Location Identification for Rapid Evacuation from a Disaster Site: A Case Study from KAPS

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Abstract

Robust plans need to be developed for rapidly evacuating victims from a nuclear disaster site. Although nuclear plants are constructed with multiple redundant safety features, the chances of a leak can never be zero. In the event of a nuclear disaster, there is a need for an efficient evacuation plan for the affected area. The plan should include shortest possible evacuation routes, rallying post for the evacuees and optimized resource allocation. Considering Bardoli as the affected area for our purposes, we have collected data like distance of each village from the radiation source, its road connectivity with nearby villages, population and availability of transportation resource. We proposed First Safety Point (FSP) for each village and its respective rallying post while providing the detailed evacuation route for each village. We have also developed a resource optimizing heuristic to allocate transportation resources to each village.

Key words: Evacuation Plan, Nuclear Disaster, Resource Optimizing Heuristic

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1. Introduction

Nuclear Power Plants (NPP) in India are designed, constructed, commissioned and operated in conformity with the relevant nuclear safety requirements to ensure an adequate operational margin of safety for prevention of undue radiological risk to plant personnel and public living around the plant (CNS, 2012). But it is very essential to have an emergency response plan for effective management of any eventualities leading to exposure of radioactive radiation to plant personnel and public. The radioactive elements are part of nuclear reactors and have detrimental impact on human on exposure.

The safety in nuclear installations follows a defense-in-depth approach and has three independent layers of safety in series. Hence, significant disaster may only be possible due to concurrent failures of multiple protective layers. The first layer of safety is in design of safe operational system for nuclear installation, taking into considerations the anticipated transients. The second layer is independent safety engineering features to mitigate the consequence of Design Based Accident scenarios. The third protective barrier is On-Site and Off-Site emergency response plans to mitigate the radiation consequences by a series of protection measures and emergency response in case of the coincident failure of the operational control and the independent safety systems (Sohier, 2002). The responsibility of On-site emergency response lies with the NPP operators but the same for Off-site emergency lies with the District and State authorities.

Off-site Emergency is the accident condition/emergency situation involving excessive release of radioactive materials/hazardous materials from the nuclear plant into the public domain calling for intervention. The off-site emergency response can be categorized into four phases: Pre-release, Early phase, Intermediate phase and Late phase. The pre-release phase is a preventive response before the anticipated release of radiation and calls for evacuation (preventive). The early phase is the situation of contaminating atmosphere and the exposure pathways primarily include external radiation from nuclear cloud and inhalation of radio-particles and to some extent due to external radiation from ground deposition and transmitting into body through skin. The protective measures for this phase include sheltering, evacuation, administering of iodine and agricultural protective measures. The Intermediate phase is the time when contamination of ground occurs and vegetation starts decreasing rapidly. In this stage, the exposure pathways will be radiation from ground deposition and intake from contaminated food chain. The countermeasure required is relocation and controlling of the food intake. The Late phase is long continued contamination of the surrounding in terms of ground and food chain. The measures are again relocation, food intake control and de-contamination of the environment (Sohier, 2002).

For this paper, we have studied Kakrapar Atomic Power Station (KAPS) which is located in Mandvi Taluka of Surat District and is located at the distance of around 80 km from the city of Surat. It has nuclear power reactors of capacity 440 MW and construction for another 1400 MW capacity is in progress. The scope of this paper is to study the off-site emergency interventions of KAPS and to provide insights for development of a robust Off-Site Emergency Response Plan. For this paper, we have limited the scope to first two phases of Off-site emergency: pre-release & early phase. These phases ask for quick response in terms of logistics optimization. The remaining two phases call for building the infrastructure for the displaced which is long term involvement.

The area under Off-site emergency which requires preparation of emergency procedures and action plans is designated as the **Emergency Planning Zone (EPZ)**. As per the existing and planned capacity of Kakrapar Atomic Power Station, the technical calculation based upon potential intensity of leakage and meteorological consideration suggests that the EPZ is upto a distance of 16Km radius from the main nuclear plant. Further, the entire EPZ has been divided into 16 sectors, each covering 22.5 degrees and centered on the corresponding main direction. The sectors have been marked from A to P as shown in Figure 1. The total of 170 villages of Surat district (Bardoli and Mandvi Taluka) and Tapi district (Songadh and Vyara Taluka) have been identified under these sectors. For this paper, as a pilot, we have taken 19 villages of Bardoli Taluka of Surat District which come under EPZ. From Figure 1, it can be identified that we have taken sectors K, L & M (bordered in red) for this paper.

Therefore, our objective is to develop an Evacuation Plan for nuclear/radiological disasters for these 19 villages of Bardoli Taluka. It includes evacuating of public & livestock from the affected area in shortest possible time. The target of shortest possible time translates into developing an evacuation route which can be covered in shortest time. The evacuation and time constraints bring in the requirement of identification of transport resource to ensure accommodation of entire inhabitants. This paper also requires the identification of Rallying Post where the displaced population can be provided a temporary shelter. The arrangement to be provided at these points in terms of food, water, medicines and others is the responsibility of concern department and this project does not cater to it. Evacuation plan also includes a well-defined communication matrix in which various concerned government officials are involved. In this project, we have assumed that they shall follow the same procedure as they have been doing for any another disaster.

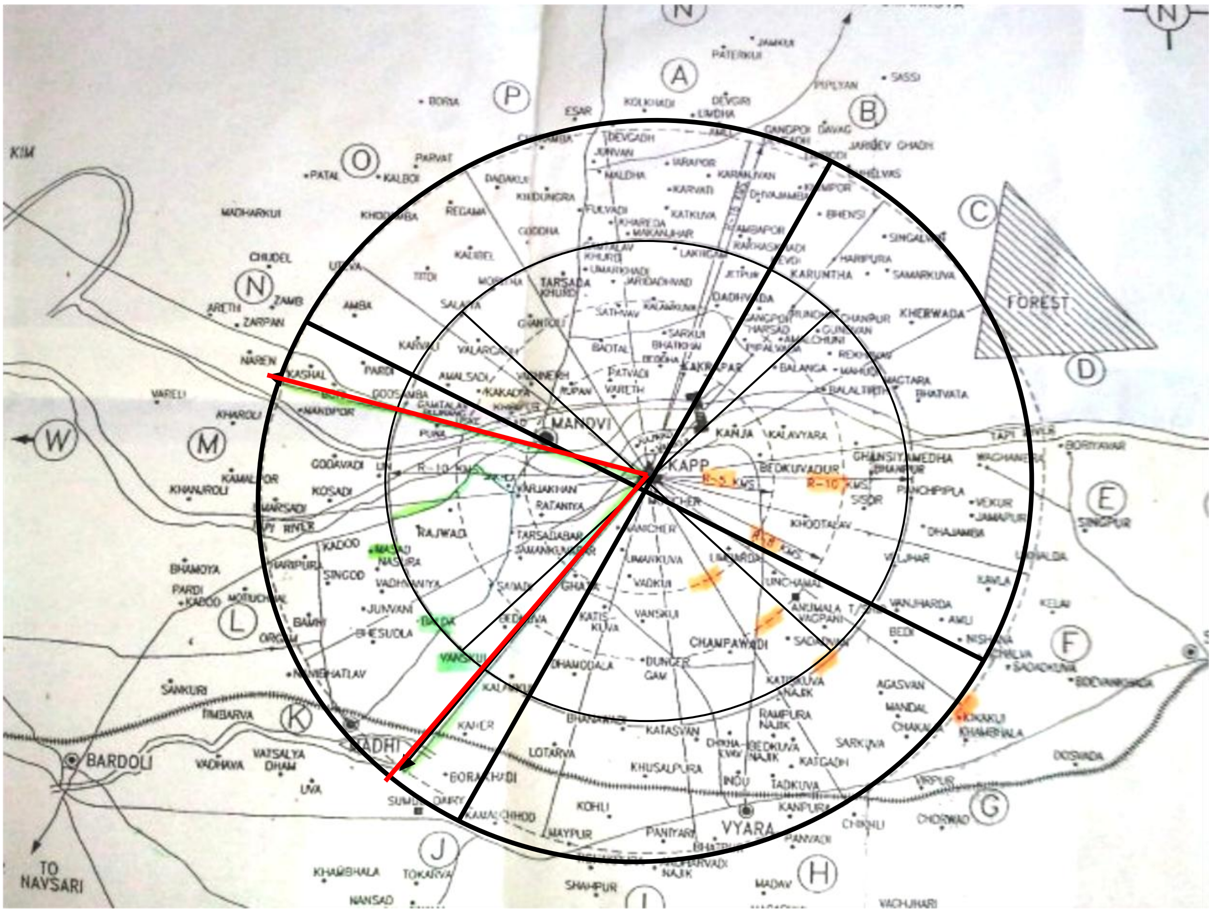

Figure 1: Pictorial representation of Emergency Planning Zone

The motivation for this paper comes from the fact that although Gujarat State Disaster Management Authority (GSDMA) has well developed Taluka Disaster Management Plan and Village Disaster Management Plans, they do not include the evacuation plan in case of a nuclear/radiological disaster. Therefore, it provides us an opportunity to understand the phenomenon of nuclear disaster and incorporate the insights into the evacuation plan. The short response time presents a huge challenge for the logistics management.

