[SARO]

D.S.S. for Search & Rescue Resource Allocation in Response to an Earthquake

CORE - AR3B012 (2023/24 Q1)
Faculty of Architecture and the Built Environment
Delft University of Technology

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Necessity of efficient Search and Rescue resource allocation

Introduction of problem

In the aftermath of natural disasters like earthquakes, the efficient management of Search and Rescue operations is crucial. Injured people are in need of medical assistance, and time is of the essence, and there are not enough rescue teams for all people in distress. Accurate decision making is challenging given the limited time, resources and chaotic environment.

Chaotic environment

- Lack of Information: Chaos can lead to a lack of comprehensive information about the extent of the disaster and the status of affected individuals. Decision makers may have incomplete or inaccurate data to base their decisions on.
- Lack of overview across multiple organizations. In case of an earthquake there are many different organizations providing aid. A lack of coordination and overview often occurs amongst these entities, potentially resulting in inefficiencies like double efforts or inadequate resource allocation.
- Poor decision making. Under the pressures of panic and desperation, individuals are prone to making poor decisions, particularly those lacking proper training.

Limited time

- Decay of life. Quick and efficient resource allocation is vital in earthquake response because it directly affects the speed of life-saving efforts and preventing further injuries.
- Secondary hazards. Once an earthquake has struck, the affected areas can experience rapidly changing conditions, such as aftershocks, fires, and collapsing structures, which can pose further dangers to trapped individuals

Limited resources

- Resource scarcity. In earthquake scenarios, the demand for SAR operations consistently exceeds the available supply, resulting in a resource scarcity that necessitates efficient allocation.
- Resource imbalances. Uncertainties and unknown data enlarge the risk of SAR resources being allocated improperly, Areas might receive more or less resources than actually required.
- Transportation limitations. Once rescue teams have been assigned to a location, it is hard for them to relocate due to the damaged infrastructure .

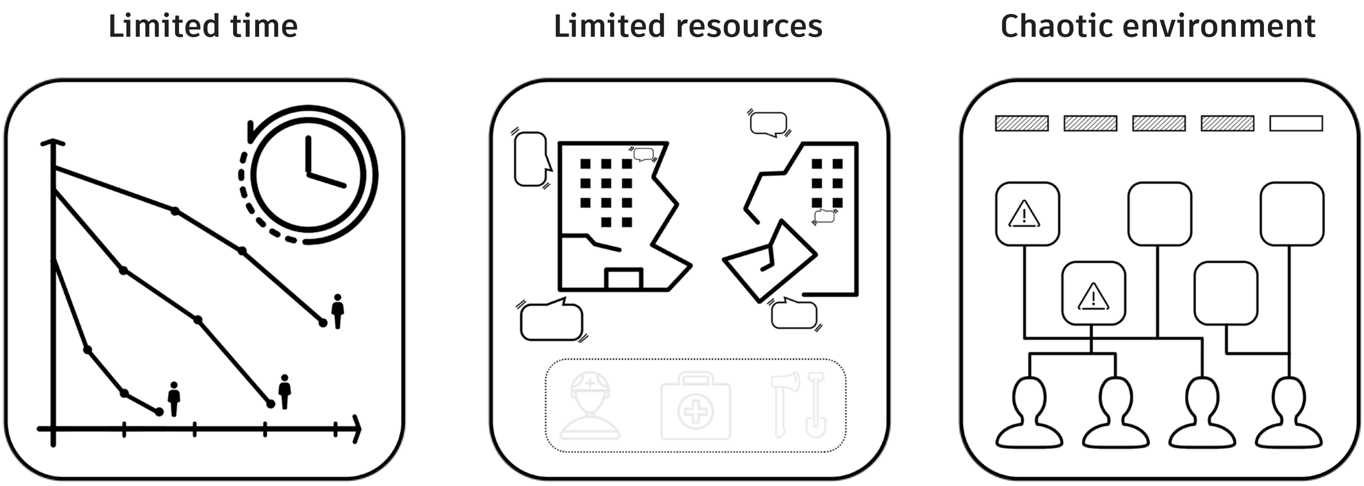


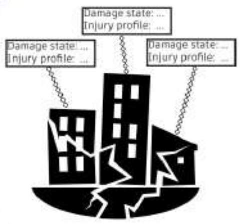
Figure 1: Challenging conditions search and rescue operations. Own work.

SARO: Search And Rescue Optimisation

Project goal

‘Saro’ is a Decision Support System Tool designed to address the challenges discussed in the previous page. It helps analyse the situation and make quick computational decisions, creating plans to allocate rescue teams of multiple organizations like Police and Firefighters, Task forces, Urban Search and Rescue Teams, and Volunteers, to various sites of action. The tool also prescribes an optimal sequence of allocation efforts for each team, in order to maximise the number of lives that can be saved, working to achieve the overarching goal:

“Minimise loss of life, alleviate suffering, and prevent further harm by more efficiently locating, rescuing, and providing aid to individuals affected by the disaster.”

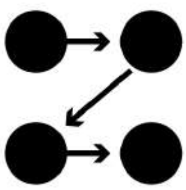


Accurately predict damages & distress

The tool accurately predicts the damage state and potential injuries for each building in the aftermath of an earthquake, addressing the problem of chaos and lack of data. This information is crucial for search and rescue operations to make informed decisions about resource allocation in chaotic post-disaster environments.

Collaborative resource allocation for Search & Rescue

The tool also facilitates better coordination among various organizations providing aid, addressing the problem of a lack of overview and coordination. By merging communication and resource allocation, it reduces inefficiencies like double efforts or inadequate resource allocation, thereby enhancing the overall effectiveness of earthquake response efforts.



Optimize allocation and its sequence based on multiple criteria

Through systematic assessment using multiple criteria, the system prioritizes critical, time-sensitive actions, improving disaster response efficiency. This approach saves lives and minimizes long-term disaster impact by addressing priorities. It optimizes resource allocation for life-saving efforts in the chaotic post-disaster setting, tackling resource and time constraints.

SARO: Search And Rescue Optimisation

Project framework

The project is set up in two parts:
Part A: Building & Context Assessment. In the immediate aftermath of the earthquake, the tool computes the probable damages and injuries incurred in buildings using theoretical models and heuristics.

Part B: Search and Rescue resource allocation and scheduling. A two-phased framework is established for optimal resource allocation

- Phase one relies on data gathered from part A and uses a 'priority weighting method' to estimate the 'criticality' of sites, allowing the allocation of first responders' capabilities in the initial 24 hours.
- Phase two starts when real-time updates from drones, satellites, recon teams or other sources are received on building conditions and trapped victims. This information guides the preparation of a second phase response, including international specialized teams. The tool aims to optimize resource allocation by matching rescue competence to site requirements and providing a time-sensitive itinerary for response.

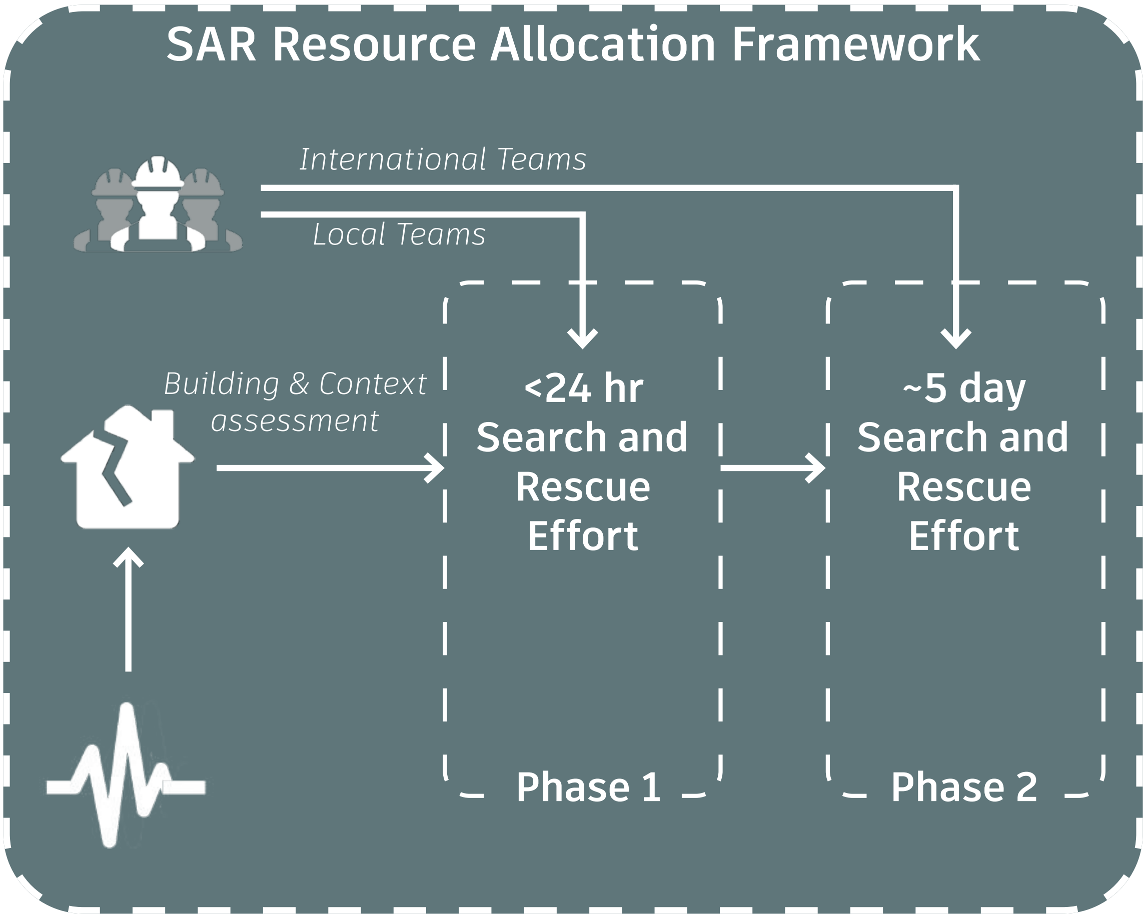


Figure 2: Phased framework of resource allocation & scheduling. Own work.

SARO: Search And Rescue Optimisation

Case study: Gaziantep

As a proof of concept, we will apply our framework on a case study on the Turkish city of Gaziantep. For two main reasons, this area has been chosen:

1. We had contact with the municipality of Gaziantep which offered the potential of acquiring essential input data.
2. Gaziantep is located close to the earthquake's epicenter (Figure 3), making it a crucial location for analysis. Therefore, studying Gaziantep is important because it helps us grasp the specific difficulties and reactions in places hit hard by earthquakes.

We will consider three areas of Gaziantep for our framework (Figure 4):

1. Pancarlı Mahallesi
2. Gazi Mahallesi Muhtarlığı
3. Sarıgüllük Mahallesi

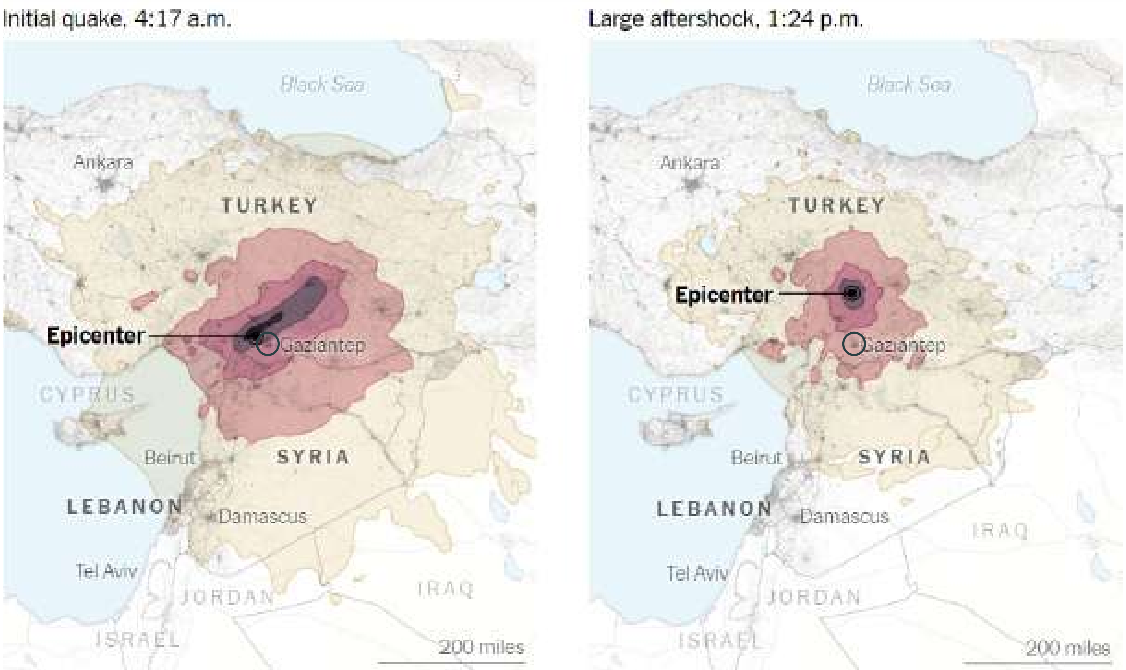


Figure 3: Earthquake epicenter. Robles et al. (2023)

Figure 4: Location Gaziantep. Google Earth (2023)

PART A

Building & Context Assessment

Part A: Overview and focus

Damage assessment, SAR assessment

The first part of the project pertains to trying to understand the problem.

In this case, it means to gather data as quickly as possible about:

- The **damages** incurred by the buildings in the aftermath of the earthquake,
- The **injuries** suffered by the building occupants as a result of the above.

