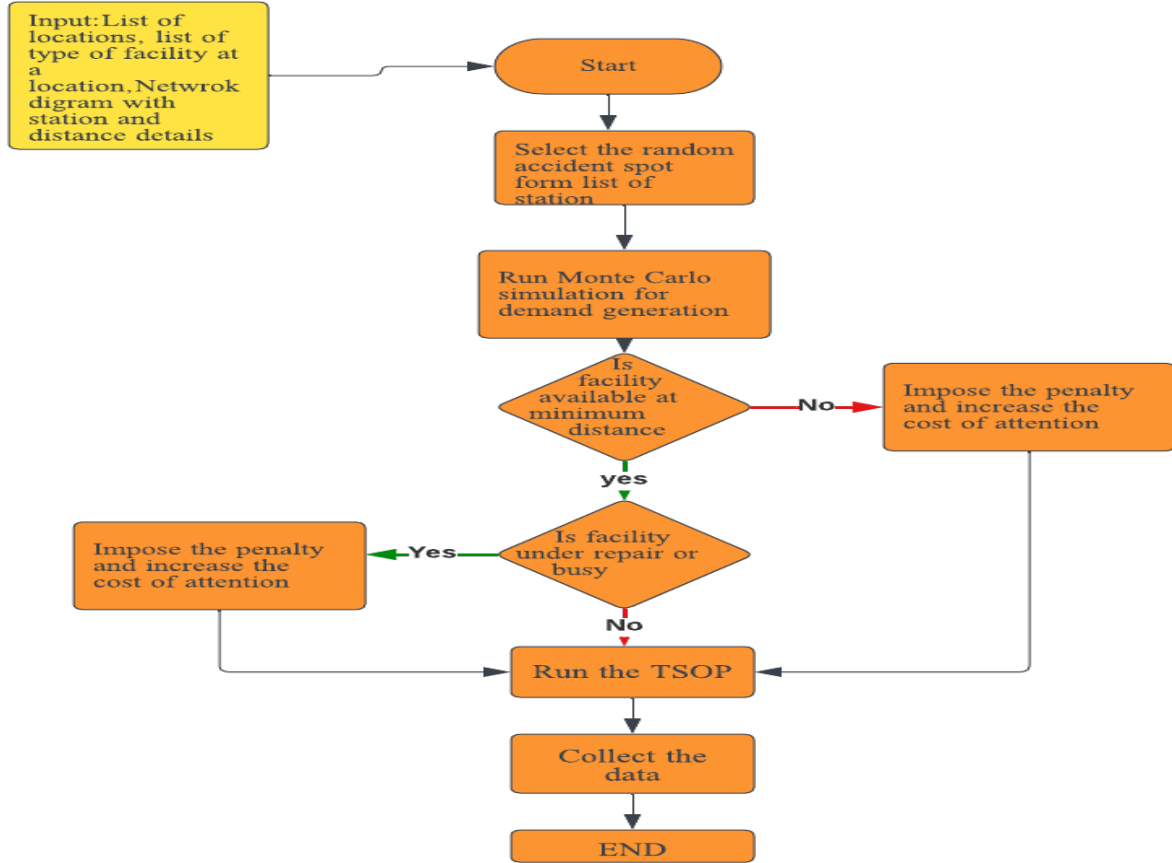


Fig. 6.2- Steps in the Simulation Algorithm.

#### 6.4 Trans-Sim Optimization Program (TSOP) :

The optimization program as described above is named as ‘Trans-Sim Optimization Program’. It is applied to simulate the scenarios based on the demand in the past accidents which have occurred over a rail network. The location of the relief equipment is already known in terms of distance from the random accident site and the capability of the equipment location to address the scale of the accident i.e. the ability to supply the

required number of equipment for a given instance of the accident. The model is formulated as follows.