The paper has been outlined as follow: Section 2 includes our review of existing literatures on Nuclear Disaster Management and Off-site emergency. In Section 3, based upon our objective and insights derived from the literature we have detailed the need and means of data collection. Section 4 sets up our analysis of the data to prepare the plan. Section 5 lists the results and recommendations of the project. Section 6 concludes and provides way forward.

2. Literature Review

We have studied various literature related to Nuclear disaster management and off-site emergency response plan for nuclear accidents. The details of the literature review have been mentioned in the subsections below.

2.1 Convention on Nuclear Safety (2012), Government of India

We studied the 'National Report on Convention on Nuclear Safety' to understand the requirement of off-site emergency response plan. The guidelines have been revised in the wake of recent nuclear accident at Fukushima, Japan. It detailed the basic requirement of the emergency response plan along with roles and responsibilities of various stakeholders like NPP operator, Regulatory bodies, district administration.

2.2 Exposure Pathways and Intervention

The countermeasure required to be carried out during the disaster depends upon the release of radiation and the exposure pathways it follows to affect the public. Therefore, it is prudent to understand the release of radiation, the exposure pathways and subsequent countermeasure required. Sohier (2002) in a 'European Manual for Off-site emergency Planning and Response to Nuclear Accidents' has explained the exposure pathways for the nuclear release and has critically examined the requirement of intervention based upon the scenario of disaster. We have analyzed the manual and have extracted the information pertaining to our scope of this paper.

2.2.1 Release of Radiation

A release of radioactive particles from the plant may occur either to atmosphere or to a water body. The release to air has greater hazardous impact over a very short period of time. The factors affecting the transport of radioactive particles downwind are wind speed, wind direction and atmospheric stability/instability. These factors determine the dispersion, direction and spread of the plume. The well dispersed plume results in lesser concentrations but over a much wider area. Also, the air concentration is inversely proportional to the wind velocity. Moreover, the release of radionuclide can be categorized into three phases. The early phase is following the urgent countermeasures to protect the public once the emergency has been declared. The intermediate phase is the time when disaster has been brought under control and there is no further release of radionuclide. The decision to be considered is either extension or withdrawal of urgent countermeasures. The last phase is the recovery stage in which long term countermeasures needs to be carried out (Sohier, 2002).

2.2.2 Exposure Pathways

After the release of radioactive particles into air, they are either transported through dispersion in air or get deposited on the ground. We are only considering air-borne release in this study as it has greater impact in a very short span of time and which requires quick countermeasures.

The radioactive particles in the air cause radiation exposure primarily in two ways. First, the exposure is through external irradiation by gamma & beta rays emitted by airborne radioactive nuclides. Second, the radiation exposure is caused through internal irradiation due to inhaling of radionuclide. The internal irradiation can also happen by absorption of radio nuclides through the skin.

The inhalation pathway is more critical. The external exposure has lesser irradiation on sensitive internal organs in comparison to internal exposure. Moreover, the irradiation effectively comes to end as soon as cloud of radioactive particles has passed. On the other hand, through inhalation radionuclides may get deposited in lungs and get transported throughout the body and may continue irradiating organs for hours, days or years. Typically, inhalation radiation is 10 or 100 times greater than the external irradiation.

The radio nuclides which got deposited on ground may continue to irradiate externally through emissions of gamma & beta rays. They may also be transported into soils, water system, plants and animals. They may come into human body through ecological cycle (Sohier, 2002).

2.2.3 Urgent Countermeasure/ Intervention

The intervention which needs to be taken in the early stage of radiation release and must be taken promptly to be effective comes under the category of 'urgent countermeasure'. Their effectiveness dramatically diminishes by a delay in their implementation. These interventions include

- SHELTERING: This provides protection from external irradiation plume & ground deposits and from internal irradiation due to inhaling of radioactive particles in plume. It refers to remaining indoors while cutting from radiated environment by closing doors & windows and shutting off the ventilation system. It also reduces deposition of radionuclides on skin.

  To get the reduction in exposure from external irradiation by factor of 10, the housing should be solidly built and reasonably airtight. Light constructions such as canvas do not provide any protection. The reduction in exposure from inhalation of particles can be up to factor of 3.

  Sheltering, in isolation, is an incomplete countermeasure as population is still in the affected area but provides protection from exposure while preparations for evacuation are due for implementation (the waiting time). The adverse effect of sheltering is very minimal on individuals provided the duration is short and is limited to a few hours.

  Moreover, on few occasions it has bigger advantage even over evacuation. There are four main occasions under atmospheric release in which Sheltering may be the optimum choice:

  1. a release consisting mainly of radioisotopes of noble gases (to reduce the external dose);
  2. a release that would result in relatively low doses;
  3. a release that would result in very large short-term doses, for which evacuation could not be carried out before the release;
  4. circumstances in which evacuation is not possible or would entail considerable risk to the evacuees.

- EVACUATION: It protects the population against external exposure and inhalation pathways and deposition on skin as well. It is considered as a complete countermeasure as affected population will be out of the affected area. But, it needs to start before the release occurs, otherwise there will be partial exposure. On the other hand, evacuation is very disruptive in nature and expensive as well. Ensuring food & security to population are other concerns related to it. It can be extended to Relocation if situation demands.

- Administering STABLE IODINE: Stable iodine reduces the uptake of radioactive iodine by thyroid and partially saturates iodine transportation across the body. The effectiveness of protection is indirectly proportional to the time lag between exposure and administration of iodine. The same can be summarized in the Table 1 as derived from average case in Kovari (1994):

Table 1 : Effectiveness of Iodine Administration

Intake time of stable Iodine after single exposure (Hrs)	Fraction of exposure averted (%)
0	**97**
1	**85**
2	70
4	50
6	35
10	20

The combination of all three urgent countermeasures is required based on the severity of the radiation optimizing the benefit and cost (Sohier, 2002)

2.3 Emergency Response Planning

Sohier (2002) in a 'European Manual for Off-site emergency Planning and Response to Nuclear Accidents' has also detailed the complex process of Emergency response planning which consists of problem assessment, diagnosis, information spread out and proper implementation during emergency situation. We tried to understand the same in detail so that we could incorporate the insights in our proposal.

2.3.1 Emergency planning and Emergency management

Before Chernobyl accident in 1986 most of the countries were not prepared for nuclear disaster at such a great extent, but after that accident things have changed and all countries with & without nuclear capability are serious on issues related to nuclear disaster. Now a nuclear emergency plan is not made only for isolated nuclear plants but a broader view related with local, regional and national values are taken into considerations. At the time of emergency, political and media pressure is also high so proper planning related to emergency situations should be made.

Emergency management is a complex process consisting of problem assessment, diagnosis, information spread out and proper implementation during emergency situation. At the time of emergency, decision should be taken quickly even the situation is ambiguous. Emergency team and staffs should be well trained and should be updated with new technologies and techniques related with nuclear disaster. Competent authorities should follow principle of "Command", "Control" and "Correct".

The linkages between these principles have been illustrated in Figure 3 below.

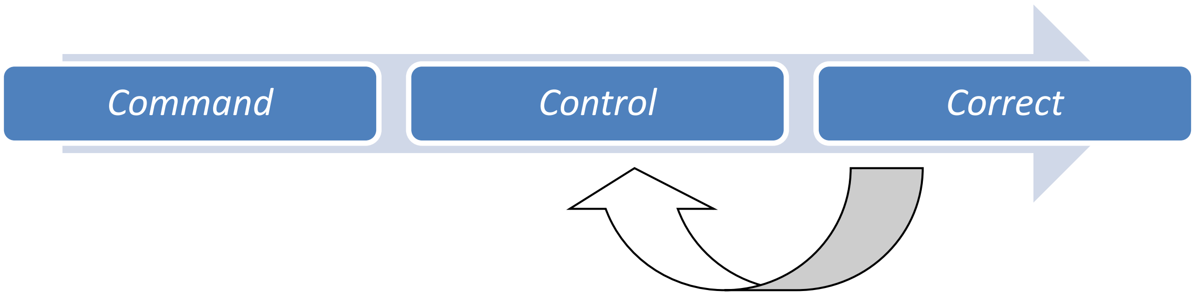

Figure 3: Pictorial representation of Principles of Emergency Management

2.3.2 Concept & planning

At the time of emergency, things should be done according to their priorities and its objectives. Some of the important objectives could be to:

- Avoid, restrict, reduce, or mitigate activity releases, exposures and its consequences
- Protect the population; consider available means in a realistic way; enable people to help themselves; do not overreact (e.g. sheltering instead of evacuation, allowing to keep roads free for emergency and monitoring teams)
- Protect emergency personnel

- Facilitate recovery
- Integrate regional radiological emergency preparedness into a general emergency response system; on the national level, plan for all kinds of events, also multiple ones, and include international co-operation.