The actual surveilled data about injuries and building damages is a data collection process that can take hours or days (and is beyond the scope of this project).

This means that for a rapid response, the tool must have a mechanism to **predict or project the probable damages and injuries incurred, to facilitate a First Phase of prompt SAR (Search and Rescue) response.**

Input data:

Occupancy

This refers to estimates of the occupants in the various buildings at the time of the earthquake event. It is based on census data and temporal building use data.

Earthquake Data

The key parameters of the earthquake- in this case primarily the Intensity Measures. This data is usually available minutes after an earthquake strikes.

Building Data

The list of parameters that describe the buildings behaviour in an earthquake, and also the nuances of the SAR scenario. There are a host of parameters possible, depending on the L.O.D. of the damage assessment and SAR simulation.

Part A: Overview and focus

Workflow concept

Processing the input data

Having collected the input data, the appropriate method must be selected to process it to create predictions of Building Damages and Injury profiles.

The key challenges to this are:

The scale of the assessment:

The number of buildings in question range in the thousands. Whereas it is possible to make somewhat more deterministic predictions of building failure modes (given Intensity Measure) using advanced methods, the computational effort to do this rapidly for a large set of buildings is formidable and likely impractical.

The lack of available building data:

In many countries, the engineered construction data is not available. It should either be methodically (and truthfully) documented during construction, or should be collected retroactively as data by an elaborate survey project. In the absence of this data, particularly in masonry and Concrete building systems, the problem approaches a black box- the mechanical behaviour is less predictable.

Building damage to Injury Relations:

Perhaps the most elusive question of all- how to create a relationship between injuries and building damage? This one of the more complex loss analysis problems.

The approach towards these are often to use probabilistic methods instead of deterministic ones, and create correlations bassed on empirical data, and codify in disaster management manuals as done by Hazus or ESRM (Crowley et al, 2021)

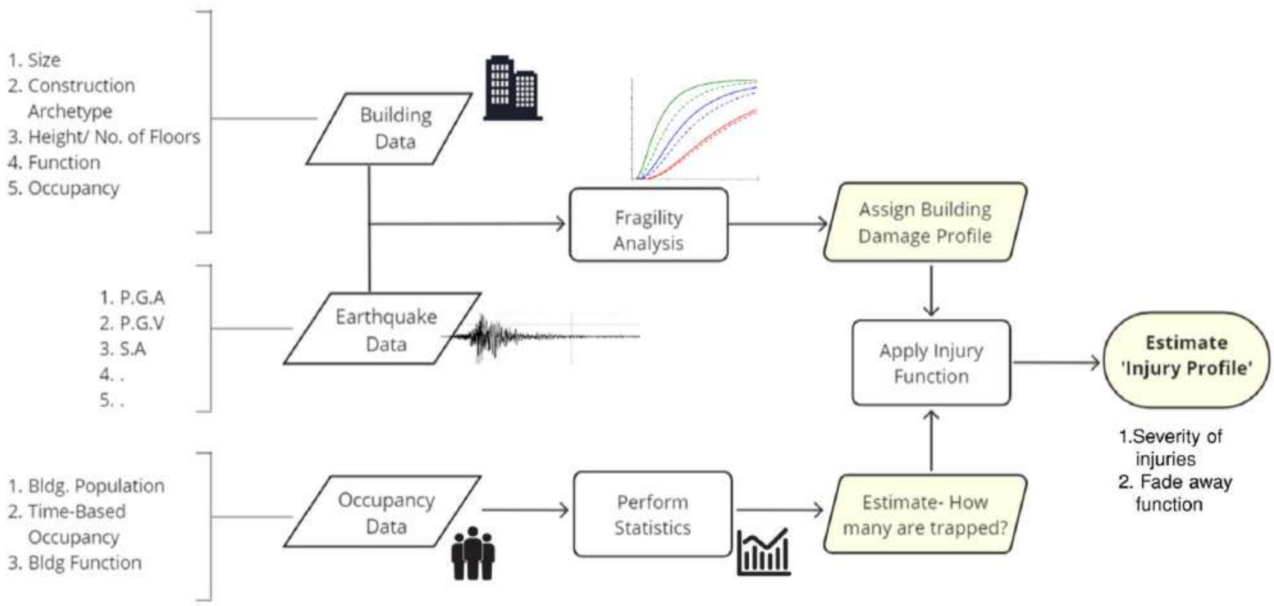


Figure 5: Part A overall workflow, early sketch (own source)

Part A: Overview and focus

Occupancy Data

The estimate of the occupants should typically be based on the census data.

The level of detail shall be at the level of each ‘dwelling’ in a building. This could be a single apartment (if residential) or a single shop(if commercial or industrial).

In the case of our project, other building types like institutional buildings, agriculture barns, warehouses or special buildings like laboratories, are not considered, as the geographical scope of our Proof of Concept simulation is quite small, and so is the percentage of these building types in the urban distribution. These buildings can be included in the scope for further study in future.

This census data is ideally available as GIS data. If not, it should be transcribed as GIS data to proceed with this tool.

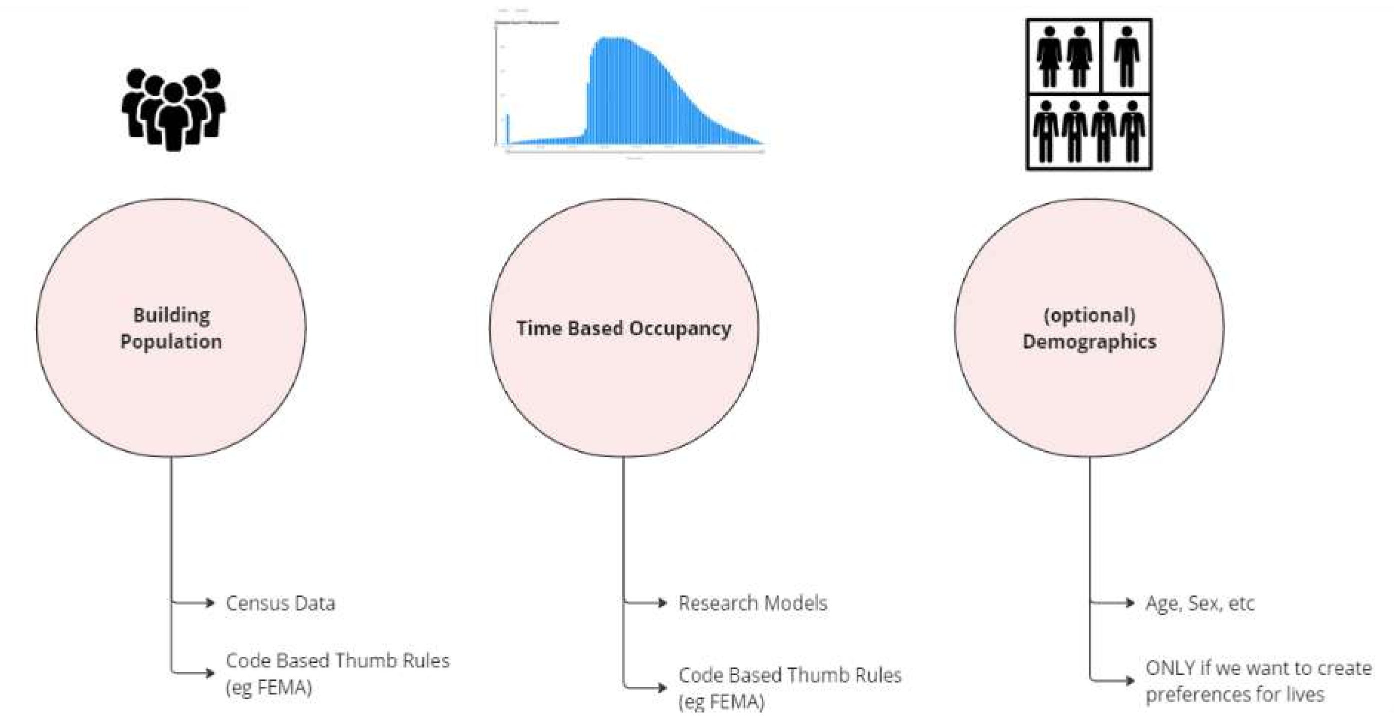


Figure 6: Components of occupancy data (own source)

Part A: Overview and focus

Occupancy Data

Temporal Patterns

The occupants of a building vary based on time of day. For example, residential buildings are fully populated at night, and commercial and industrial buildings are quite empty. In the day, this is somewhat reversed.

This level of detail cannot often be captured reliably in census data, due to the changing nature of employments etc. It may be more convenient to describe this behaviour at a city (or country) level with Occupancy Curves (Figure 1), or Personnel occupancy distrubution as used by agencies like HAZUS-MH OR ESRM (Figure 2).

IN the development of SARO, ESRM's occupancy distribution has been used as calculated for Gaziantep, Turkiye, using the population distribution model from PAGER(Jaiswal and Wald, 2010)

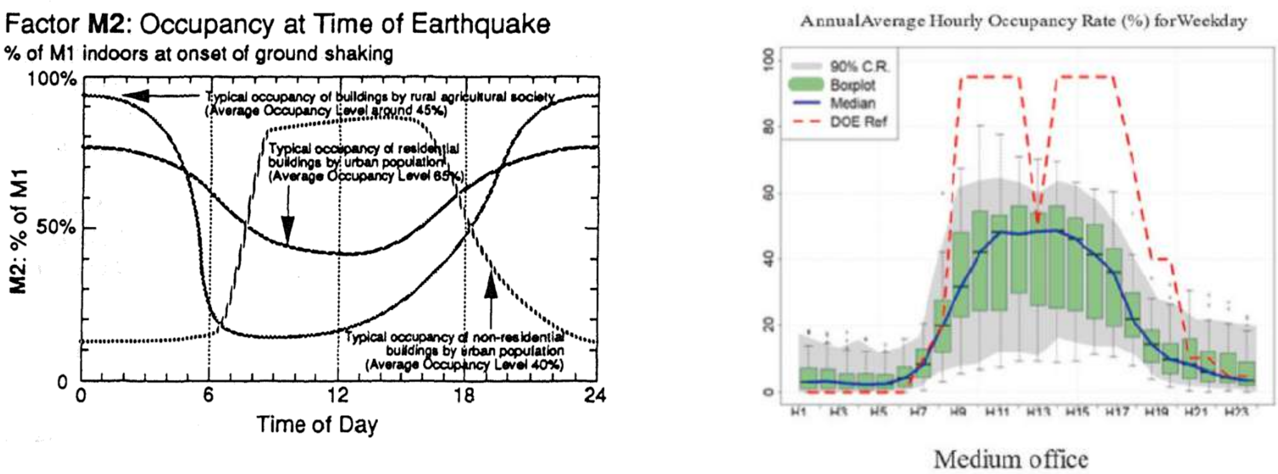


Figure 7: a, b: Coburn et al, 1992, Occupancy Curves for various type of buildings; G. Jiefan, 2018, Extracting typical occupancy data of different buildings from mobile positioning data, Energy Build 180

Table A2
Distribution of people in census tract (indoors).

Occupancy	2:00 a.m.	2:00 p.m.
Residential	0.99	0.75
Commercial	0.02	0.8
Educational	–	0.8
Industrial	0.10	0.8
Hotels	0.999	0.19

MACRO_TAXONOMY	OCCUPANTS_PER_ASSET	OCCUPANTS_PER_ASSET_DAY	OCCUPANTS_PER_ASSET_NIGHT	OCCUPANTS_PER_ASSET_TRANSIT	OCCUPANTS_PER_ASSET_AVERAGE
Concrete frame with infill panels, mid rise, low/moderate code	918.749	246.72	893.553	564.611	568.294
Wood, low rise	30.5232	8.19667	29.6861	18.7578	18.8802
Concrete frame with infill panels, mid rise, low/moderate code	3557.48	955.322	3459.92	2186.23	2200.49
Concrete frame with infill panels, mid rise, low/moderate code	14238.5	3823.58	13848	8750.15	8807.24
Concrete frame with infill panels, mid rise, low/moderate code	5604.37	1504.99	5450.67	3444.13	3466.6
Concrete frame with infill panels, mid rise, low/moderate code	1539.76	413.486	1497.53	946.249	952.422
Concrete frame with infill panels, low rise, low/moderate code	912.072	244.927	887.059	560.507	564.164
Concrete frame with infill panels, mid rise, low/moderate code	610.87	164.042	594.117	375.406	377.855
Concrete wall, low rise, low/moderate code	203989	54779.1	198395	125360	126178

Figure 8: a, b: F.E.M.A, 2001, Specific description of building types; Crowley, H. 2021, Distribution of occupant data for buildings in Gaziantep

Part A: Overview and focus

Earthquake Data

The type of earthquake data used depends on the nature of the seismic analysis being conducted on the building stock. For simulations or calculations on smaller buildings, a wave form has been usen containing frequency, acceleration and directionality data, to compute dynamic loading on buildings using tools like Alpacafor Grasshopper or other such, as used by our colleagues.

For larger data sets like those used to calculate the risk metrics of ESRM20, stochastic catalogues are used (Crowley et al, 2021).

Typically a hazard model comprises both **Ground Motion Models** and **Seismogenic Source Models**. The latter informs about the Fault Types and distribution. The former describes the median and beta for a range of ground shaking intensity measures.