**Table 6.1-List of Notations**

Category	Symbol	Description
Sets and indices	I	Set of demand nodes in the network indexed by i
	J	Set of potential locations (stations) for siting relief facilities indexed by j
	F	Set of relief facilities indexed by f, $F = \{ART, ARMV, Crane\}$
Parameters	$C_{ij}^f$	Travel cost of asset f from a node I to node j
	$H_j$	Cost of deployment of asset from a location J
	$\Delta_j^f$	1 if asset f is available at location j, 0 Otherwise
	$\beta_i^f$	1 if asset f is in demand at location I, 0 Otherwise.
	$D_i^f$	Demand of asset f at location i
Decision variable:	$x_{ij}^f$	1 if an asset f is deployed from point j to a location I, 0 Otherwise.
	$Y_j$	{1 if the asset is available at location j 0 Otherwise

## Mathematical Model (TSOP) :

### Objective Function:

$$\text{Min } \sum_{f \in F} \sum_{j \in J} c_{ij}^f * x_{ij}^f + \sum_{j \in J} Y_j * H_j \quad \dots (1)$$

### Constraints:

$$\sum_{j \in J} x_{ij}^f = D_i^f \quad \dots (2)$$

$$x_{ij}^{CRANE} \leq x_{ij}^{ART} \quad \dots (3)$$

$$x_{ij}^f \leq \Delta_j^f * \beta_i^f \quad \dots (4)$$

$$\sum_{j \in J} \sum_{f \in Demand} x_{ij}^f \leq \sum_{j \in J} \sum_{f \in Demand} \Delta_j^f \quad \dots (5)$$

$$x_{ij}^f \in \{0,1\}, \forall (i, j, f) \in (I, J, F) \quad \dots (6)$$

$$Y_j \in \{0,1\}, \forall j \in J \quad \dots (7)$$

The first equation represents the Objective Function of the problem (TSOP), which minimizes overall cost of transportation of assets from available location to the demand point. Constraint Eq. (2) ensures that complete demand at a point should be met by supplying assets from different locations. The additional condition of movement of CRANE always and with ART is satisfied with constraint Eq. (3). The constraint in Eq. (4) restricts supply of an asset from a location where it is available to a location of demand if it is actually in demand and is available at the location. The total numbers of assets to be supplied to a location should not never exceed the demand at that location is depicted through Eq. (5).

### 6.5 Application of the Simulation “Trans-Sim Optimization Program (TSOP)”:

The algorithm is applied to validate various results obtained through the studies mentioned above. The three cases are considered in chapter and their effectiveness is compared on the parameters like total cost involved in attending 500 accidents at randomly chosen locations of a railway network. Comparative analysis of these three cases have been done in terms of utilization of equipment from various locations, cost of attending total cases generated during this simulation study.

**Table 6.2 Input Parameters for the Case Study**

Parameter	Description
Number of nodes (stations) in the network	105
Number of links	132
Type of accident relief facilities	ART, ARMV and CRANE
The average speed of the relief facilities	75 kmph
Maximum allowable time (hours)	ART      3 hrs
	ARMV    2 hrs
	Crane    4 hrs

The locations obtained through three cases mentioned above are summarized in the table given below (table 6.3). These locations of equipment are used as input parameters.

**Table 6.3 Results of The Facility Locations Obtained Through Different Studies.**

Sr. No.	Station	Existing			Solution from Multi_objective Problem			Set Covering problem		
		ART	ARMV	Crane	ART	ARMV	Crane	ART	ARMV	Crane
1	PRYJ	✓	✓		✓	✓				
2	CNB	✓	✓	✓	✓	✓	✓	✓	✓	✓
3	BAND A	✓	✓		✓	✓	✓			
4	TDL	✓	✓		✓	✓		✓	✓	
5	GZB									
6	JHS	✓	✓	✓	✓	✓		✓	✓	
7	AGC	✓	✓	✓	✓	✓	✓	✓	✓	
8	MTJ	✓	✓		✓	✓				
9	GWL	✓	✓		✓	✓		✓		