One should be clear in its objectives, structures, tasks, responsibilities, competencies intervention levels and obligations for co-operation and training of staff and members related with nuclear disaster managements. Entire affected area should be divided into different zones and each zone should be planned for accordingly based on intensity & effectiveness of radiation.

Preparatory planning should be there in case of nuclear disaster events so that prompt action could be taken at the time of disaster. Things that should be considered for preparatory planning should be as follows:

- Warning and activation of authorities and emergency teams; notification and start-up procedures for emergency teams
- Monitoring capability and strategy
- Intelligence strategy
- Preventive actions and countermeasures
- Communications and back-ups
- Information directives for media and public
- Psychological aspects (emergency teams, public), participation of affected population in decision making (recovery phase)

The staff and people related with preparatory disaster planning should have following obligations towards the management:

- In-depth knowledge of emergency plan
- Familiarity with the role
- Have upgraded training programme
- External contacts & help
- Do rehearsals, exercises and drills
- Familiarity with tools & techniques

2.3.3 Steps to be taken by disaster management at the time of emergency

In case of disaster, the competent authority should have a structured approach to tackle the situation without creating panic. At first, authority should detect the source of information and then cross verify it from other sources. When it is confirmed that the disaster has taken place then start monitoring the situation meticulously. They should start gathering information related with disaster from different authorities and also monitor the information to be given to general public so that panic is not created. All authorities should come up with a plan for the evacuation of human life and livestock in time. They should also collect data regarding the level of radiation and its effect on masses. Proper feedback from nuclear plant officials, government officials, Gram Panchayats, doctors should be taken to analyze the real situation and its effects. Figure 4 gives the sequence of steps to be taken by disaster management authority at the time of emergency

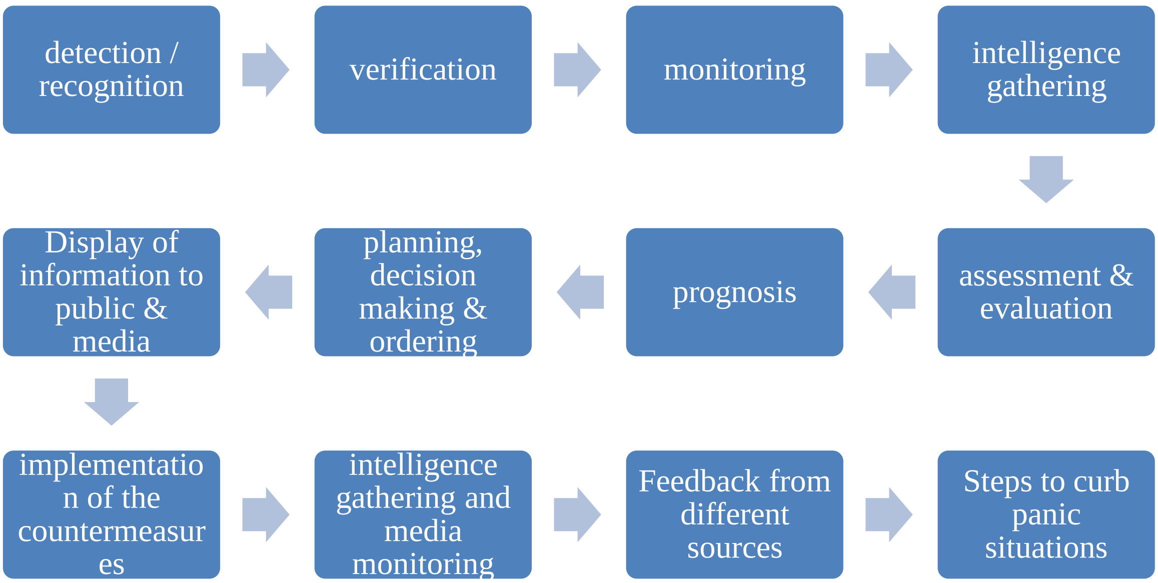

Figure 4: Sequence of steps to be taken by disaster management authority at the time of emergency

2.3.4 Data, Information & Activities required prior to disaster and during emergency situation and strategic model to be used

- Information, analysis and decision making
    - ➢ contamination control
    - ➢ intermediate and recovery phase countermeasures

- protection of emergency and recovery workers
- agricultural countermeasures, food restrictions
- plume trajectory, detection of release

- Data required
  - meteorological data
  - ambient dose and dose rate
  - airborne radionuclide concentration
  - environmental deposition
  - food, water and environmental contamination
  - individual dose
  - object surface contamination

- Different phases
  - pre-release phase
  - release phase and immediate post-release phase
  - intermediate phase
  - recovery phase

- Emergency planning zone
  - urgent protective action planning zone
  - food and agricultural restriction area

- area farther from release

2.4 Generic Emergency Plan

Emergency Planning Group of British Energy Generation Limited (2007) has developed a ‘Generic Emergency Plan’. It outlines various components of the emergency response plan and specifies generic notification chain of the emergency and communication flow among various stakeholders/organization.

3. Data Collection

For the preparation of evacuation plan for 19 villages, we needed to understand the existing road connectivity for each village to come up with the shortest evacuation route. We also require the data pertaining to human and cattle population to distribute the resources available with us. We also collected data for villages beyond the EPZ to consider them for the rallying post. We also needed the information regarding the availability of transportation resource to allocate them accordingly for our evacuation plan. We gathered information about the spread of radiation to understand the phenomenon better and to garner some insights which could be helpful for implementation of our plan.

3.1 Villages Details: Population & Road Connectivity

For the preparation of evacuation plan for 19 villages we needed various data pertaining to human & livestock population, distance from the source of release & road connectivity. The data related to population have been taken from Gujarat State Disaster Management Authority website. The road connectivity has been mapped through Google Maps and the road maps of each village which have been taken from Village Disaster Management Plan (VDMP). The same was collected from the Bardoli Mamlatdar Office. The distance from the KAPS has also been derived with the help of Google Maps & Google’s application to calculate air-to-air distance between two locations.

3.2 Location Search: Rallying Post

We needed to find a rallying post where the evacuation population can be provided shelter with basic amenities. We collected details of other villages beyond the Emergency Planning

Zone (EPZ) to find their suitability for the rallying post. The data was collected from the Bardoli Mamlatdar Office and was verified by physical visit to those locations. The data related to distance and road connectivity was collected as mentioned above.

3.3 Transportation Resource

The data related to availability of buses in and around the EPZ was collected from District Transport Office, Surat.

3.4 Iodine Administration

The data regarding the distribution of Stable Iodine was collected from Chief District Health Officer, Surat.

3.5 Radiation

To understand the phenomenon of radiation and its spread, we conducted a telephonic interaction with personnel of KAPS.

4. Analysis

To process and analyze the data collected, we have developed a user driven Excel based analysis tool. This tool captures important assumptions from the users that are required to generate the results. To solve our goal of finding the shortest evacuation route, we attempted to work out the parameter which will lead us to the solution. We started with the first metric of 'distance from the nuclear plant' as the basis of our analysis. This metric provided us the priority which can be assigned to each village and the target evacuation time for each of them. Further, we analyzed the route-connectivity of each village and came to the conclusion that road-mix of the route will provide us better understanding of the priority. This was based on the fact that some villages may be better connected with high speed state highway and hence will take lesser time to evacuate. So, we developed our second metric of "Standard Evacuation Running time". Moreover, we extended our analysis to bring in the factor of number of population in prioritizing each village for resource allocation. This metric calculated the total evacuation time for each village based on their population. Each of these metrics is explained in detail in the coming sections. Based on these metrics and analysis we developed our Excel Model for resource optimization which has been discussed in Section 5.