The SARO Project

For SARO, such a hazard model based approach is out of the scope, as it is assumed that the key intensity measures are appropriately recorded/ probabilistically computed for the location (Gaziantep) and do not need to be determined by the SARO team. The Intensity Measures considered are

-Peak ground Acceleration
- Spectral Acceleration 0.3s
- Spectral Acceleration 0.6s
- Spectral Acceleration 1.0s

These are the attributes used by the OpenQuake Engine (EFEHR) to describe damage state probabilites for Buildings using fragility and capacity curves.

This data is available at resources like USGS and SAGE. For SARO simulations, some past earthquake presets are used, like the Feb 2023 Elbistan (Turkiye) Earthquake.

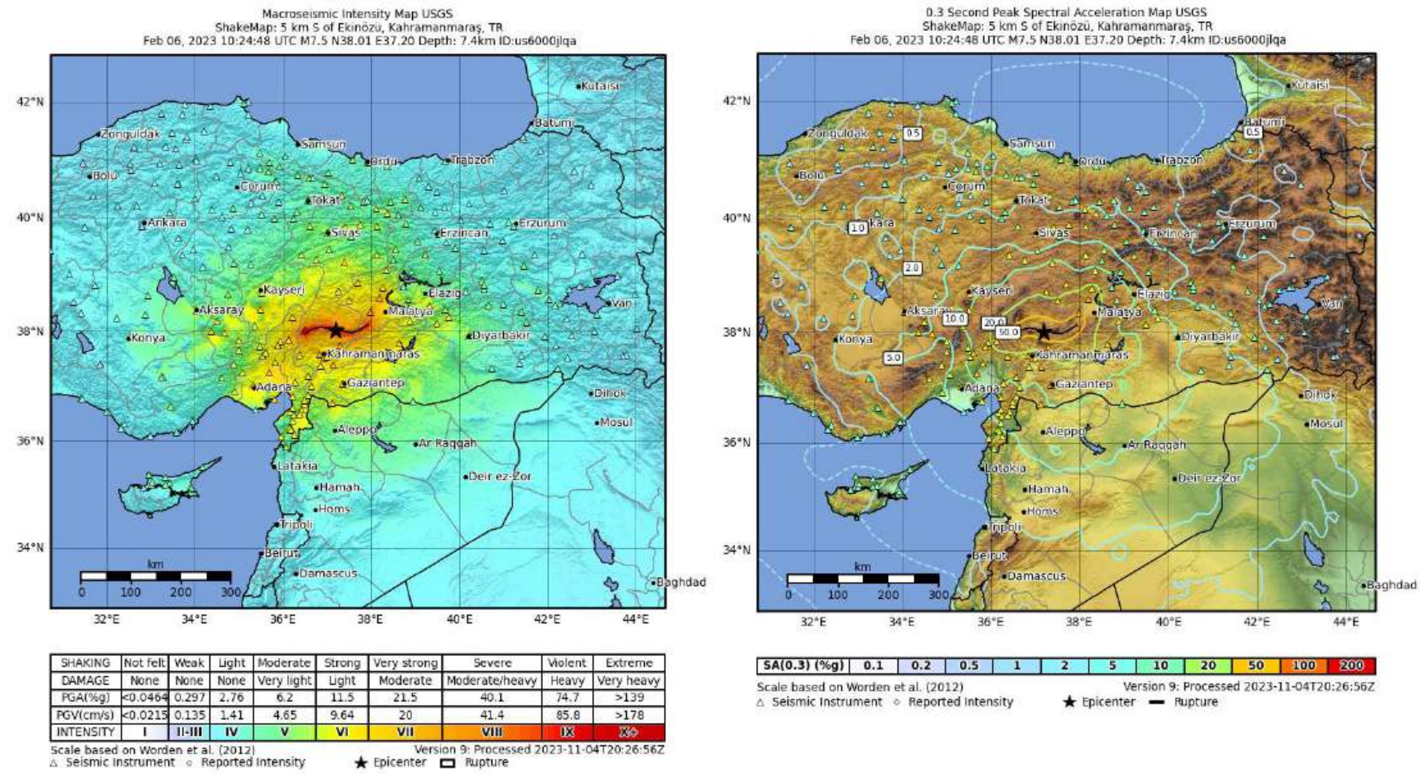


Figure 9: Key earthquake parameters are sources from USGS and SAGE databases

Part A: Risk Analysis: Research

Overview

There are multiple models that may be used to for the Seismic analysis of Buildings at an uurban scale. Some of the commonly used methods are:

1. Fragility Analysis
2. Capacity Spectrum methods using pushover analysis (SDOF simplified)
3. Nonlinear Time History Analysis (THA) using MDOF models
4. Nonlinear THA using FEM models.

Fragility analysis method:

In principle, this method is used to relate an engineering demand parameter (like a spectral response) to the probability of a building being in, or exceeding a given damage state. Oftentimes there is assumed to be a deterministic relation between a seismic intensity measure (IM)and p.Exceedance, so the fragility curve can also be plotted with p exceedance against the I.M itself (as is recommended in the HAZUS manual for Lifeline buildings (FEMA, 2001)

The key features of this description involve a Median value of IM/ EDP measure at which the building reaches the DS threshold, and a beta value- the standard deviation of the natural logarithm of the IM for the given DS.

These median and beta functions are usually developed empirically, statistically and by expert judgment (FEMA, 2001).

Advantages:

1. Computationally simple and efficient (Singhal and Kiremidjian 1996; McCormack and Rad 1997)
2. Especially applicable for non engineered buildings (Xiong C, 2019)
3. Statistical base makes it particlarly suitable for large datasets of buildings. (FEMA, 2001).

Disadvantages:

1. A bit oversimplified and loses accuracy for smaller building sets, cannot cater to variations at individual building level.
2. Cant capture the frequency and time domain dependent characteristics of Earthquakes (Xiong C, 2019).

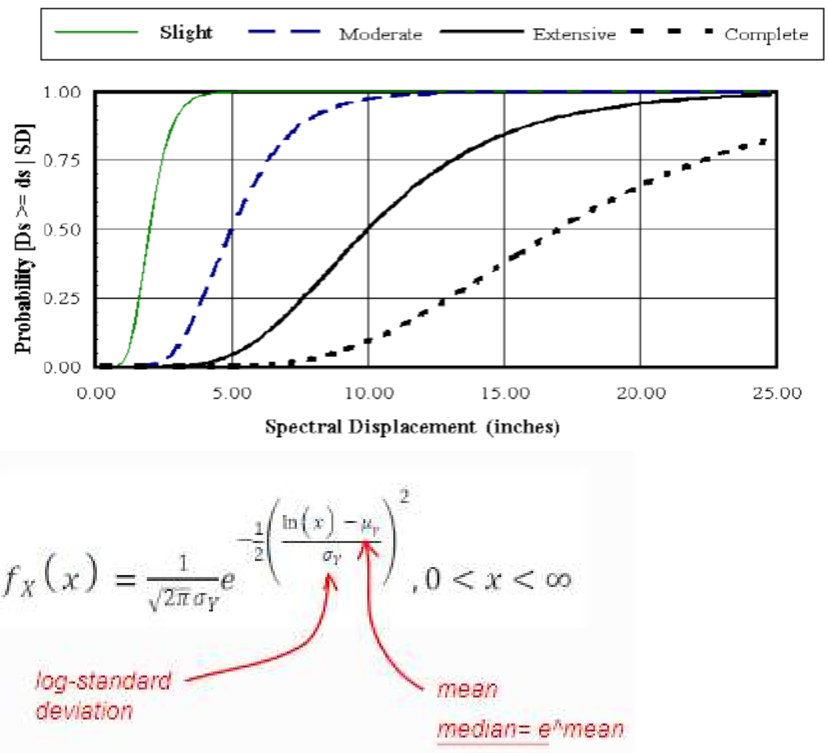


Figure 10: a. Typical fragility curve plotset for a builing againast the EDP- Spectral Displaement. Each curve represents the domain of one damage state, from 1 to 5. b. The mathematical relation- lognormal distibution.

Capacity spectrum method:

A building capacity curve(pushover) is a plot of a building's lateral load resistance as a function of a characteristic lateral displacement (i.e., a force-deflection plot). Three control points that define model building capacity describe each curve (FEMA, 2001).

-1. Design Capacity
2. Yield Capacity
3. Ultimate Capacity

The capacity curve of each building can be obtained from the pushover curve by simplifying the building into a single-degree-of-freedom (SDOF) model.

Median capacity curves are intersected with demand spectra to estimate the seismic response of the building. The variability of the capacity curves is used, with other sources of variability and uncertainty, to define total fragility curve variability. (FEMA, 2001).

Advantages:

1. Much better to capture the nonlinear behaviour of structural materials (plasticity)

2. Can take into consideration the frequency parameter of Earthquake motions

3. Computationally relatively efficient compared to other techniques.

Disadvatages:

The only major disadvantages arise during analysis of tall structures as it does not properly seem to account for higher order vibration modes of high rise structures.

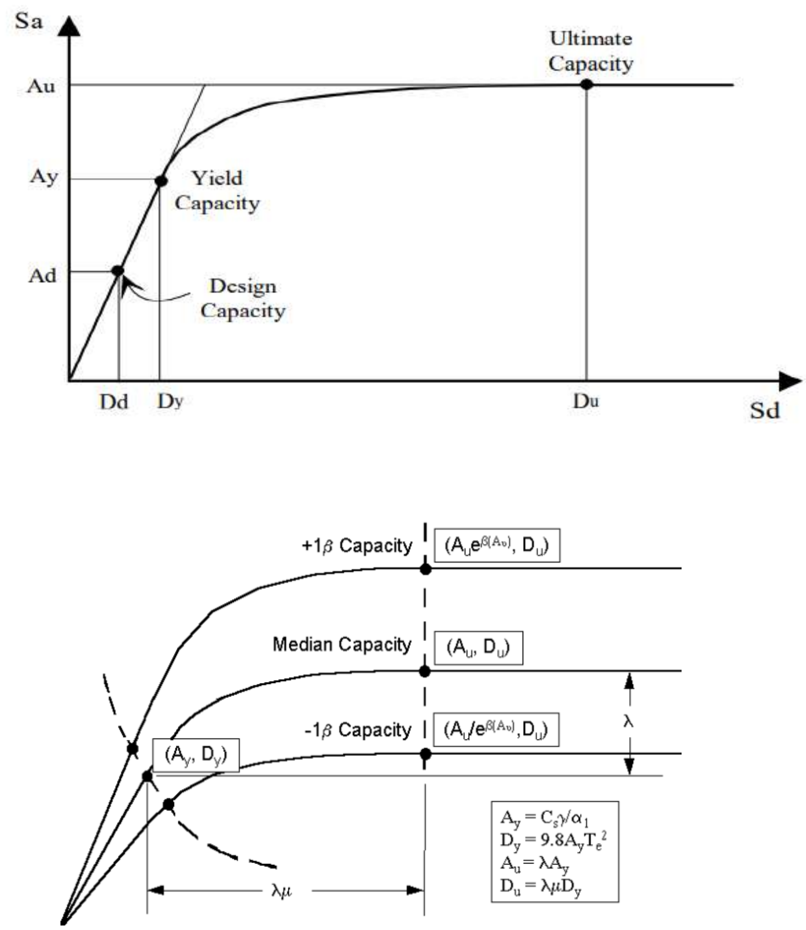


Figure 11: a. Typical capacity curve plotset for a builing- Spectral Acceleration Vs Spectral displacement. (FEMA, 2001) b. Demand spectrum overlaid on a typical capacity curve to identify seismic responses (FEMA 2001)

Part A: Risk Analysis: Research

Overview

NonLinear Time History Analysis using multiple degrees of freedom, or FEM methods:

These methods and hysteretic analyses are particularly suited to tall buildings and can better capture the effects of higher order vibration modes, as well the he effects of cyclic loading on buildings.

However they seem to require assumptions or data on joint behaviour. This demands more documentation on the specifics of the buildng construction and are moreover, computationally intensive analysis methods.

For these reasons, these methods have not been considered for application for the SARO project. At the urban scale it was deemed unfeasible.

Furthermore, floor level or join level failure iformation is to fine a Level of Detail for the requirement of the Saro Project.

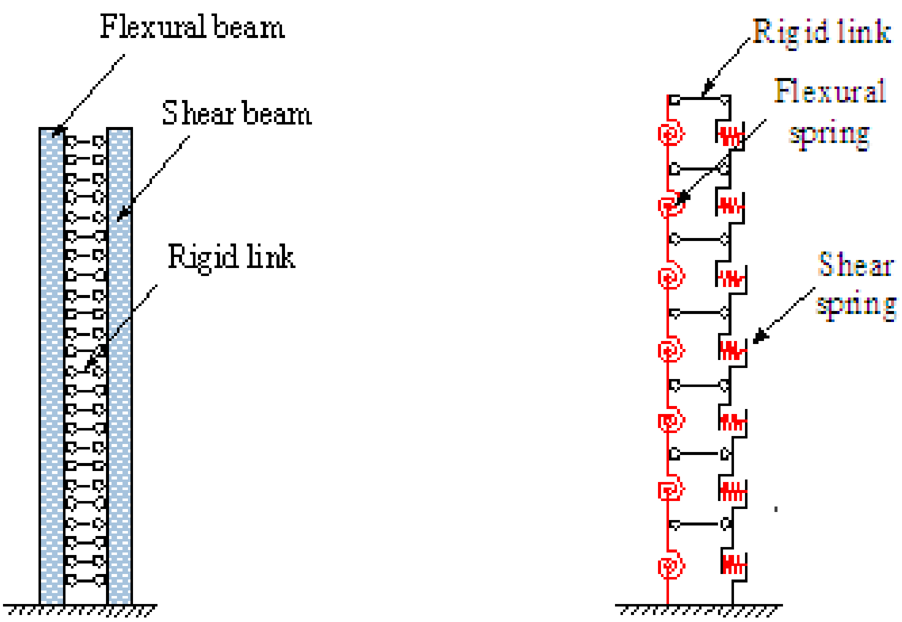


Figure 12: a. TThe elastic continuum model proposed by Miranda and Taghavi (2005) b. NMFS model proposed by Xiong c et al, 2016

Part A:

Chosen Loss Assessment method- Fragility Functions

The chosen Method of building analysis

After an overview of some of the available analysis methods, the chosen one was with the use of **Fragility Analysis method.**

This decision was made for the following reasons:

1. Amount of Building and earthquake data required to perform this analysis is quite simple and easily available, making it a good option for a large nunber of cities. EFEHR had City level data (Gaziantep) available in the Github repository of the ESRM model. (Crowley H. et al 2021).