10 KURJ

11 MBA

12 CAR

13 NYN

✓

14 MKP

✓

15 LAR

16 DHO

✓

17 BHA

✓

✓

18 AH

19 MHF

20 AWR

✓

21 PWL

22 ALJN

23 SKB

24 MNQ

25 ETW

✓

26 UDMR

27	BZM		
28	KID	✓	✓

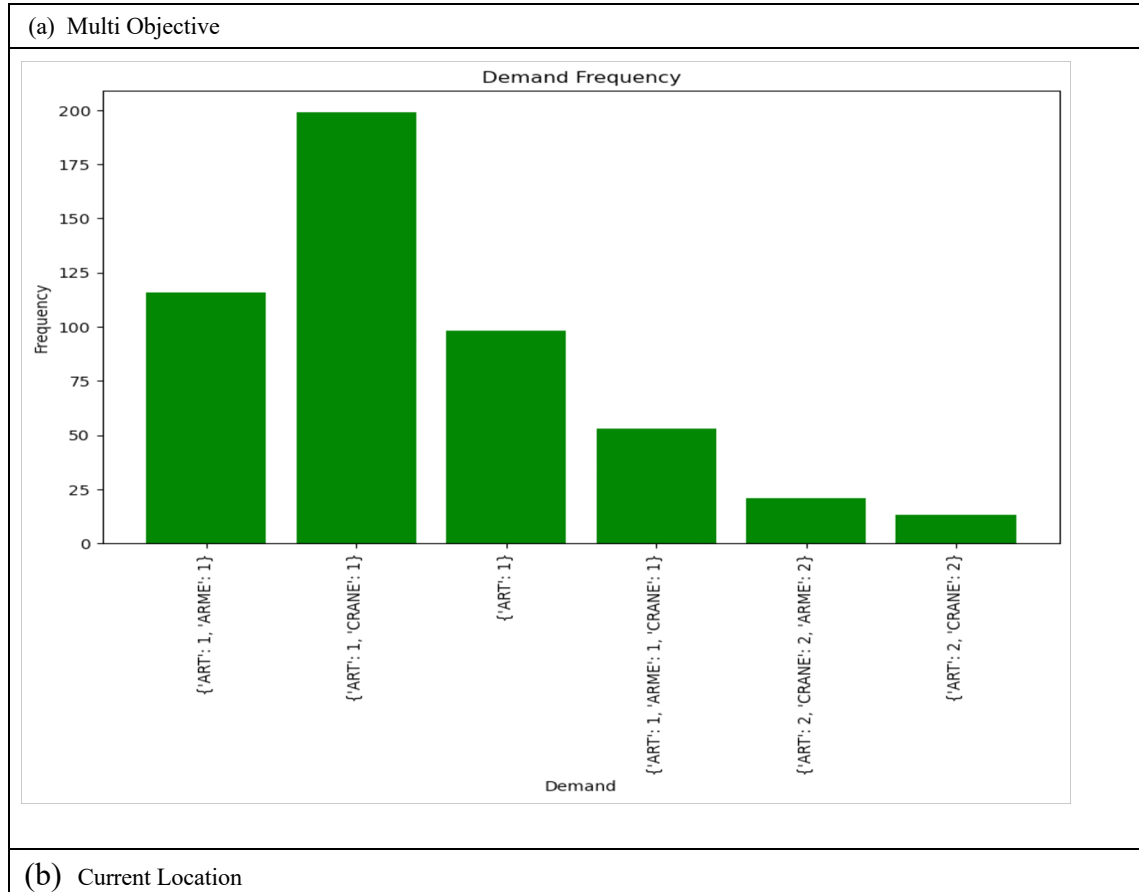
### 6.6 Equipment and Experiment :