4.1 Distance Matrix: (Village- KAPS)

We sub-divided the 16 Km radius of Emergency Planning Zone (EPZ) into 4 layers and segregated villages on the basis of that. We prioritized the villages on the basis of their distance from the source of release of radiation (KAPS) which is inversely related to time available to implement safe evacuation. The topmost priority was given to villages that come under the radius of 0-5 Km. The other categorizations are 5-8 Km, 8-10 Km & 10-16 Km. The spread of radiation tends to die as it moves outward and hence we have provided this prioritization, based on our discussion with KAPS personnel. The first layer includes two sub-zones. According to Atomic Energy Regulatory Board (AERB), the area under radius 0-1.6 Km is called Exclusion Zone and there is no public habitat. This comes under On-site emergency. The area under 1.6-5 Km only has naturally developed habitat and is named Sterilized zone by AERB (Convention on Nuclear Safety, 2010). The second layer has been taken as 5-8 Km radius while third one makes the radius between 8-10Km. The last interval has least priority, although they are not out of potential danger. The distance of each village has been depicted in Figure 5.

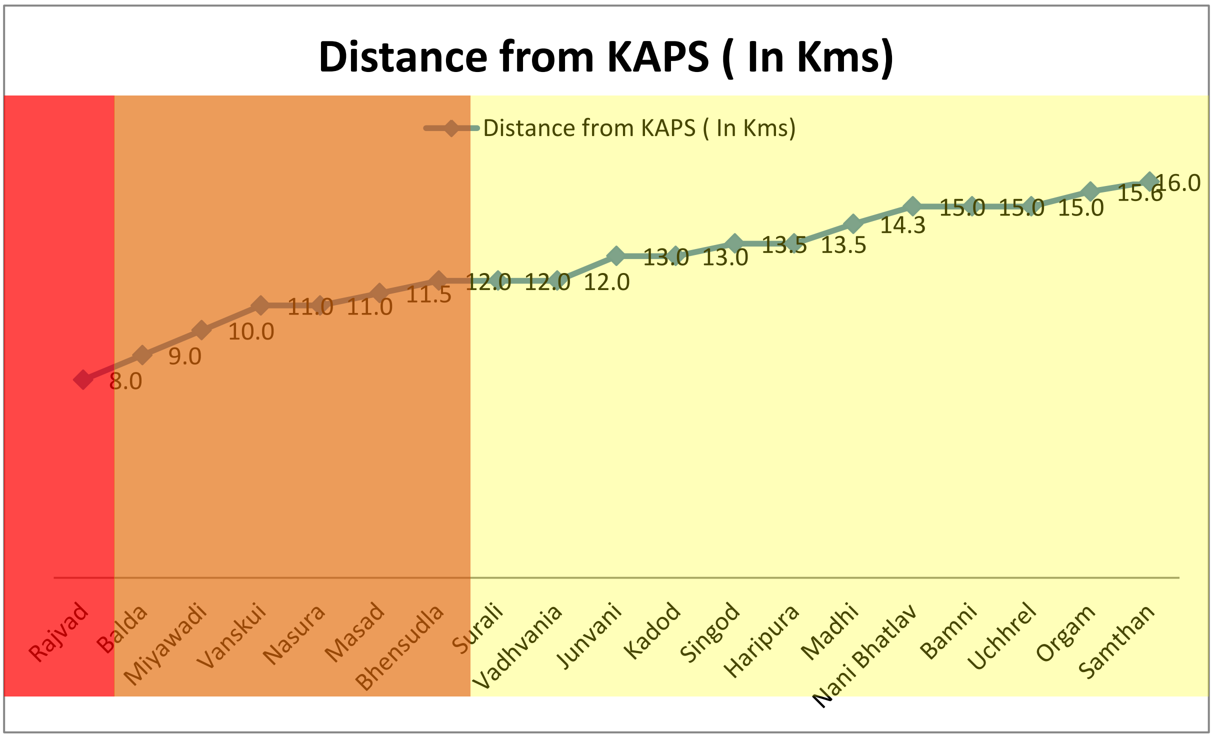

Figure 5: Distance of each village from KAPS

Considering the broad spread of villages, we have incorporated that correction in our distance interval and have prioritized the villages as mentioned in Table 2.

Table 2 : Sub-Zone Prioritization of Each Village

Sub Zone	Distance Interval (In Kms)	No. of Villages under the interval
1	0-5	0
2	5-8	1
3	8-10 (Upto 11.5)	5
4	10-16 (Beyond 11.5)	13

This matrix is also critical because it is not necessary that all zones will be asked for evacuation all the time. Irrespective of time taken, this distance is critical for spread of effect of radiation and there may be a chance that few zones may not be asked to evacuate, based upon the intensity of radiation. Hence, it is important to categorize the villages according to this sub-zonal basis.

4.2 First Safe Point (FSP) beyond Emergency Planning Zone (EPZ)

The main deliverable of this project is to develop shortest evacuation route for the villages under EPZ. This translates into fastest evacuation when converted into unit of time, which is most relevant in this context. We had to evacuate the village and place it at the rallying post. So, one metric could have been 'shortest time of evacuation from the village to the rallying post'. But, we comprehended that 'time to come out of EPZ' is more critical than 'time to reach rallying post'. Hence, we developed the concept of 'First Safe Point (FSP)' beyond the boundaries of EPZ. **Therefore, we worked out the shortest time & route for each village to reach their respective FSPs.** Logically, FSPs will be radially outward of EPZ and most probably each sector of EPZ will have one FSP just beyond its boundary. Another criteria needed is the availability of enough temporary holding space. Villages with schools, temples, community halls, Panchayat halls, Anganwadis and other open spaces are ideal in this respect.

4.3 Shortest Time for Evacuation

With possibility of resource constraint in the hand, we have divided time for evacuation into two parts:

1. From village to its respective First Safety Point (FSP)
2. From FSP to Rallying Post

Now, for the safe evacuation, the minimization of first part serves our purpose. The time required for transferring population from their FSP to final rallying post is less critical provided there may be other population still within the affected zone and needs immediate displacement. Hence, for preparing priority matrix of villages we have considered only the time required for the first part of evacuation.For the calculation of time, we have divided the road connectivity into three categories: State Highways (SH), Non-Highways Road (N-HR) & Village Roads (VR). Each has been assigned different running speeding. Therefore, for each village we have calculated the optimal route on the basis of shortest running time. The standard evacuation running time has been plotted for each village in Figure 6. This is standard time for one trip and without any waiting for resource to get deployed.

For example, let's calculate this value for Rajvad village. The shortest evacuation route suggested that we have to travel for 15 km to get out from the EPZ. Out of these 15 kms, distance of 13 km needs to be travelled on National/State-highway (Surat-Nasik Highway) which can be covered at the average speed of 50Km/hr. Another 2 Kms shall be travelled on village-level road which can be averaged at speed of 15Km/hr only. So, upon calculation we get that it will take total of 23.6 minutes as a standard running time for evacuation. This standard time has been used as a metric to prioritize the villages.