2. The computational effort to perform on a large set of buildings is small and fast.

3. The Urban Profile of Gaziantep does not consist of a large number of tall buildings. Further, there are likely a large number of unengineered buildings (masonry buildings and buildings not constructed to the theoreticalstandard of RC behaviour, as per media reports and expert opinions after the Feb 2023 Elbistan Quakes).

4. To some extent the focus of the SARO project was a proof of concept, and the scope extended beyond vulnerability analysis, to the actual Search and Rescue problem which needed to be tackled in the project.

In this sense, finding a quick solution to the Damage assessment problem was crucial to be able to proceed with the project.

Part A:

Chosen Loss Assessment method- Fragility Functions

Buildng Data Required:

To be able to perform a fragility analysis on a building, the ESRM20 uses the The GEM Building Taxonomy v3.1 (https://github.com/gem/gem_taxonomy) to describe the buildings vulnerability given an intensity measure, which is also used in the SARO project: These are the parameters:

1. Materials

- CR; Reinforced Concrete
- MR: reinforced masonry,
- MCF: confined masonry,
- MUR: unreinforced masonry,
- MUR-ADO: adobe,
- MUR-CB99: concrete block masonry,
- MUR-CL99: clay brick masonry,
- MUR-STDRE: dressed stone masonry,
- MUR-STRUB: rubble stone masonry,
- S: steel,
- W: wood/timber

For SARO, the material description classes are restricted to CR, MUR, S, and W. This is because these are the primary material types used in GAziantep construction, as per the ESRM database (Crowley H. et al 2021)

2. Lateral load resisting systems

- LDUAL: dual frame-wall system,
- LFINF: infilled frame,
- LWAL: load
- bearing wall,
- LFM: moment frame,
- LFBR: braced frame

3. Code Level or Ductility.

- CDN: absence of seismic design,
- CDL: low code level (designed for lateral resistance using allowable stress design),
- CDM: moderate code level (designed for lateral resistance with modern limit state design),
- CDH: high code level (designed for lateral resistance
- coupled with target ductility requirements and capacity design),
- DNO: non-ductile,
- DUL: low ductility,
- DUM: moderate ductility,
- DUH: high ductility

4. Height. H: Number of storeys.

5. **Lateral Force Coefficient-** This is perhaps also a location based parameter. What fraction of the building weight (%) is considered for lateral load resistance in the seismic code? TI depends on the contrys seismic design code.

The GEM v3.1 also has a higher level of detail to describe the building stock, but at present the ESRM20 databased do not describe fragility functions to this LOD, so it is not considered in the project.

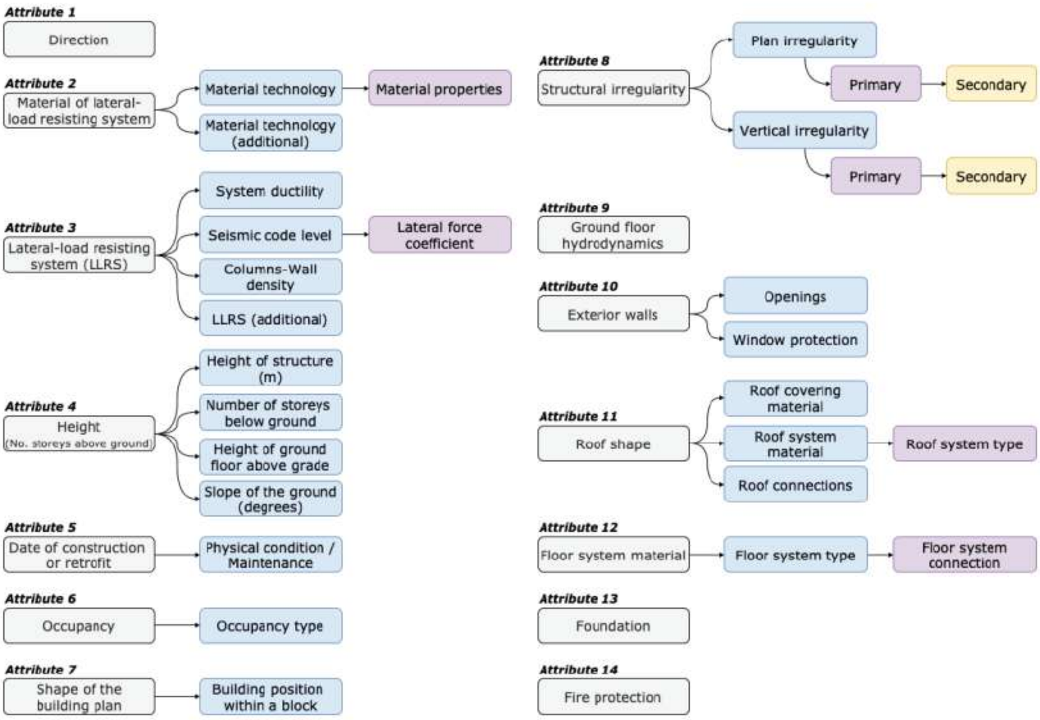


Figure 13: The full scope of the GEM Building Taxonomy v3.1 (https://github.com/gem/gem_taxonomy)

Part A:

Chosen Loss Assessment method- Fragility Functions

Fragility Curves for Various Buiding Types

IN the ESRM20, the fragility curves are developed based on the median capacity curves for each of the building attribute combinations.

It is interesting to note that in the ESRM20, the capacity curves developed are derived from the SDOF models based on the hysteresis behaviour of the uniaxial Pinghing4 modelling material. (Crowley H., 2021)

This means that to an extent, the strength and stiffness degradation from cyclic loading are accounted for, along with mass proportional damping for concrete and masonry materials.

Relations between building types and intersity measures

The final intensity measure used to describe the fragility behaviour of a given building is actually dependent on the Building attributes such as material, lateral load resistance and height.

This is established based on a study of fragility behaviour for each Intensity meansure, and then choosing the one that delievered the highest Efficiency, meaning it is the practically likely the most conservative fragility estimate.

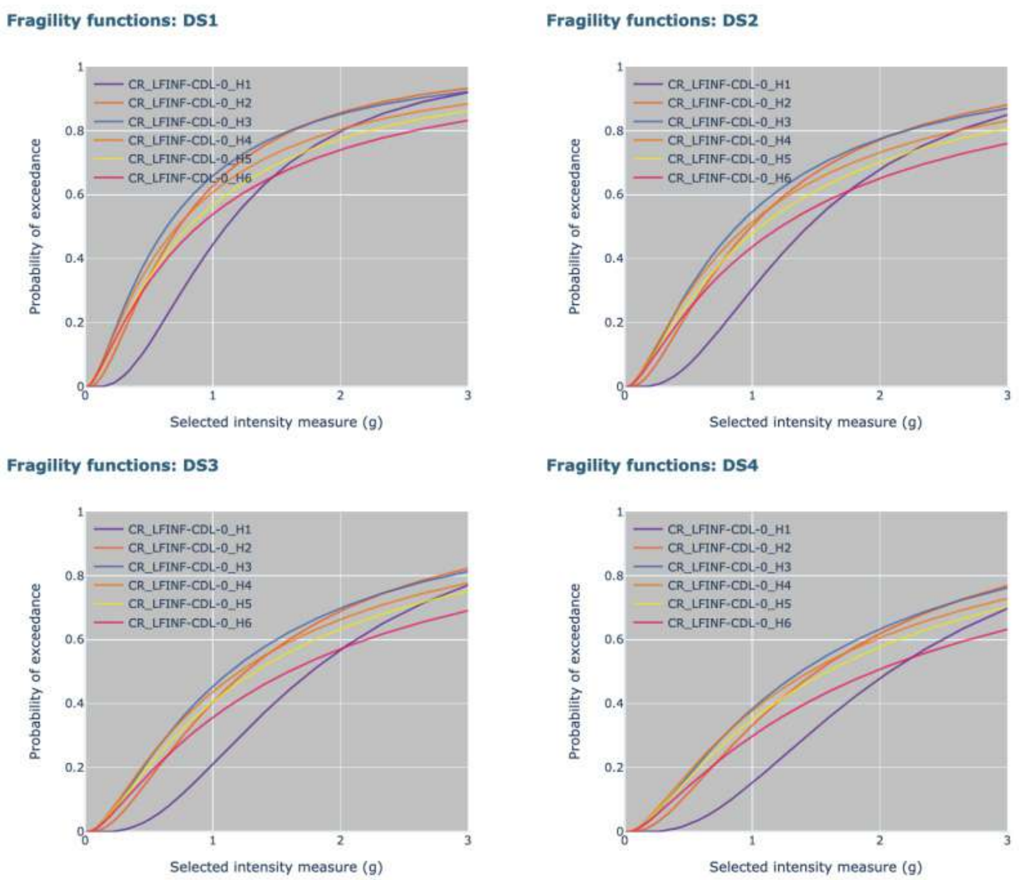


Figure 14: The set of fragility curves derived for reinforced concrete infilled frame buildings with no seismic design (CDN) from one to six storeys (from https://vulncurves.eurisk.eucentre.it/)

Part A:

Damage states of Buildings

The fragility curves method now allows to compute the probability of each building achieving various 'damages states'.

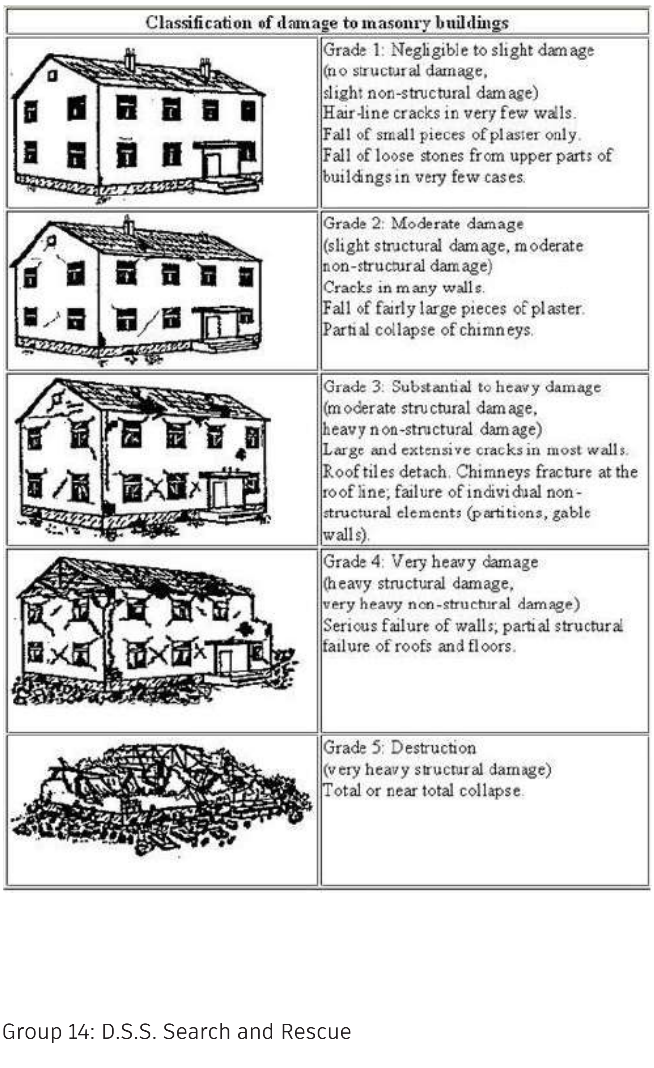
Simply put- a damage state is a grade of damage that a building can incur. This can be used to describe damages to both structural and nonstructural elements.

Both the ESRM20 and HAZUS-MH models recommend a classification of building into damage states. IN the Hazus-MH, it is described as:

'Building damage can best be described in terms of its components (beams, columns, walls, ceilings, piping, HVAC equipment, etc.). For example, such component damage descriptions as "shear walls are cracked", "ceiling tiles fell", "diagonal bracing buckled", "wall panels fell out", etc. used together with such terms as "some" and "most" would be sufficient to describe the nature and extent of overall building damage.' (FEMA, 2001)

It is imprtant to note that damages are possible to both structural and non structural components. Damages to nonstructural components, however are likely to cause injuries of mild to moderate severity, and structural damages can cause serious and mortal injuries as well.

The fragility curves developed for the ESRM20 describe damages to both structural and non-structural components.



Classification of damage to masonry buildings	
	Grade 1: Negligible to slight damage (no structural damage, slight non-structural damage) Hair-line cracks in very few walls. Fall of small pieces of plaster only. Fall of loose stones from upper parts of buildings in very few cases.
	Grade 2: Moderate damage (slight structural damage, moderate non-structural damage) Cracks in many walls. Fall of fairly large pieces of plaster. Partial collapse of chimneys.
	Grade 3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage) Large and extensive cracks in most walls. Roof tiles detach. Chimneys fracture at the roof line; failure of individual non-structural elements (partitions, gable walls).
	Grade 4: Very heavy damage (heavy structural damage, very heavy non-structural damage) Serious failure of walls; partial structural failure of roofs and floors.
	Grade 5: Destruction (very heavy structural damage) Total or near total collapse.