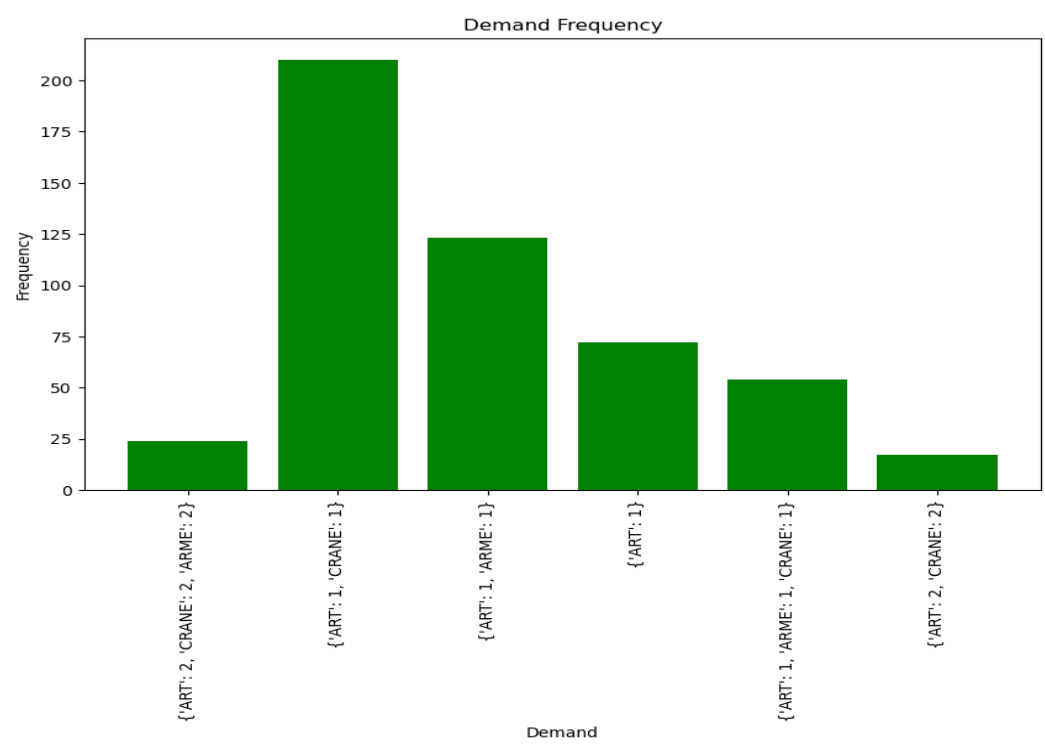
All experiments were carried out on a personal computer equipped with an Apple M2 chip, running with the Mac operating system. The computer boasts impressive hardware specifications, including an 8-core CPU, an 8-core GPU, a 16-core Neural Engine, 8GB of unified memory, and a 256GB SSD storage drive. For the simulation model, we utilized Python in conjunction with the Gurobi Optimizer version 10.0.2 build, which represents the latest and most advanced mathematical programming solver available. This implementation was executed within the Jupyter Notebook Integrated Development Environment (IDE). The results obtained from the computational experiments are discussed below:

### 6.7 Results and Discussion :

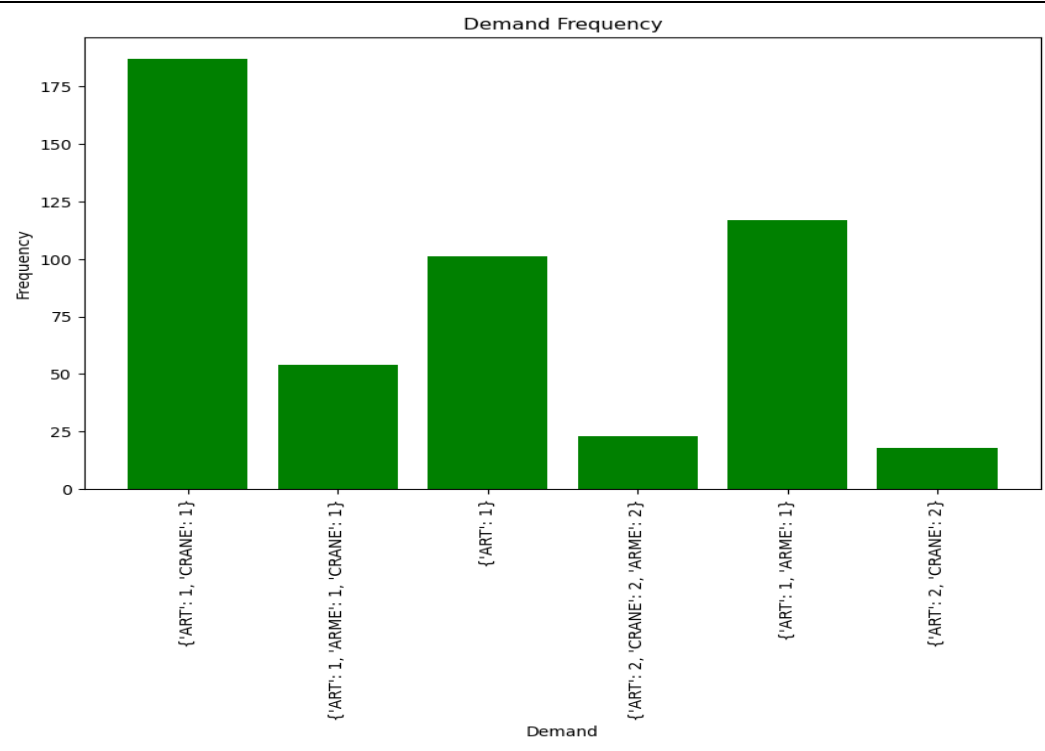
The distribution of this demand is illustrated in Fig 6.3 below, which were obtained after 500 iterations for each case. Remarkably, across all three cases, the highest demand is consistently observed for the combination of one ART and one CRANE, closely followed by the demand for one ART and one ARME, which matches the historical demand data available and considered for this study.

Fig. 6.3 — Demand Pattern in Different Case of Simulation: (a) multi objective, (b) Current Location, (c) Set Covering model.





(c) Set Covering



To fulfil these demands, equipment deployment is executed from various locations, subject to predefined movement conditions or combinations dictated by the demand. The most influential factor governing equipment movement is the condition that the CRANE always moves in tandem with ART. The distribution of asset utilization is presented in Table 6.4. Notably, in the current location of equipment and the location determination through multi-objective problem solving, the highest equipment utilization is observed from AGC. Conversely, in the case of the Set Covering model solution, CNB location yields the maximum utilization. It is noteworthy that the Set Covering model involves more equipment than the other two considered solutions. In some of the cases, the use of the equipment has been noted to be zero. It is because the equipment is not available at that location in the solutions, or it is not located at the location in current scheme of locating the equipment.

**Table 6.4 -The Distribution of Asset Utilization for Various Scenario and Demand Profiles in Different Studies.**

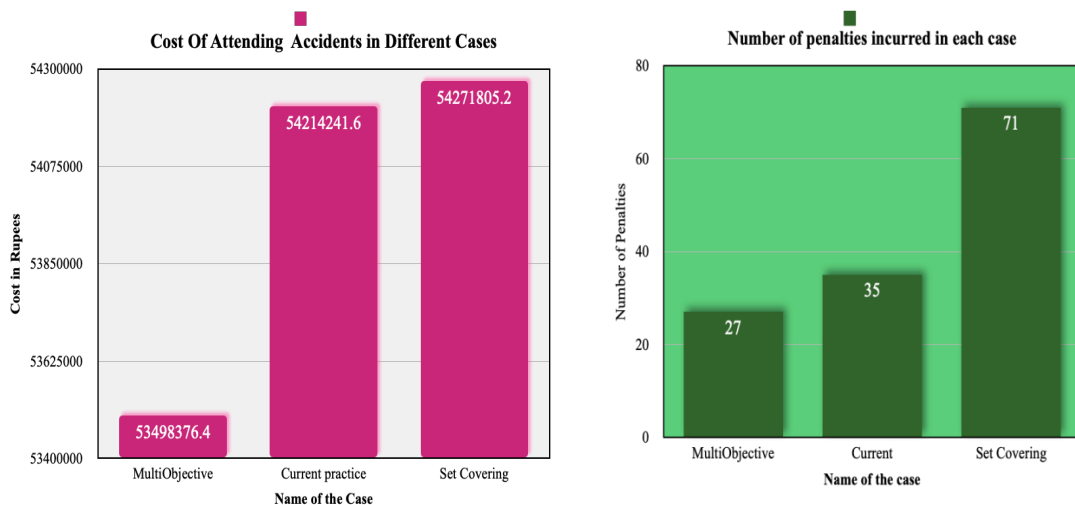
		Multi_bjective	Current Location	Set Covering
ARME	AGC	70	63	26
	BANDA	26	6	0
	BINA	16	13	22
	CNB	19	34	45
	DDU	10	26	21
	GWL	7	5	0
	JHS	12	27	11
	JP	9	9	27