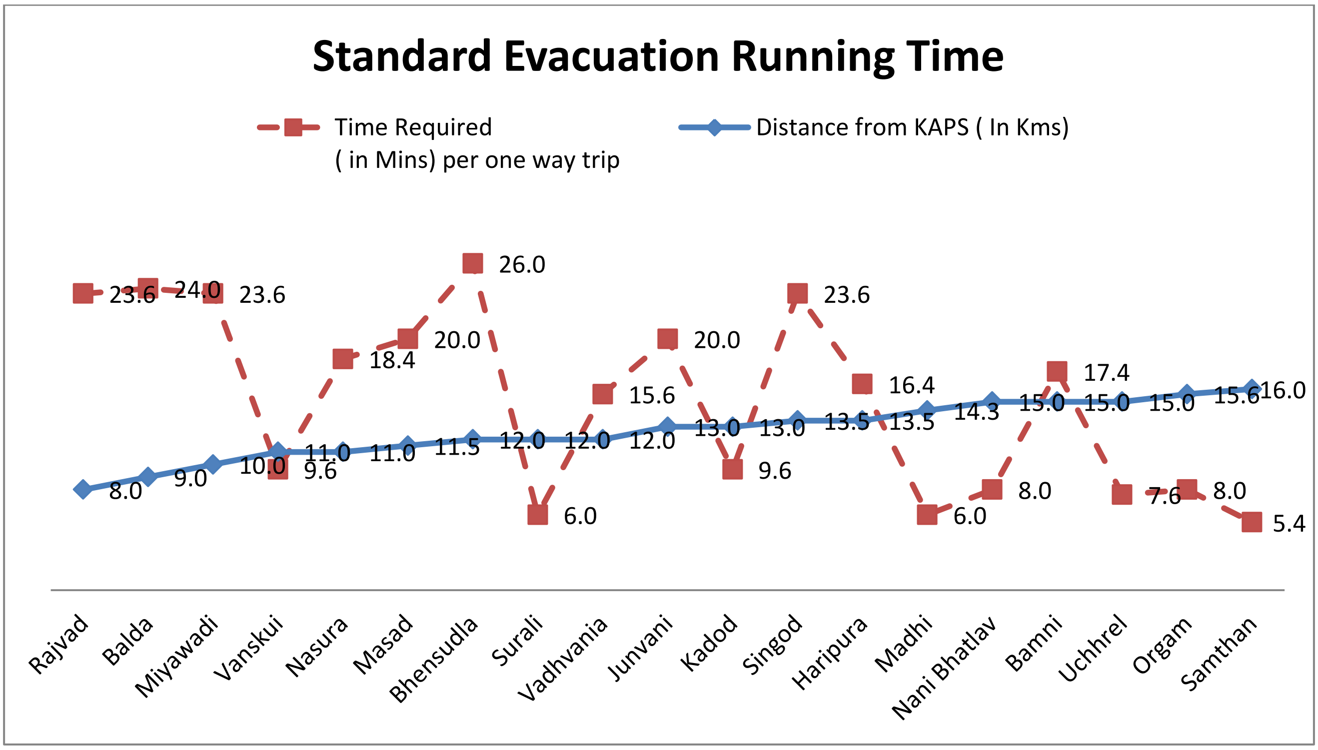

Figure 6: Standard Evacuation Running Time for each 19 villages

Ideally, the running time & distance should be indirectly proportional hence the red line should had been more smooth and continuously decreasing. But, due to orientation of village with respect to above classified types of road the running time does not hold the continuous proportionate relation with the distance. For example, we may observe from the graph that villages like Vanskui, Surali and Kadod have considerably lesser running time in comparison to their near villages. Similarly, on the other hand Bamni is disadvantageously located and takes larger time in comparison to nearby villages. The time shown in Figure 4 is based on the inputs of speed for each category of road and hence the final figure shall vary if we change the input. But, the priority which we have derived from this analysis will remain unchanged unless we change the input speed in proportion. Moreover, Table 3 provides the priority rank for each village within the each sector considering the distance impact of the radiation. Hence, default priority has to be on Sub-Zone basis.

Table 3 : Priority Rank for each village within its zone based upon Standard Evacuation Running Time

Sub Zone	Village	Sector	Standard Evacuation Running Time (In Mins)	PriorityRank (Time)
1 (0-5 Kms)	-			
2 (5- 8 Kms)	Rajvad	L	23.6	1
3 (8-11.5 Kms)	Balda	K	24	1
	Miyawadi	M	23.6	2
	Vanskui	K	9.6	5
	Nasura	L	18.4	4
	Masad	L	20	3
4(11.5-16 Kms)	Bhensudla	K	26	1
	Surali	K	6	11
	Vadhvania	L	15.6	6
	Junvani	L	20	3
	Kadod	M	9.6	7
	Singod	L	23.6	2
	Haripura	L	16.4	5
	Madhi	K	6	12
	NaniBhatlav	K	8	9
	Bamni	L	17.4	4
	Uchhrel	L	7.6	10
	Orgam	L	8	8
	Samthan	L	5.4	13

4.4 Population Factor

The population of each village will also have the impact on '**Total required time for evacuation"** and hence the priority index will change in accordance with the population. This factor also becomes crucial in the scenario that available transport resource may be scarce on immediate basis. We have taken forward the priority rank developed based on 'evacuation running time' and factored the population of each village into it. This rank is converted to an overall rank for all sub-zones as detailed in Table 4.

Table 4: Priority Rank for each village within its zone based upon Effective Evacuation Time including the Population Factor.

Sub Zone (Kms)	Village	Evacuation Running Time (In Mins)	Population (P)	Population Factor PF= (Pi/Pmin)	Eff. Evacuation Time Index (=P*PF)	Priority Rank (Effective Time)	Overall Rank
1(0-5)	-	-				-	
2(5-8)	Rajvad	23.6	1296	5.23	123.33	1	1
3(8-11.5)	Balda	24	2600	10.48	251.61	1	2
	Miyawadi	23.6	**248**	**1.00**	23.60	5	6
	Vanskui	9.6	2541	10.25	98.36	3	4
	Nasura	18.4	1087	4.38	80.65	4	5
	Masad	20	1990	8.02	160.48	2	3
4(11.5-16)	Bhensudla	26	1236	4.98	129.58	5	11
	Surali	6	10724	43.24	259.45	2	8
	Vadhvania	15.6	1724	6.95	108.45	7	13
	Junvani	20	720	2.90	58.06	9	15
	Kadod	9.6	11424	46.06	442.22	1	7
	Singod	23.6	2028	8.18	192.99	3	9
	Haripura	16.4	1741	7.02	115.13	6	12
	Madhi	6	7240	29.19	175.16	4	10
	NaniBhatlav	8	987	3.98	31.84	12	18
	Bamni	17.4	1399	5.64	98.16	8	14
	Uchhrel	7.6	1321	5.33	40.48	11	17
	Orgam	8	1330	5.36	42.90	10	16
	Samthan	5.4	978	3.94	21.30	13	19

Although, the data which we got is from 2001 census but any of the inputs can easily be updated in our model. A fair assumption is that population will grow in proportion over entire villages, hence the priority index will not change significantly.

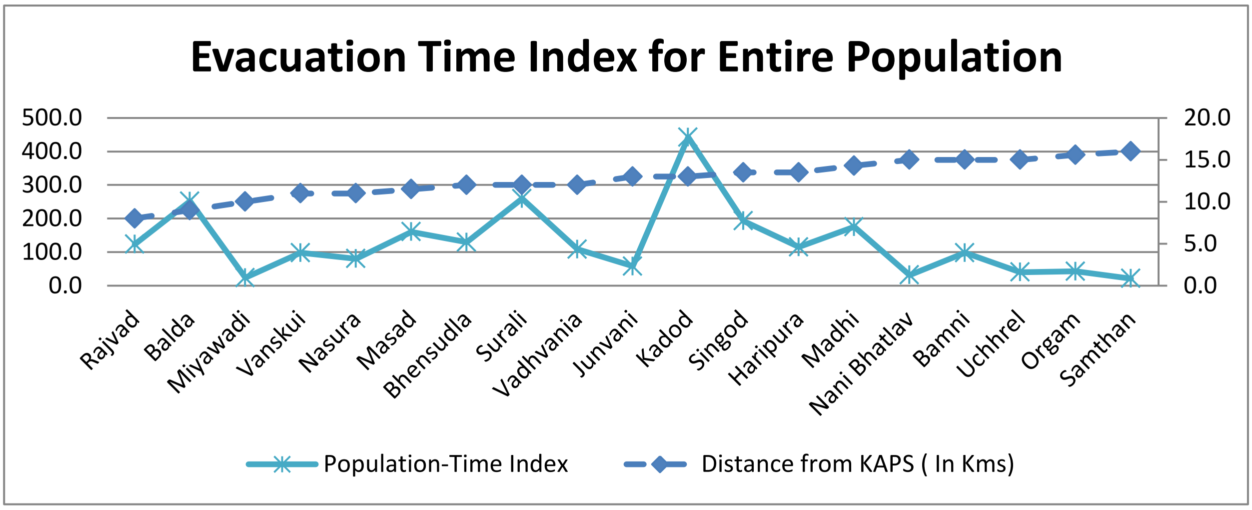

Figure 7: Evacuation Time Index with Entire Population for Each Village.

From Figure 7, we can visually observe that villages like Balda, Surali, and Kadod show huge spikes in comparison to their relatively nearby villages and hence need more attention and priority. Also, other villages like Madhi, Bamni, and Masad stand out for more attention.

4.5 Rallying Post

In order to determine the appropriate rallying post(s) we analysed the holding capacity of the potential locations that were nearby in terms of existing infrastructure and open spaces. Following are the details of the locations analysed:

Bardoli : (Enclosed 3200 + Temporary tents 5000 + Open Field)

- Primary School :
  - 500 person
- Community Hall:
  - 350 person
- High School:
  - 2200 person
- Gram Panchayat and Anganwadi :

  - 150 person
- Tent:
  - 5000 person

Kantali : (500 + 1200 + Open Field)

- Primary School :
  - 10 rooms each of capacity of 25 person = 250 person
  - Open fenced space = (40x75) 2000 sqft = 400 person
- Community Hall:
  - 2 nos. = 15 * 2 = 30
- Temple:
  - Enclosed premise : 200 person
  - Open fenced premise : (40 x 150) sqft = 800 person
- Gram Panchayat and Anganwadi :
  - 20 person
- Other Open Field:
  - Depend upon Government nod to tent-close the open fields.