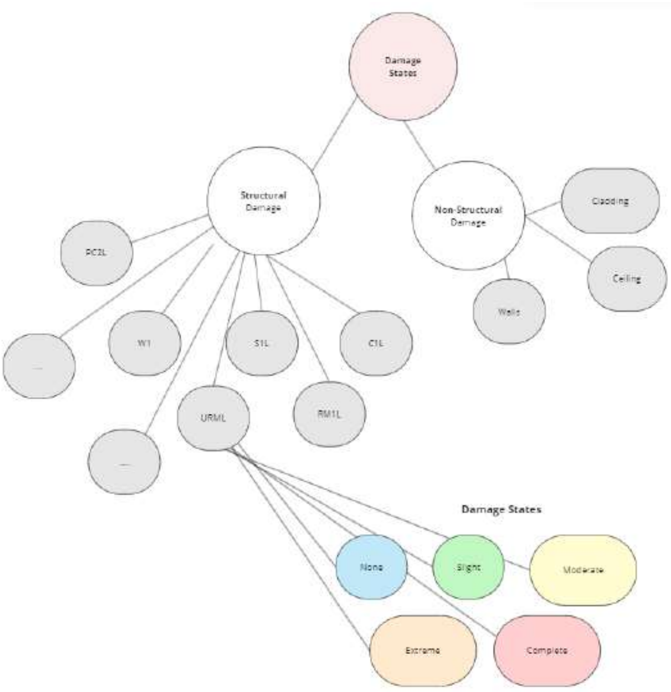


Figure 15: a An illustration of 5 damage states for masonry buildings (Borg, 2010), b. All building types can be expressed to have one of 5 damage states in a seismic event.(own source).

Part A:

The need for Synthetic Data- Part A

The Challenge

For Gaziantep, it was not possible to acquire all layers of necessary GIS data for the buildings.

THe municipality of Gaziantep had generously agreed to share some data of two neighbourhoods, including data of teh damage states of the buildings. However, the building type, structural system, lateral load resistance and height (in metres or storeys) were not available in this dataset.

As a result, the prediction theories based on correlations between building types and building damage states (given an intensity measure) could not be tested.

The alterate approach

The SARO team chose instead to prepare a synthetic dataset of buildings for Gaziantep, as illustrated in Figure 10.

We studied the ESRM Exposure Database for Turkiye and Gaziantep (Crowley et al, 2011), and using using list comprehension or simple excel methods, collected the statistical distribution of various building attributes for Gaziantep (see appendix).

Creation of areas and subaareas:

We then selected the neighbourhoods of or choice in Gaziantep (which we shall call 'Areas') and randomly assigned them the building attributes, using a probability weighting based on the patterns gleaned from the ESRM database. This created a 'realistic' (though not real) dataset of buildings. Each 'area' was further divided into 'sub areas', each of 20 buildings or so.

Care was taken to respect the correlations between building attributes as observed in the ESRM dataset. For Example, masonry storeys could only be 5 storeys tall at most, or that the lateral load resistance system for masonry structures was always LWAL, and so on.

A missed Opportunity

Becasue we chose this approach to create synthetic data, we are unable to test our predictions/ projections model of building damage with what was actually observed in Gaziantep.

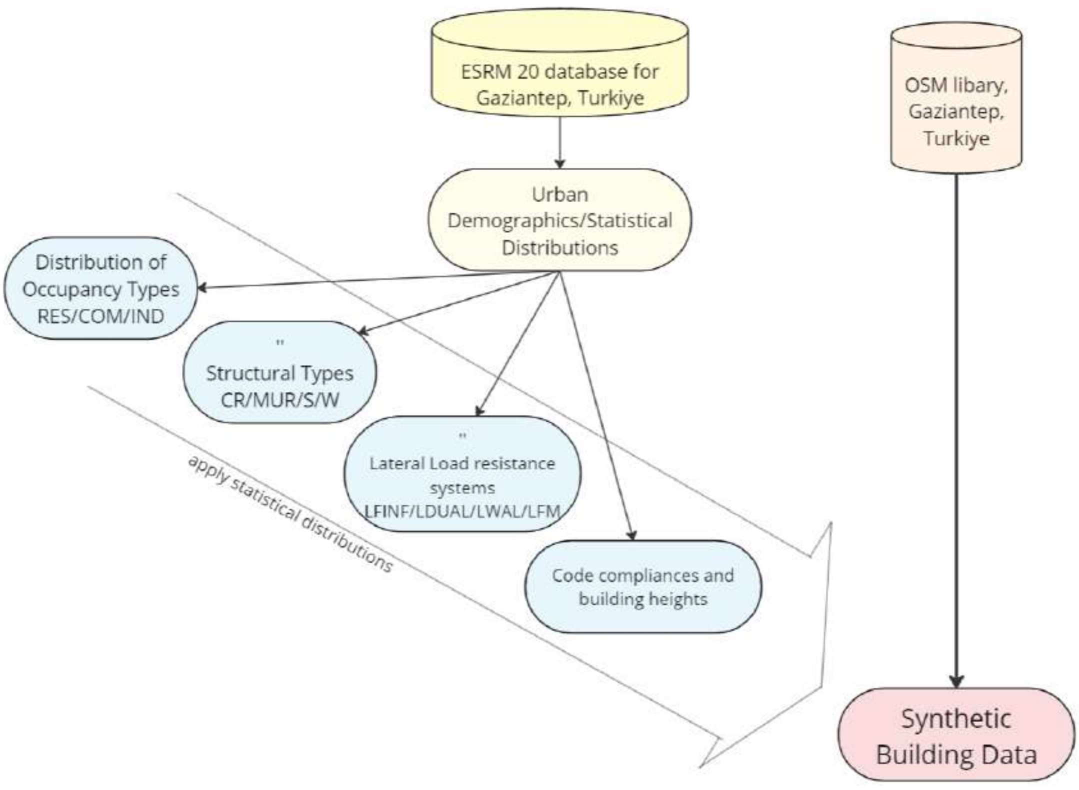


Figure 16: Workflow used to create synthetic data based on ESRM and OSM databases (own source)

Part A:

Relating Damage States to injury profiles

We now have the relevant data to characterize a set of buildings (in a sub-area and area) and predict the probability of it entering the various damage states.

What next?

We must calculate the vulnerability functions for casualties in various injuries.

Broadly speaking, these are based on expert judgment and past observations, taking into account probability of collappse and probability of entrapment of victims in buildings of various damage states and times of day. Hovever it is a far from exact science at the moment, depending on a variety of factors beyond those we are using to characterize the earthquake.

THe HAZUS methodology provides a simplification categorizing injury states of 4 severities

-Severity 1: Mildly Injured
-Severity 2: Moderately Injured
-Severity 3: Severely Injured
-Severity 4: Mortally Injured or Immediately Killed.

This is the methodology that we have used for the SARO project.

Example: Consider that there are 100 people in a building at the time of an earthquake event. consider that it is an RC frame midrise construction

Given an earthquake, consider that the relative probabilities of the building being in the 5 damage states are:

DS1: 25%, DS2: 25%, DS3: 23% DS4: 17% DS5: 10%

Next we look up the injury severity for each of the damage states (for that building type), as shown below- each row refers to a damage state, and each column refers to the percentage of population in injury classs 1 to 4

20	C2M	0.05	0	0	0
20	C2M	0.25	0.030	0	0
20	C2M	1	0.1	0.001	0.001
20	C2M	5	1	0.01	0.01
20	C2M	40	20	5	10

We then multiply the injury severity distribution of each danage state to the probability of that damage state and take the weighted mean. As follows

injury severity 1: [100ppl x (25% x 0.05%) + (25% x 0.25%) + (23% x 1%) + (17% x 5%) + (10% x 40%)/[25 + 25 +23 +17 +10]

and so on. **This way, a final probably injury profile can be computed for each building-** in the case of the above building, it is **[91.2, 5,1, 2.2, 0.5, 1]**

Injury Severity Level	Injury Description
Severity 1	Injuries requiring basic medical aid that could be administered by paraprofessionals. These types of injuries would require bandages or observation. Some examples are: a sprain, a severe cut requiring stitches, a minor degree or second degree on a small part of the body), or a bump without loss of consciousness. Injuries of lesser severity that could be are not estimated by Hazus.
Severity 2	Injuries requiring a greater degree of medical care and use of medical such as x-rays or surgery, but not expected to progress to a life threate Some examples are third degree burns or second degree burns over la the body, a bump on the head that causes loss of consciousness, frac dehydration or exposure.
Severity 3	Injuries that pose an immediate life threatening condition if not treated and expeditiously. Some examples are: uncontrolled bleeding, punct other internal injuries, spinal column injuries, or crush syndrome.
Severity 4	Instantaneously killed or mortally injured

Table 13.7: Indoor Casualty Rates by Model Building Type for Complete Structural Damage (With Collapse)

#	Building Type	Casualty Severity Level			
		Severity 1 (%)	Severity 2 (%)	Severity 3 (%)	Severity 4 (%)
1	W1	40	20	3	5
2	W2	40	20	5	10
3	S1L	40	20	5	10
4	S1M	40	20	5	10
5	S1H	40	20	5	10
6	S2L	40	20	5	10
7	S2M	40	20	5	10
8	S2H	40	20	5	10
9	S3	40	20	3	5
10	S4L	40	20	5	10
11	S4M	40	20	5	10
12	S4H	40	20	5	10
13	S5L	40	20	5	10
14	S5M	40	20	5	10
15	S5H	40	20	5	10
16	C1L	40	20	5	10
17	C1M	40	20	5	10
18	C1H	40	20	5	10
19	C2L	40	20	5	10
20	C2M	40	20	5	10

Figure 17: HAZUS characterization of injury severities based on building structure type as well as building damage state

Part A:

Fade-Away functions

Perhaps the most elusive relation of all:

When a given set of occupants are trapped/injured in a given building in a given damage state, how does their life decline as a function of time?

There is some evidence that the types of injuries inflicted by different construction systems vary considerably, and there has been efforts to create a correlation between fada away times and injury profiles (Coburn et al, 1992)(Figure 12).

Shiono K et al (1992) propose to express mathematically the deterioration of life as a function of time, using the concept of an 'Animation Score'

$$h(t)=(a_0{}^{1/N}-t/D_0)^N \quad (1)$$

where

h: Animation score
a_0: Animation score at t=0
D_0 and N: Coefficients
t: Time (hour).

When the animation score reaches 0 the occupants are assumed to die, and the severtiy of their injuries a tthe time of event strike is expressed in their starting score.

Use of FadeAway functions on the Saro project:

Here, the formula proposed by Shiono et al (1992) was used to describe life expectancy, using a set of constants for each injury severity.

However, due to lack of available data, and to proceed with a proof of concept approach, these constants were arbitrarily assigned such that Casualties with injury severity 1 had a 5 day life expectancy and a high animation score at t0, and the Casualties with high injury severity were described with a decay spanning only 24 hours and a much lower animation score at t0.

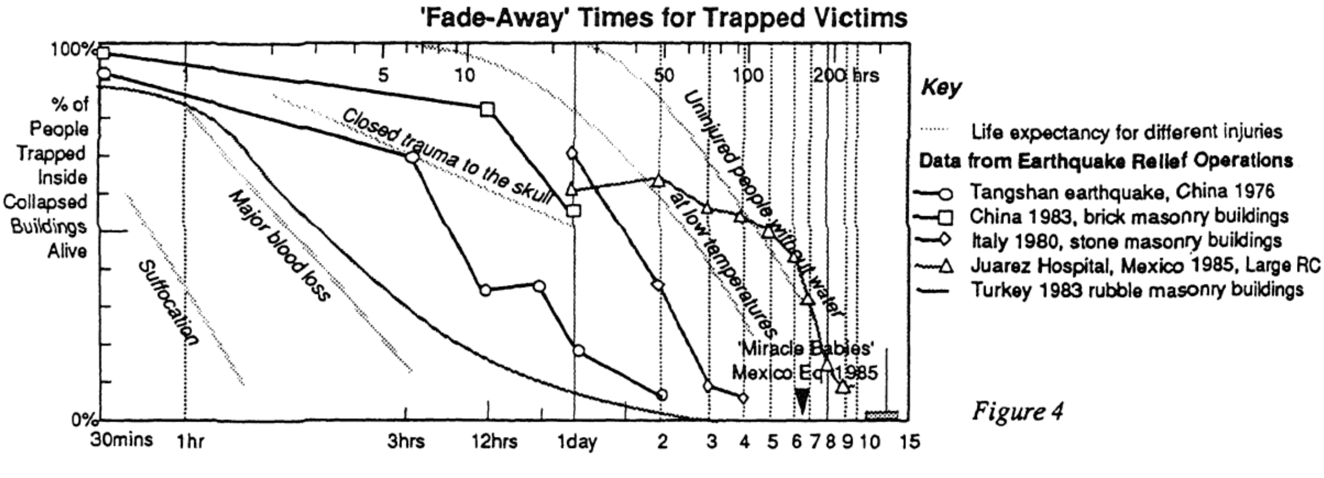


Figure 18: Coburn et al, 1992, 'FadeAway' times for trapped victims as observed in some historical earthquakes.