	NDLS	21	16	32
	PRYJ	10	14	14
	TDL	11	12	19
ART	AGC	174	172	45
	BANDA	66	18	0
	BHA	0	0	91
	BINA	43	20	44
	CNB	71	89	109
	CPU	2	1	0
	DDU	37	60	63
	DHO	0	0	5
	ETW	0	0	5
	GWL	13	8	6
	JHS	24	77	20
	JP	27	20	45
	MKP	0	0	4
	NDLS	41	33	48
	PRYJ	18	19	29
	TDL	18	24	27
CRANE	AGC	125	121	0
	BANDA	45	0	0
	BHA	0	0	89
	BINA	31	15	30
	CNB	48	68	87

	DDU	27	44	45
	JHS	0	59	0
	JP	17	16	34
	NDLS	27	23	38

The value of the objective function (i.e. the minimum cost involved in attending an accident) of the transportation problem revolves around minimizing the cost associated with responding to accident events. For a comparative assessment of the solutions considered as use cases, the total cost incurred in responding to 500 simulated accident cases has been compared. Intriguingly, the solution derived from solving a multi-objective problem resulted in the lowest cost for attending to accidents.

We define coverage (as previously described in chapter 4 ) and impose penalties on the cost of attending an accident if it remains uncovered due to specified time limits for attention and constraints already defined above.



**Fig 6.4- Comparison of the Cost of Attending the Accident and Number of Penalty Imposed in 500 Iterations.**

The total number of penalties imposed for 500 iterations in each case is calculated and compared using the graph presented in Fig. 6.4.

Notably, in the case of the multi-objective approach, the total number of penalties is the lowest when compared to the other two cases. Conversely, the set covering model incurs the highest penalties despite ensuring coverage of the entire network. The reason behind this intriguing result lies in the demand for specific combinations of equipment movements for certain cases. In some instances, the demand necessitates the use of equipment combinations such as 'ART' and 'CRANE' or 'ART,' 'ARME,' and 'CRANE,' while the available equipment for the set covering solution consists of single units or combinations not suitable for the required movements. Consequently, even though specific equipment is available, a location may not be adequately served for the desired combination, resulting in the imposition of penalties. The detailed insight in multi-objective optimization considered in the exercise reveals that the solution obtained through multi-objective optimization serves the best amongst all three solutions available as it provides best result meeting optimality of conflicting objectives.

## **6.8 Conclusion :**

The vital realm of accident relief simulation is explored in this chapter, shedding light on the complex dynamics and intricate decision-making processes involved in responding effectively to unexpected incidents across a vast network. Through the application of Monte Carlo simulation, and transportation problem-solving, it addresses the challenges and opportunities of location of accident relief equipment and effective utilization of resources over a railway network. The interplay of various factors in real life situations has been captured through simulation modelling. The strategy of movement of one facility

with another emerges as a single primary factor influencing the location decision of the equipment on the network. The study further revealed intriguing variations in asset utilization across different locations. The concept of penalty imposition for uncovered accident sites serves as an important decisive factor in location decision. The operation constraint had played a major role on overall cost of the accident attention including the number of penalties and associated cost. The research proposed through this chapter is applicable over a vast network of railways with various operational characteristics. As we move forward, these findings can serve as a foundation for further research and practical applications in the field of accident relief and emergency response.

\*\*\*\*\*