Akoti : (215 + 250+ Open field)

- Primary School :
  - 4 rooms each of capacity of 25 person : 100 person
  - Open fenced space : (20x30) sqft = 100 person
- Community Hall:
  - 1 no. :15 person
- Temple:
  - Enclosed premise : 100 person
  - Open fenced premise : (20 x 50) sqft = 150 person
- Gram Panchayat and Anganwadi :
  - 20 person
- Other Open Field:
  - Depend upon Government nod to tent-close the open fields.

Khoj : (Open field)

- Primary School :
  - 80 person
  - Open fenced space :100 person
- Community Hall:
  - 2 nos. :15 * 2 = 30
- Temple:
  - Enclosed premise : 50 person
  - Open fenced premise :100 person
- Gram Panchayat and Anganwadi :
  - 20 person
- Other Open Field:
  - Depend upon Government nod to tent-close the open fields.

4.6 Inbound Logistics

From our discussion with the District Transport Office, we gathered that there are 5 bus depots that can contribute to the vehicle requirements for the evacuation plan - Bardoli, Mandvi, Songad, Surat & Olpad. However, we have eliminated 2 of these (Mandvi and Songad) as they would be handling the vehicle requirements of the other sectors. Each of the bus depots has a fleet of about 80 buses. Among the 3 bus depots that will be used, Bardoli is the nearest to all the villages. We have assumed a response time equal to time to travel from source depot and the respective villages.

4.7 Resource Allocation

As discussed previously, the evacuation of the villages depends on their priority which is determined by its population, evacuation time and sub-zone. Therefore, we have assumed the target evacuation time for each priority level. This is user configurable. For each village we have also determined the time taken by people/livestock to reach FSP on foot (by assuming an appropriate speed). If the time taken on foot is less than the target evacuation time for a particular village, we have assumed an appropriate proportion of the population (people/livestock) to be evacuated on foot. This proportion has also been left as a user input. We have used a VBA based optimization heuristic to calculate the optimum no. of buses and trucks required for each village. The objective is to evacuate the entire population within the target evacuation time.

4.7.1 Optimization Heuristic

We have developed an algorithm to optimally allocate the available buses to different villages. According to this algorithm, we go in order of the overall rank of the villages and allocate buses needed from the nearest available bus depot. For each village, we first calculate the total no. of bus trips needed using the following formula

No. of Bus-Trips needed (BT) = Population needing evacuation / Bus Capacity

The algorithm then increases the bus allocation to the village from the nearest available depot in increments of one. After every increment it checks whether the total implied time for evacuation is less than the target time for evacuation. The implied time for evacuation is calculated as follows

Implied time for evacuation = (LIF(BT / Buses allocated)*2 – 1) * (Time to reach safety point + Bus Capacity*Loading Time per person) + Time for bus to reach from the farthest depot allocated [*LIF(x) = Least integer greater than equal to x*]

The allocation stops when the implied time becomes less than target time. Figure 8 depicts the flow chart of the allocation algorithm.

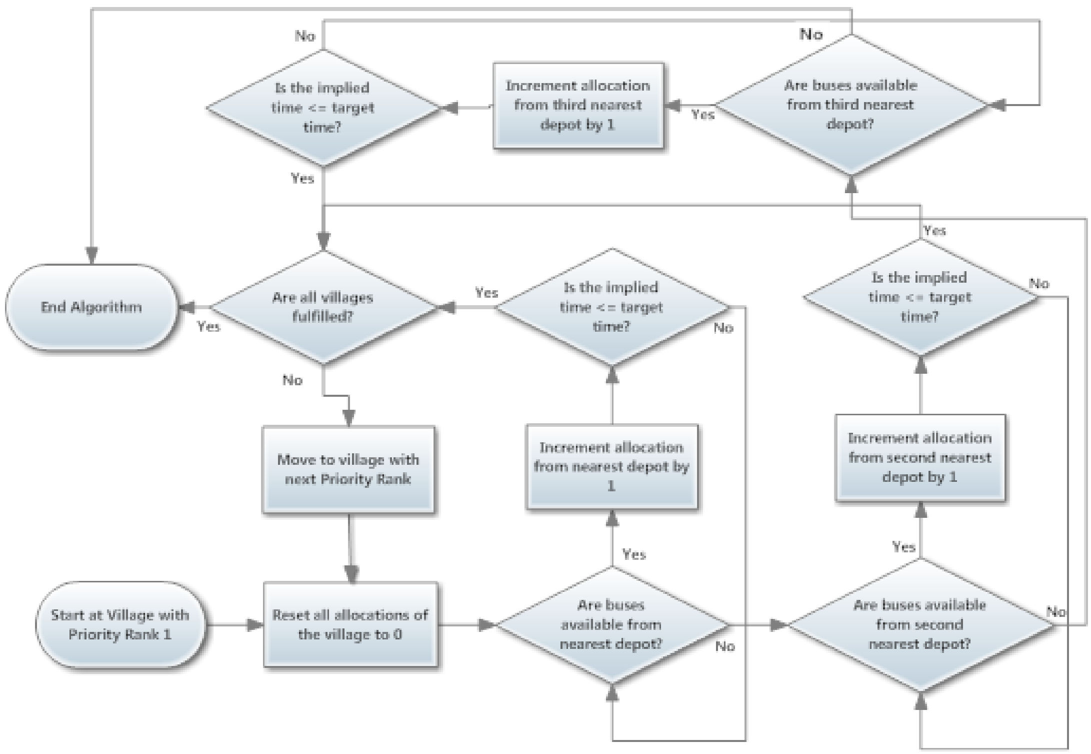

Figure 8: Flow chart of Resource Allocation Algorithm

Let's the take the example of Nasura (Overall rank = 5).

BT = 14.5

Target time = 120 mins

Time to reach safety point = 18.4 mins

Bus capacity = 75

Loading time per person = 0.067 mins

Time for bus to reach from Bardoli = 30 mins

Time for bus to reach from Surat = 67.2 mins

Time for bus to reach from Olpad = 93.6 mins

Iteration 1

	Allocated buses to Nasura	Available buses
Bardoli	1	5
Surat	0	80
Olpad	0	80

Implied time for evacuation = (LIF(14.5/1) * 2 - 1) * (18.4 + 75 * 0.067) + 30 = 709.3 mins

Implied time > Target time => Continue

Iteration 2

	Allocated buses to Nasura	Available buses
Bardoli	2	4
Surat	0	80
Olpad	0	80

Implied time for evacuation = (LIF(14.5/2) * 2 - 1) * (18.4 + 75 * 0.067) + 30 = 381.4 mins

Implied time > Target time => Continue

Iteration 3

	Allocated buses to Nasura	Available buses
Bardoli	3	3
Surat	0	80
Olpad	0	80

Implied time for evacuation = (LIF(14.5/3) * 2 - 1) * (18.4 + 75 * 0.067) + 30 = 240.8 mins

Implied time > Target time => Continue

Iteration 4

	Allocated buses to Nasura	Available buses
Bardoli	4	2
Surat	0	80
Olpad	0	80

Implied time for evacuation = (LIF(14.5/4) * 2 - 1) * (18.4 + 75 * 0.067) + 30 = 194 mins

Implied time > Target time => Continue

Iteration 5

	Allocated buses to Nasura	Available buses
Bardoli	5	1
Surat	0	80
Olpad	0	80

Implied time for evacuation = (LIF(14.5/5) * 2 - 1) * (18.4 + 75 * 0.067) + 30 = 147.1 mins

Implied time > Target time => Continue

Iteration 6

	Allocated buses to Nasura	Available buses
Bardoli	6	0
Surat	0	80
Olpad	0	80

Implied time for evacuation = (LIF(14.5/6) * 2 - 1) * (18.4 + 75 * 0.067) + 30 = 147.1 mins

Implied time > Target time => Continue

Iteration 7

	Allocated buses to Nasura	Available buses
Bardoli	6	0
Surat	1	79
Olpad	0	80

Implied time for evacuation = (LIF(14.5/7) * 2 - 1) * (18.4 + 75 * 0.067) + 67.2 = 184.3 mins

Implied time > Target time => Continue

Iteration 8

	Allocated buses to Nasura	Available buses
Bardoli	6	0
Surat	2	78
Olpad	0	80

Implied time for evacuation = (LIF(14.5/8) * 2 - 1) * (18.4 + 75 * 0.067) + 67.2 = 137.5 mins

Implied time > Target time => Continue

Iteration 9

	Allocated buses to Nasura	Available buses
Bardoli	6	0
Surat	3	77
Olpad	0	80

Implied time for evacuation = (LIF(14.5/9) * 2 - 1) * (18.4 + 75 * 0.067) + 67.2 = 137.5 mins

Implied time > Target time => Continue

Iteration 10

	Allocated buses to Nasura	Available buses
Bardoli	6	0
Surat	4	76
Olpad	0	80

Implied time for evacuation = (LIF(14.5/10) * 2 - 1) * (18.4 + 75 * 0.067) + 67.2 = 137.5 mins