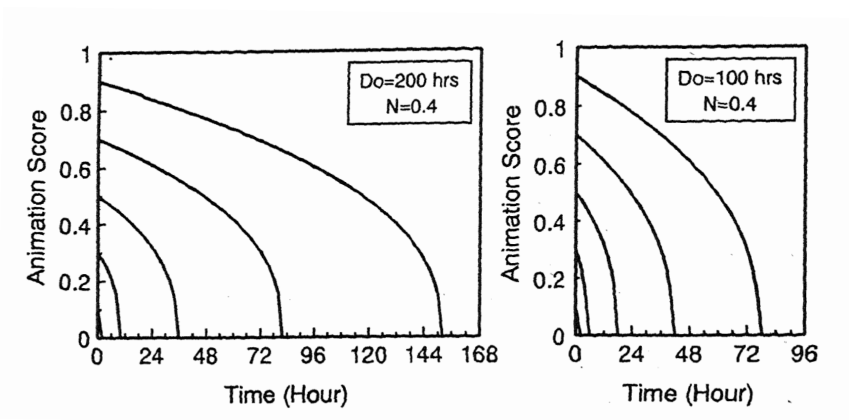
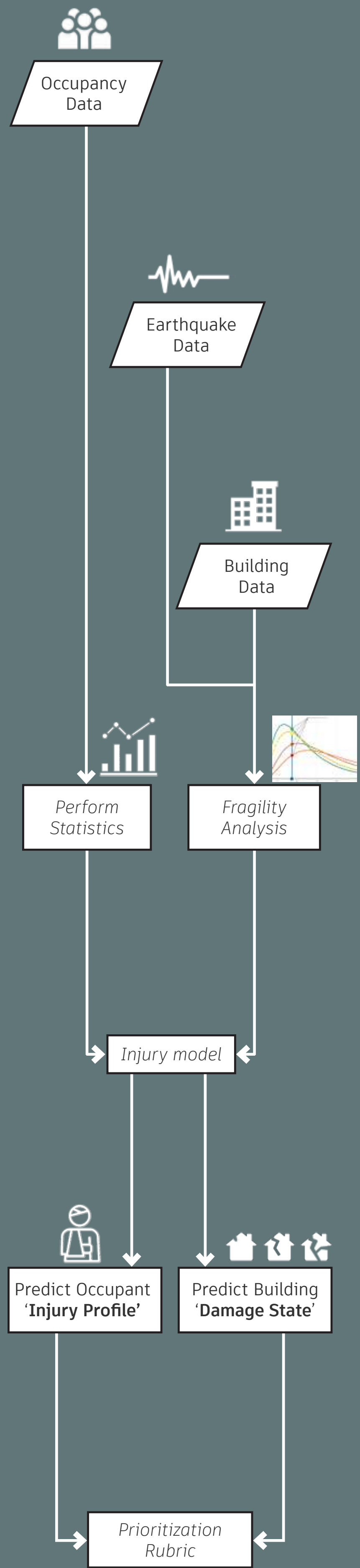


Figure 19: (Shiono, K. et al, 1992), examples of fade-away functions

Part A: Flowchart

The process begins once the earthquake strikes, collecting the earthquake data, and using preexisting building and occupancy data.

- Building and earthquake data are processed in a risk model or tool to project the likelihood of damage. In our case is this with the fragility curve method.
- Occupancy data from census and accurate GIS is used with the building damage data output to create a correlational prediction of the 'injury profile'- The spectrum of various injury severities that are expected in each neighbourhood- At the level of an "area', and 'sub area'. THis is the output of Part A
- Based on these numbers, as well as other parameters , called 'weights' (such as the building damage state, etc), apply the 'prioritization rubric' to rank order the various areas.



Part A: Class definitions: Area

Code & flowchart logic

This class describes an area or neighbourhood in a city. It has some general attributes such as:

- Area ID
- Geometry
- Bounding box
- Name
- Address
- Address type

There are also attributes which are associated with the other location classes, these are:

- Priority weight, describing the necessity for help.
- Sub-areas, describing the sub-areas in the area.
- Buildings, describing the buildings in the area.

Finally, there are attributes which are associated with the allocation of rescue assets:

- People requirement
- Heavy teams, describing the number of teams.
- Medium teams, describing the number of teams.
- Light teams, describing the number of teams.
- Task force teams, describing the number of teams.
- Fire fighter teams, describing the number of teams.
- Police teams, describing the number of teams.
- Volunteer teams, describing the number of teams.

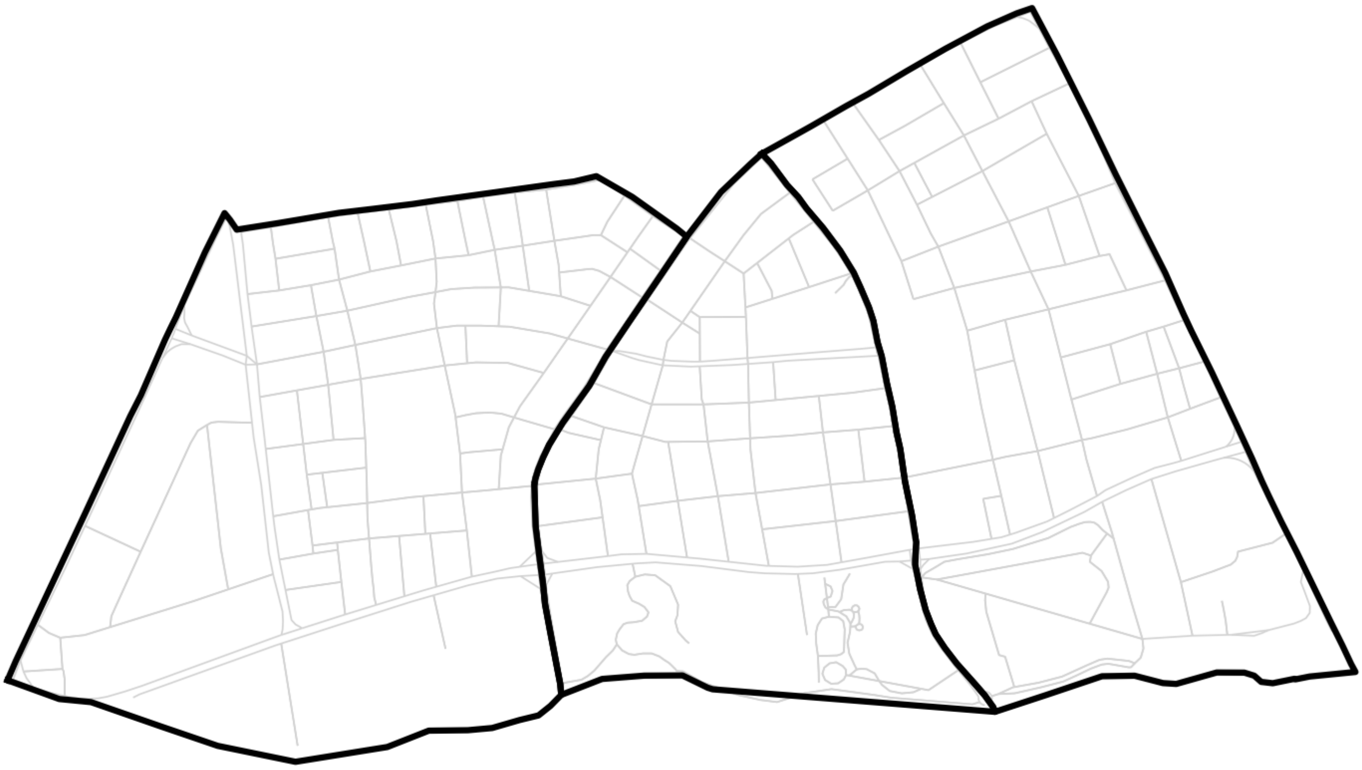


Figure 20: Areas. Own work.

Part A: Class definitions: Area

Code & flowchart logic

Function: Add sub-area
Input a sub-area object.
Add the sub-area to the areas' list of sub-areas.
Set the areas' priority weight to be the average of the priority weights of all sub-areas currently associated with the area.

Function: Add building
Input a building object.
Add the building to the areas' list of buildings.

Function: Update priority weight
If there are any sub-areas in the areas' list of sub-areas, set the areas' priority weight to be the average of all sub-areas currently associated with the area.

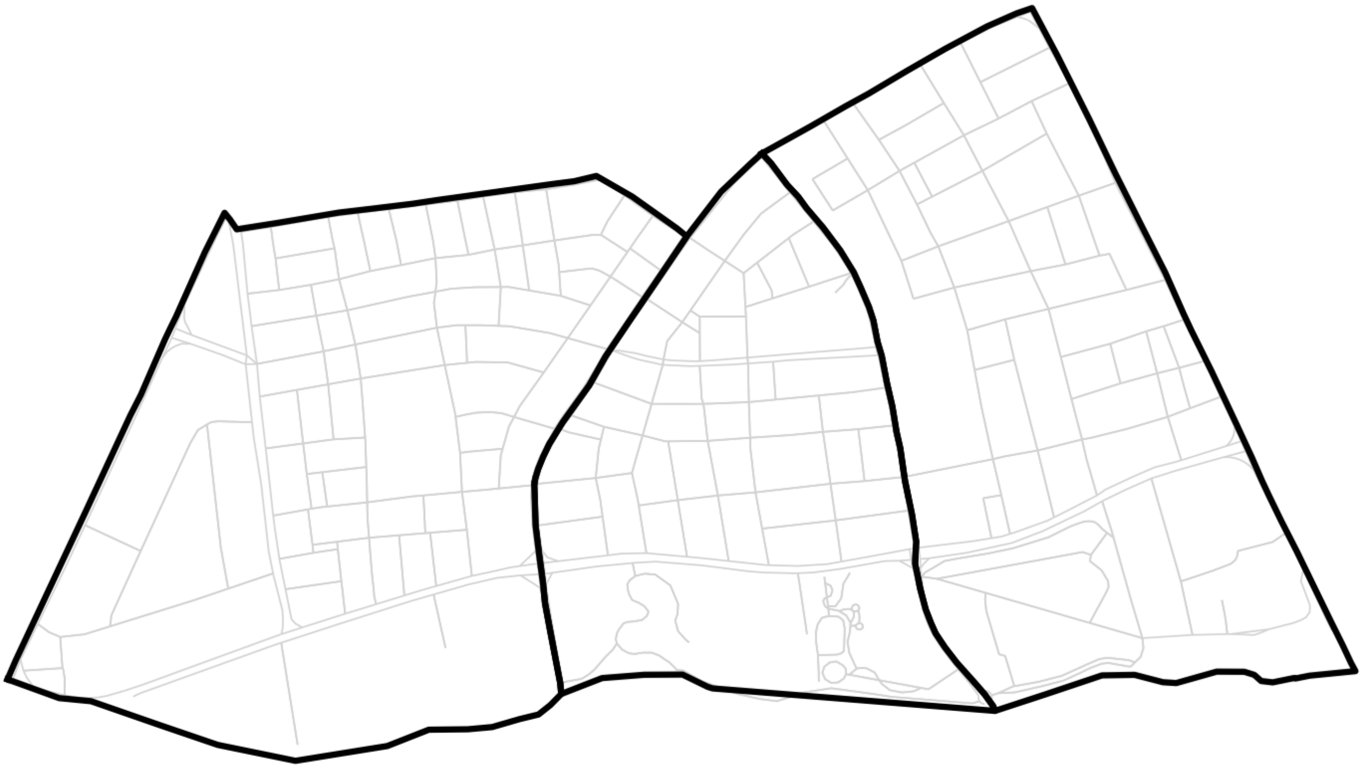


Figure 21: Areas. Own work.

Part A: Class definitions: Sub-area

Code & flowchart logic

This class describes a sub-area within an area of a city. Its general attributes are:

- Sub-area ID
- Geometry

Other attributes which are associated with the other location classes:

- Priority weight, describing the necessity for help.
- Area, describing the area in which the sub-area is located.
- Buildings, describing the buildings in the area.
- Average occupancy, describing the average occupancy for a building in the sub-area.

And another set of attributes which relate to the allocation of rescue assets:

- Sub-team, this is the sub-team that is tasked with clearing this sub-area.
- Cleared, describing whether the sub-area is cleared or not.
- Required actions, describes the actions that are required to clear the sub-area.
- Clear time, describes the time required to clear the sub-area.

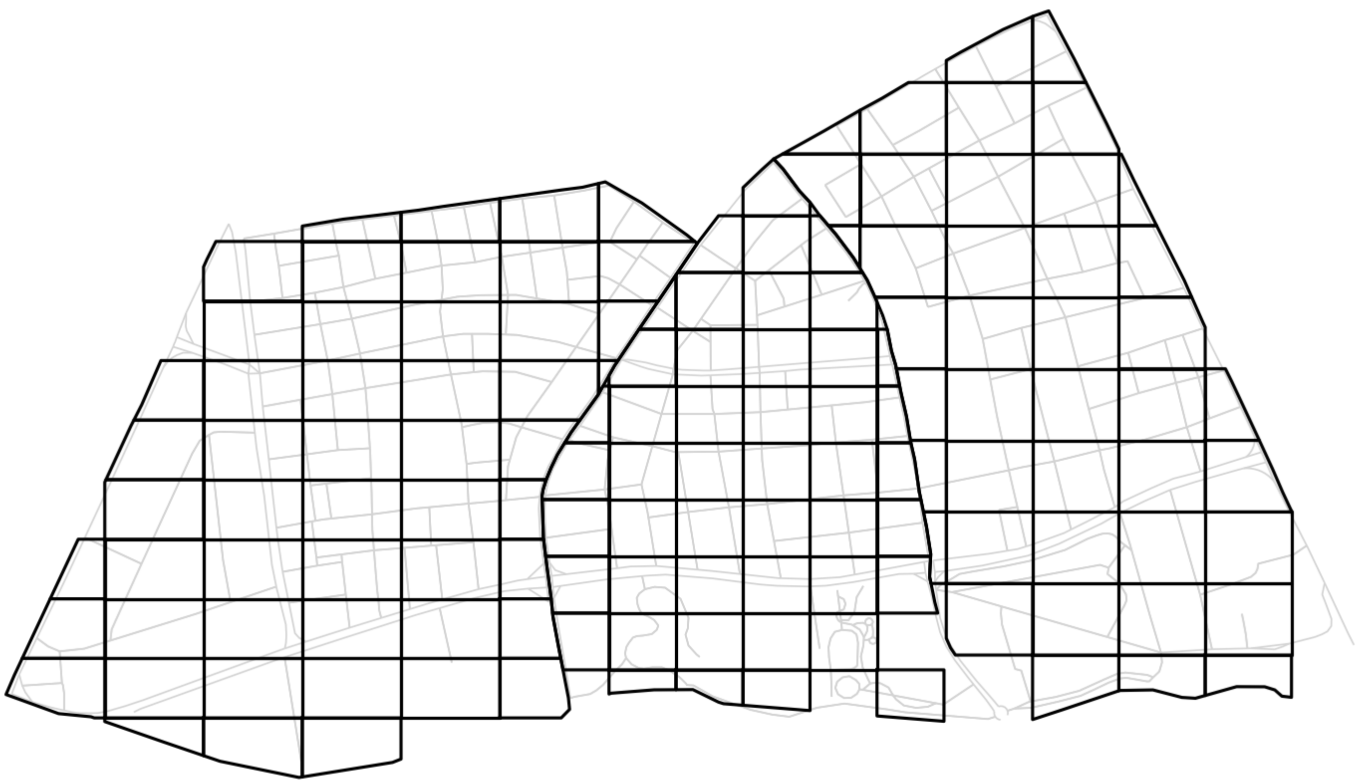


Figure 22: Sub-areas. Own work.

Part A: Class definitions: Sub-area

Code & flowchart logic

Function: Add building

1. Input a building object.
2. Set the buildings sub-area to be this sub-area.
3. <u>Update the priority weight of the sub-area.</u>
4. <u>Calculate the average occupancy for the sub-area.</u>
5. Set the clear time to be the sum of all buildings associated with the sub-area.
6. Add the actions required to clear the building to the list of actions required to clear the sub-area.

Function: Crop geometry

1. Crops the geometry of the sub-area object with the geometry of its area.

Function: Update priority weight

1. If there are any buildings in the sub-area, set the priority weight of the sub-area to be the average of priority weights of all buildings associated with the sub-area.

Function: Calculate average occupancy

1. If there are any buildings in the sub-area, set the sub-area's average occupancy to be the average occupancy of all buildings associated with the sub-area.
2. If there are no buildings in the sub-area, set the sub-area's average occupancy to be 0.

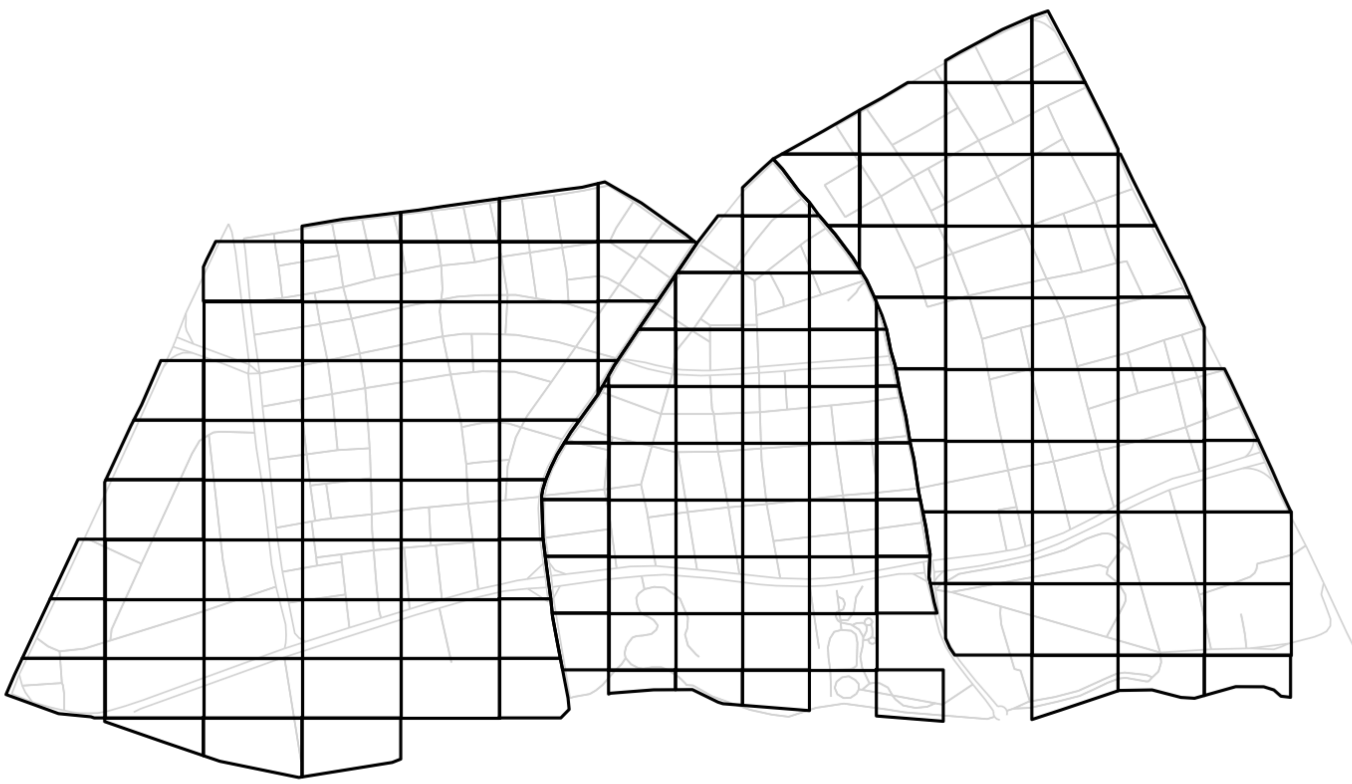


Figure 23: Sub-areas. Own work.

Part A: Class definitions: Building

Code & flowchart logic

This class describes a building within a sub-area of a city. Its general attributes are:

- Building ID
- Geometry
- Centre point, describing the coordinate of the centre of the building.
- Footprint, describes the area of the building's footprint.

The following attributes are 'synthetically' assigned to the building by estimation/ randomisation:

- Occupancy type, describes the function of the building.
- Structural system
- Lateral resistance, describes the method of providing the building with lateral resistance.
- Building typology, describes the types of materials and assemblies utilised in the building.
- Stories, describes the number of stories the building has.
- Height code, describes what category of height the building belongs to.
- Population day, describes the number of people that are expected to occupy the building during daytime.
- Population night, describes the number of people that are expected to occupy the building during night-time.
- Damage state probabilities, describes the probability of the building to be in each of the damage states (DS2, DS3, DS4, DS5).
- Damage state, describes the damage state with the highest probability.
- Injuries, describes the amount of people that are in each injury level (uninjured – mortally injured).
- Occupancy, describes the total number of people that occupy the building.

Figure 24: Buildings. Own work.

Part A: Class definitions: Building

Code & flowchart logic

These attributes are associated with the other location classes:

- Area, describes the area in which the building's sub-area is located.
- Sub-area, describes the sub-area in which the building is located.

The next set of attributes relate to the allocation of rescue assets:

- Priority weight, describing the necessity for help.
- Actions, describes the actions required to clear the building.
- Safe, describes if there are any actions required to clear the building or if the building is safe.
- Cleared, describing whether the sub-area is cleared or not.
- Cleared by, describing what sub-team has cleared the building.
- Clear time, describes how long it takes to clear the building.

Function: Set cleared

1. Set the cleared attribute of the building object to true.
2. Set the cleared by attribute of the building object to be the sub-team that is tasked with clearing the buildings' sub-area.
3. If all buildings in the buildings' sub-area are now either safe or cleared set the sub-area to be cleared.

Function: Set typology

1. Check what combination of structural system and lateral resistance the building object has to determine its building typology.

Function: Get action codes

1. Load the excel file and tab which corresponds to the damage state of the building object.
2. Select the row which refers to the

Figure 25: Buildings. Own work.

Part A: Class definitions: Building

Code & flowchart logic

1. building typology and height code of the building object.
2. If the row is empty return an empty list, otherwise save the column names in a list if the value of the cell is.
3. Return the list with the column names, the names refer to action codes.

Function: Calculate damage state rating
1. Import damage state probabilities for the building object.
2. Multiply the damage state probabilities with a list of rating factors that correspond to each damage state.
3. Take the sum of the factored damage state probabilities to get the damage state rating.
4. Return the damage state rating.

Function: Calculate risk level rating
1. Import the damage state probabilities, occupancy type and stories of the building object.
2. Check whether the damage state probability for damage state 3 or higher > 0.6 and if the amount of stories > 7 or if the occupancy type is 'industrial'.
3. Assign risk level rating value accordingly.

Function: Calculate injury severity rating
1. Import the injuries of the building object.
2. Calculate total injury weight.
3. Define rating by multiplying each individual injury severity value by corresponding injury rating.
4. Calculate overall rating by dividing the rating with the total injury weight.

Function: Calculate trapped people rating
1. Import the occupancy of the building object and the average occupancy of the building's sub-area.

Figure 26: Buildings. Own work.

Part A: Class definitions: Building

Code & flowchart logic

1. Check if the occupancy of the building is higher than the average occupancy of the building's sub-area.
2. Assign trapped people rating value accordingly.

Function: Calculate priority weight

1. Initialise static methods to calculate damage state, risk level rating, injury severity and occupancy ratings.
2. Multiply all the ratings with a weight to calculate the priority weight.
3. Assign the calculated priority weight to the priority weight attribute of the building object.

Figure 27: Buildings. Own work.

Part A: Class definitions: Earthquake

Code & flowchart logic

This class describes a specific earthquake event. The class describes values which are available minutes after an earthquake and, for past earthquakes, these values are available in the USGS Shakemap and SAGE databases. The attributes of the earthquake class are:

- Peak Ground Acceleration (P.G.A)
- Spectra Acceleration at 0.3 second period (S.A.- 0.3)
- Spectra Acceleration at 0.6 second period (S.A.- 0.6)
- Spectra Acceleration at 1.0 second period (S.A.- 1.0)
- Time of day when the Earthquake strikes, in a 24 hrs format

Figure 28: Earthquake. Own work.

Part A: Functions: Import areas

Code & flowchart logic

1. Input addresses/names of the areas.
2. Load the area from OpenStreetMap as a geodataframe.
3. Extract data from the geodataframe.
4. Create a new Area object based on the data.
5. Repeat for remaining areas.

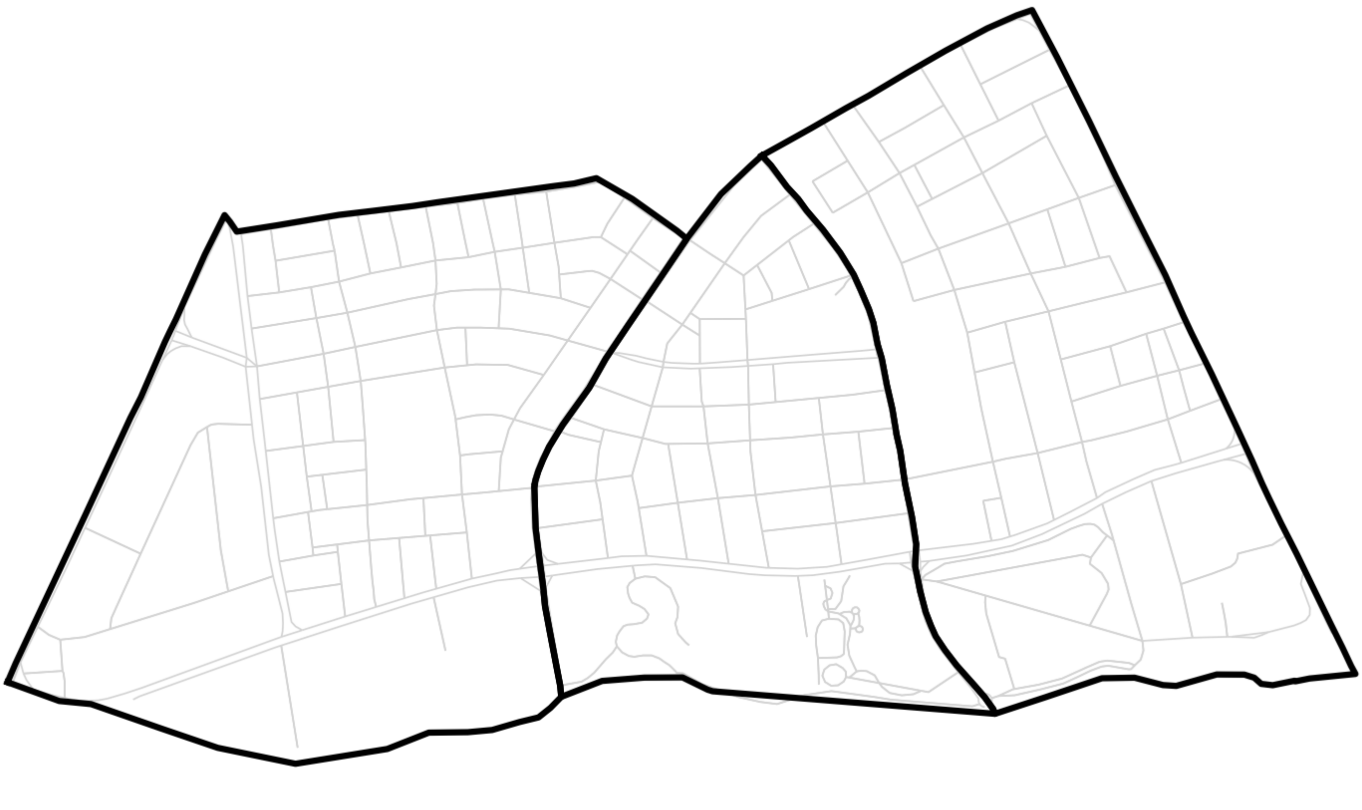


Figure 29: Created areas. Own work.