Implied time > Target time => Continue

Iteration 11

	Allocated buses to Nasura	Available buses
Bardoli	6	0
Surat	5	75
Olpad	0	80

Implied time for evacuation = (LIF(14.5/11) * 2 - 1) * (18.4 + 75 * 0.067) + 67.2 = 137.5 mins

Implied time > Target time => Continue

Iteration 12

	Allocated buses to Nasura	Available buses
Bardoli	6	0
Surat	6	74
Olpad	0	80

Implied time for evacuation = (LIF(14.5/12) * 2 - 1) * (18.4 + 75 * 0.067) + 67.2 = 137.5 mins

Implied time > Target time => Continue

Iteration 13

	Allocated buses to Nasura	Available buses
Bardoli	6	0
Surat	7	73
Olpad	0	80

Implied time for evacuation = (LIF(14.5/13) * 2 - 1) * (18.4 + 75 * 0.067) + 67.2 = 137.5 mins

Implied time > Target time => Continue

Iteration 14

	Allocated buses to Nasura	Available buses
Bardoli	6	0
Surat	8	72
Olpad	0	80

Implied time for evacuation = (LIF(14.5/14) * 2 - 1) * (18.4 + 75 * 0.067) + 67.2 = 137.5 mins

Implied time > Target time => Continue

Iteration 15

	Allocated buses to Nasura	Available buses
Bardoli	6	0
Surat	9	71
Olpad	0	80

Implied time for evacuation = (LIF(14.5/15) * 2 - 1) * (18.4 + 75 * 0.067) + 67.2 = 90.6 mins

Implied time < Target time =>End

The algorithm has been used to allocate buses from the three bus depots to each village for the human population that needs evacuation. For livestock, since there is no available data for source of trucks, we have calculated the required no. of trucks assuming source to be entirely from Bardoli.

5. Results & Recommendations

Based upon our analysis, we have come up with the First Safety Points as an intermediate point for each village. Then, we have proposed rallying post for each FSP based upon the capacity. We have developed shortest evacuation route for each village which can be used during the disaster. We also incorporated the resource allocation to these villages based upon our heuristics model. We, further, translated our findings into recommendations for preparedness and immediate response.

5.1 First Safety Point & Rallying Post

Based on the analysis of the time taken to get to safety, the villages have been divided into 3 clusters. Each of the clusters has been allotted an FSP. Table 5 shows the village-FSP mapping.

Table 5 : Village- FSP Mapping

Villages	Priority Level	Safety Point
Balda	3	Syadla
Vanskui	3	Syadla
Bhensudla	4	Akoti
Surali	4	Syadla
NaniBhatlav	4	Akoti
Madhi	4	Syadla
Rajvad	2	Syadla
Masad	3	Kantali
Nasura	3	Kantali
Vadhvania	4	Kantali
Singod	4	Kantali
Junvani	4	Akoti
Orgam	4	Akoti
Bamni	4	Kantali
Haripura	4	Kantali
Uchhrel	4	Kantali
Samthan	4	Kantali
Miyawadi	3	Kantali
Kadod	4	Kantali

Based on our analysis we found that the FSPs would not be able to hold the entire population allocated to them on a long term basis. Thus post assembly at the FSP, part of the population needs to be diverted to other locations. Following are the final rallying posts for each FSP as shown in Table 6:

Table 6 : FSP & their Potential Rallying post

First Safety Point	Population Arrived	Rallying Post 1	Rallying Post 2	Rallying Post 3
Kantali	24401	Kantali	Villages between Kantali and Bardoli	Bardoli
Akoti	4273	Akoti	Bardoli	-
Syadla	23950	Syadla	Bardoli	-

The available data about the capacity of the villages are unable to meet the requirement of the entire population to be evacuated. We recommend developing facilities in the three FSPs and Bardoli based on the latest available population data. These facilities could be strategic in nature and not necessarily to be built for this disaster plan, for example high schools, hospitals etc.

5.2 Evacuation Route

Based upon our analysis of distance-matrix and First Safety Point (FSP), we have developed an evacuation route for all 19 villages. The snapshot of a sample route has been attached in Appendix 1. Each village has been assigned its FSP based upon the minimization of the evacuation time.

5.3 Resource Allocation

Using the Excel tool we have determined the vehicle requirement for each village based on certain user changeable assumptions. While running the resource allocation tool we have used some default assumptions (Appendix 2). Appendix 3 has the results for human population and Appendix 4 has results for Livestock.

5.4 Communication Strategy

Communication plays a pivotal role in disaster management. Lack of effective communication strategy can single handedly lead to the failure of a well thought out evacuation plan. Our recommended communication strategy is along the following three aspects:

a) **Nuclear Site Communication**

This aspect is responsible for maintaining the link between the nuclear site and the disaster management authorities. The disaster management authorities should be kept up to date with information on any radiation leaks and their intensity. We recommend using multiple channels of communication to ensure connectivity in the event of a disaster. Fixed line and wireless linkages should be supplemented with satellite communication sets to cover power failures and other disruptions.

b) Organizational Communication

This aspect is responsible for the coordination among government and non-government agencies involved in managing the disaster. During the time of evacuation the disaster management authority (GSDMA) would become the hub for all coordinated efforts of evacuation and relief. Robust communication channels should exist between the hub and the other agents involved like District transport office, Village administration (Panchayats), Local Hospitals etc. During the time of evacuation, the hub would monitor the progress of evacuation though these channels.

c) Ground Level Communication

This is the most critical aspect of communication during a disaster. It involves informing the masses about the disaster and the next steps in a timely manner. The responsibility of conveying information to the people lies with the village authorities. The village head could employ volunteers to gather the inhabitants in a single location and provide them with instructions for evacuation. Loudspeakers can be used for this purpose.

5.5 Evacuation Guidelines

These guidelines are specific to nuclear disaster plan and any other specific guidelines for an emergency disaster plan apply over it. It can be divided into preparedness, preventive measures and immediate response.

5.5.1 Preparedness

These activities need to be done as preparedness for the emergency response and should be reviewed every year. The prime responsibility lies with District Magistrate/Collector of Surat District who shall delegate the activities to concerned personnel at Taluka & Village level.

1. Communicate the Evacuation Route to each village: Gram Panchayat office should have the route-map stuck on the wall. It should be well communicated to residents on regular basis in case people want to use their private mode of transportation. Moreover, FSPs should be mentioned clearly. Assembly point in the village from where public transports will pick-up should be well marked and kept unblocked all the time.

2. Education & Training of villagers so that at the time emergency there is no panic. Nodal officer to identify volunteers.
3. Emergency Equipment: Equipment like Siren, Torch, Emergency Light, and Loud Speakers should be made available at each village.
4. At First Safety Point :
    a. Materials for temporary shelter should be available at these three FSPs - Tent cover, bamboos, rope, tools & tackle.
    b. Facility to administer Iodine.
    c. Iodine storage locations should be near to these places.
5. Wooden ramps for Loading & Unloading of Cattles & Sheep: Standard wooden ramps should be kept at each village and rallying post.
6. Issue guidelines to specify what to carry and what not to do: Locking up of individuals' home. Taking portable valuables with them. Avoid taking any food stuff and so on.
7. All contacts of bus depot, nuclear disaster management authorities etc. should be at one place in gram panchayat and in situation of emergency it should be easily accessible.
8. Sheltering: Sheltering is also very effective when radiation is quite low and for shorter duration. Evacuation has a disruptive effect hence, facilities for sheltering could be better alternative for certain situations. Sheltering facilities for at least sub-zone 1 & 2 is highly recommended. It also allows population to wait in safer conditions for the response to reach them. District administration to carry the Cost-Benefit analysis primarily in terms of social cost.

The responsibility of above mentioned activities has been identified in Table 7.

Table 7 : Responsibility Matrix for Preparedness Activities

Activity Sl. No.	Responsibility
1	Taluka Mamlatdar Officer to arrange and distribute the guidelines to Gram Panchayat Office. Nodal officer to communicate the guidelines among villagers on quarterly/half yearly basis.
2	Taluka Mamlatdar Officer to arrange, Gram Panchayat Office & Nodal officer to identify volunteers
3	District magistrate through Taluka Mamlatdar Office
4	a. District magistrate through Taluka Mamlatdar Office b. Chief District Health Officer (CDHO), Surat c. CDHO, Surat to recognize nearby Hospital as a storage center for Iodine.
5	Gram Panchayat Office to ensure as per village's need.
6	Taluka Mamlatdar Officer to arrange and distribute the guidelines to Gram Panchayat Office. Nodal officer to disseminate the guidelines among villagers on quarterly/half yearly basis.
7	Taluka Mamlatdar Officer to arrange from District Transport Office and distribute the list to Gram Panchayat Office. Nodal officer to ensure its easy accessibility at each village level.
8	District Magistrate is to take it up for approval. Project for building the Sheltering needs to be initiated.

5.5.2 Immediate Response: Village Level

These activities to be carried out as the Off-site emergency are announced by the concerned authority.

1. Communicate all to gather at assembly point without creating panic to the masses: Nodal Officer to take the responsibility.
2. Ask people to wait for the public transportation to arrive. Let people with their private vehicle move out either to FSP or Rallying Post.
3. Store water as much as possible for drinking purpose during sheltering.

4. Communicate consistently with government authorities and give updates of the ground situation on real time basis.
5. Check for the stuffs to be carried, locking up of individual houses while waiting for the transportation.
6. If there are doctors in villages do give them responsibility for general disease take-up during entire evacuation to safe zone.
7. At first safety point people will be dropped at one common place from where they would be guided to temporary shelters like mandir, community hall, gram panchayats, aanganwadi, government schools.
8. At first safety point, required iodine dose to the affected victims should be provided for which necessary guidelines related with health and safety are to be provided to gram panchayats of FSPs.
9. All FSPs should have good communication and co-ordination during emergency so that affected people could be evacuated to rallying points in due time.
10. Gram panchayat could identify some private houses which could be asked for shelters at the time of emergency.

The responsibility for these activities has been mentioned in Table 8 as follows:

Activity Sl. No.	Responsibility
1	Nodal officer to inform Volunteers and villagers.
2	Volunteers & Guidelines Sheet
3	Volunteers
4	Volunteers ->Nodal Officer -> Panchayat -> Taluka Mamlatdar - > District magistrate (if any)
5	Volunteers
6	Volunteers
7	Taluka Level team-> Nodal Officer
8	Chief District Office
9	Taluka Level team-> Taluka Level team →Nodal Officer
10	Gram Panchayat to mark those houses after discussing with the families.

6. Conclusion

The evacuation plan developed in this project includes evacuation routes for all 19 villages, resource allocation to them to ensure fastest possible evacuation. The optimization of risk and resources was based on the analysis of distance, standard evacuation running time and effective evacuative time for each village within the EPZ and location search for potential rallying post. The same analysis and methodology can be carried forward for all other villages and sectors under EPZ.

Due to our limited duration of engagement with the project, we envisage the future scope of project to have more detailed recommendations on operational level. For example, a model to monitor the ongoing operations with various communication mechanisms could be incorporated. We can also extend it to develop a Standard Operating procedure manual for the nuclear disaster and the evacuation plan. Moreover, the project can easily be extended for remaining villages of all sectors under EPZ.

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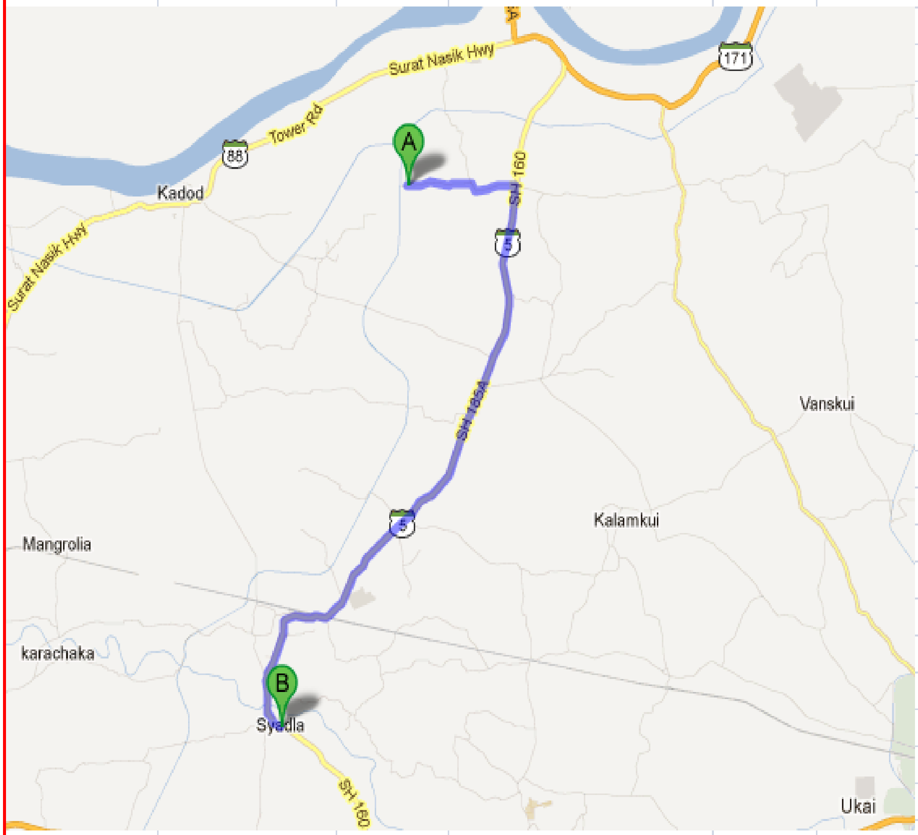
Appendix

Appendix 1

Sample Evacuation Route

Speed (Km/Hr)				
50	25	15		A= Rajvad
Evacuation Distance (Km)				B= Syadla (Beyond 16 Km)
State Highway	Other Route	Village	Time Required (in Mins)	
13	0	2	23.6	
SH-5		Nasura Rd		



Village	Rajvad
FSP	Syadla

Appendix2

Default Assumptions

Speed Assumptions

Road Type	Expected Speed (Km/Hr)
Village	15
Other Route	25
Highway	50
Pedestrian	5
Livestock	3

Target Evacuation Time

Priority Level	Time (Mins)
1	45
2	90
3	120
4	150

Vehicle Capacity Assumptions

		Type of Passenger		
		Humans	Cattle	Sheep/Goat
Vehicle Type	Bus	75	0	0
	Truck	N/A	10	25

Vehicle Loading/Unloading time per person (mins)

		Type of Passenger		
		Humans	Cattle	Sheep/Goat
Vehicle Type	Bus	0.067	N/A	N/A
	Truck	N/A	2	0.5

Appendix 3

Resource Allocation for Human Population

Villages	Overall Rank	Population	% of population needing evacuation	Target Evacuation Time	Bardoli Depot	Surat Depot	Olpad Depot
Balda	2	2600	100%	120	35	0	0
Vanskui	4	2541	60%	120	7	0	0
Bhensudla	11	1236	60%	150	0	0	10
Surali	8	10724	60%	150	0	22	0
NaniBhatlav	18	987	60%	150	0	0	0
Madhi	10	7240	60%	150	0	0	20
Rajvad	1	1296	100%	90	18	0	0
Masad	3	1990	100%	120	14	0	0
Nasura	5	1087	100%	120	6	9	0
Vadhvania	13	1724	60%	150	0	0	14
Singod	9	2028	60%	150	0	14	3
Junvani	15	720	60%	150	0	0	6
Orgam	16	1330	60%	150	0	0	1
Bamni	14	1399	60%	150	0	0	12
Haripura	12	1741	60%	150	0	0	14
Uchhrel	17	1321	60%	150	0	0	0
Samthan	19	978	60%	150	0	0	0
Miyawadi	6	248	100%	120	0	4	0
Kadod	7	11424	60%	150	0	31	0

Appendix 4

Resource Allocation for Livestock

Villages	Cattle Popl'n	Sheep & Goat Popl'n	% of population needing evacuation	Target Evacuation Time	Cattle Trucks Allotted	Sheep / Goat Trucks Allotted
Balda	1426	8	100%	120.0	143	1
Vanskui	1364	36	100%	120.0	138	1
Bhensudla	1100	6	100%	150.0	111	1
Surali	4880	37	0%	150.0	0	0
NaniBhatlav	732	0	0%	150.0	0	0
Madhi	962	35	0%	150.0	0	0
Rajvad	563	36	100%	90.0	58	2
Masad	1078	167	100%	120.0	115	7
Nasura	199	213	100%	120.0	29	9
Vadhvania	369	273	100%	150.0	24	6
Singod	248	103	100%	150.0	29	3
Junvani	116	21	0%	150.0	0	0
Orgam	512	194	0%	150.0	0	0
Bamni	353	79	0%	150.0	0	0
Haripura	302	160	100%	150.0	19	4
Uchhrel	372	98	0%	150.0	0	0
Samthan	258	32	0%	150.0	0	0
Miyawadi	28	38	100%	120.0	5	2
Kadod	673	113	0%	150.0	0	0