Part A: Functions: Assign ‘synthetic’ building attributes

Code & flowchart logic

1. Input a geodataframe with buildings.
2. Assign the correct CRS to the geodataframe of buildings.
3. Use list comprehension to calculate the sum of each building occupancy of Gaziantep from the relevant database (ESRM in this case).
4. Compute the percentages distribution of occupancy types in the stock of buildings.
5. Use list comprehension to compute the percentage distributions of various structural systems, lateral resistance systems, seismic code compliances, heights (in storeys), and occupancy fractions.
   Notice that some of the attribute distributions are interrelated, relations are as follows: Occupancy type> Structural System>Lateral Load Resistance>Code compliance>Height>Occupancy percentages.
6. For a building in the geodataframe, assign each of the attributes randomly using the computed percentage distributions.
7. Add the attributes to the geodataframe in the column relating to the attribute, and the row relating to the building.
8. Repeat from step 5 for all remaining buildings.
9. The buildings now have synthetic attributes that are ‘realistic’.
10. Return the extended geodataframe.

Figure 30: Occupancy type. Own work.

Part A: Functions: Assign 'synthetic' building attributes

Code & flowchart logic

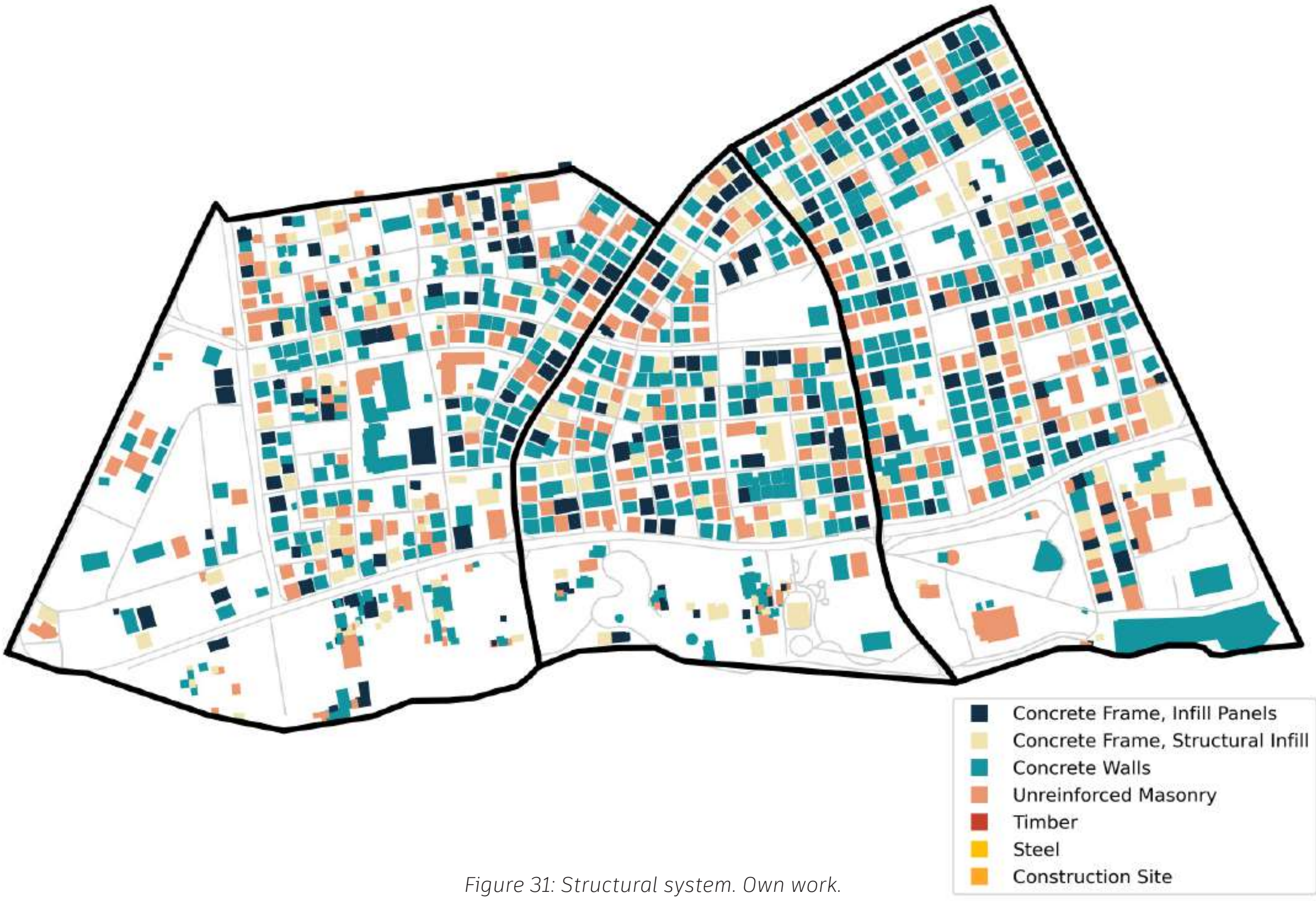


Figure 31: Structural system. Own work.

Figure 32: Lateral load resistance. Own work.

Part A: Functions: Assign fragility attributes

Code & flowchart logic

1. Input a geodataframe with buildings and an earthquake object.
2. Import the chosen building fragility documentation as a dataframe. (HAZUS/ESRM etc) (it contains the relevant fragility function variables along with the governing seismic intensity measure for each building typology, height, and lateral load resistance system)
3. Create a set of empty lists for collecting the governing intensity measures, fragility function median and standard deviation variables.
4. Look up the correct row in the geodataframe with buildings, using the building attributes and matching them with the attribute columns in the ESRM building fragility dataframe.
5. For each building in the geodataframe with buildings, retrieve the appropriate intensity measure from the earthquake object, and the median, and standard deviation values from the ESRM building fragility dataframe. Append these values to the geodataframe with buildings.
6. For each building in the geodataframe with buildings, calculate the probability of each damage state, by creating a lognormal probability density distribution using the median and std deviation.
7. For each building and damage state, save the probability of the damage state being achieved for the appropriate seismic intensity measure.
8. For each building and damage state, append the list of damage state probabilities to the geodataframe of buildings as 4 columns.

Figure 33: Damage states. Own work.

Part A: Functions: Assign injury profile

Code & flowchart logic

1. Input a geodataframe with buildings and an earthquake object.
2. Import the chosen building fragility documentation as a dataframe. (HAZUS/ESRM etc)
3. Create a set of empty lists to collect the injury probability distribution belonging to each damage state for each building.
4. For each building in the geodataframe and each type of damage state, create a mask to sort through the ESRM dataframe using attributes from the building and the earthquake object.
5. For each building, use the mask to retrieve the probability distributions for 4 levels of injury severities from the ESRM building fragility dataframe.
6. Append these probability distributions to the lists created in step 2.
7. Calculate the weighted average of injuries for each injury severity. Once for the estimated population at day, and once for the estimated population at night. (This is basically - the probability of each damage state (the weight) x the population proportion for that damage state (ds1_ numbers, ds2 numbers etc) x the population of the building at the time of the earthquake.)
8. For each building in the geodataframe, append to the geodataframe, the prediction of injures as a list of 5 numbers [p,q,r,s,t]. (This is the prediction of injuries for a given building, given a seismic intensity.)

*Figure 34: Number of injured people * injury level. Own work.*

Part A: Functions: Assign injury profile

Code & flowchart logic

Figure 35: Number of uninjured people. Own work.

Figure 36: Number of slightly injured people. Own work.

Figure 37: Number of moderately injured people. Own work.

Figure 38: Number of gravely injured people. Own work.

Figure 39: Number of mortally injured people. Own work.

Part A: Functions: Import buildings

Code & flowchart logic

1. Input an area and an earthquake object.
2. Load the buildings inside the area from OpenStreetMap as a geodataframe.
3. Input the geodataframe to assign additional building attributes.
4. Input the updated geodataframe to assign fragility attributes to the buildings in the dataframe.
5. Input the updated geodataframe and the earthquake object to assign injury profiles to the buildings in the dataframe.
6. Extract data from the updated geodataframe.
7. Create a new Building object based on the data.
8. Add the Building object to the area.
9. Repeat for all buildings remaining in the updated geodataframe.

Figure 40: Imported buildings. Own work.

Part A: Functions: Generate sub-areas

Code & flowchart logic

1. Input an area object, the number of sub-area cells in the x direction, and the number of cells in the y direction.
2. Extract the minimum and maximum co-ordinates in the x and y direction of the area's geometry.
3. Use the coordinates and the number of cells in x and y direction to determine the width and height of a cell.
4. Create a list of the minimum x coordinates of a cell based on the width and height of a cell, and the minimum and maximum x and y coordinates of the area.
5. Create a list of the minimum y coordinates of a cell based on the width and height of a cell, and the minimum and maximum x and y coordinates of the area.
6. Sort the list of buildings in the area based on their x coordinates, then y coordinates.
7. Create a Sub_area object based on the lists of minimum x and y coordinates of a cell.
8. Associate all buildings at the start of the list with the sub-area while their coordinates are in the sub-area.
9. Repeat creating Sub_area objects and associating buildings until all possible sub-areas are created.
10. Associate the sub-area with the area object if it has buildings in it.

Figure 41: Generated sub-aeas. Own work.

Part A:

Afterthoughts and Improvements

Variations in Building construction quality:

The quality of a fragility curve method is only as good as the median and logstandard deviation values developed for a building set. The values used for the SARO project are generalizations at a continent level and must be used with caution.

For example, a major known unknown is the **quality of construction of buildings**. One way to account for this is to have a more conservative Beta calculation

$$\beta_{Sds} = \sqrt{\left(\mathrm{CONV}\left[\beta_C, \beta_D, \overline{S}_{d,Sds}\right]\right)^2 + \left(\beta_{M(Sds)}\right)^2}$$

Source: FEMA HAZUS-MH

Here the beta c refers to std deviation from variability in the capacity curve. Here we can perhaps more conservatively account for variations in construction quality.

Another way to do it would be to create a different subsets of median, beta values for buildings of various suspected levels of construction quality (low quality, medium, high), similar to how separate subsets are maintained for Seismic Code Compliances. This would be tricky though, as it depends on expert judgments and possibly even the reputation of the contractor.

Capacity curves instead of fragility Curves:

Instead of prbabilistic fragility curves, it might be possible to simplify the building set into a SDOF model and apply the eartquake parameter as a demand spectrum for each building. It would better capture the nonlinear seismic behaviour of buildng materials and components, and take into accont the frequency parameters of the earthquake better.

The computational effort is slightly higher than fragility curves but maybe still manageable if each neighboourhood is tackled step by step.

Higher LOD for failure modes? Collapse Models

The method in SARO presently makes a simplistic deterministic relation between the damage state of a building to then injury distribution.

In reality, the majority of casualties come from the collapse of buildings, which can be partial or complete. Two buildings that are in DS5 may be collapsed 20% in one case and 100% in the other case, and have vastly different casualties.

Theoretically predicting the Failure location and the failed element in a building might give a better prediction of the degree of collapse of a building.

For this, perhaps methods like **SLaMA** (Gentile, 2017) can be used to predict the location and sequence of failing members particularly in larger buildings, and determine the probable mode of collapse.

Alternately, it may be viable to use rapid satellite image-segmentation-based collapse degree assessment (partial to complete). The colleague team working on this could provide the crucial input. IN reality, considering the vast number of casualties only coming from DS5, this may be the correct real time data to turn to.

Probabilistic Estimation of Lives not advisable for SAR scheduling?

Speaking of real data, it is important to take a step back... fragility curves are likely to provide a good estimatioon of PROBABLE damage states and injuries. This means that the larger the set of buildings in consideration, the closer the estimate.

This might suggest that this method should be used only at the level of evaluating larger neighbourhoods ('Areas' and 'Sub-Areas') to give an idea of how many injured there might be. At the building level, it is likely to be quite inaccurate, and our phase 2 allocations (Building Level), rightly rely on real time data instead of probabilistic projections.

PART B

Search and Rescue resource allocation and scheduling

Part B: Overview and focus

Allocation and scheduling

The second part of the project concerns itself with the allocation of rescue assets to rescue sites and the scheduling of this allocation.

This allocation is structured in two phases. Phase 1 performs an allocation based on predictions of damage states and injury distributions in the form of a priority weight which have been defined in part A. This phase exists so that rescue assets can respond before real time data has been acquired.

Phase 2 starts after 24 hours of the earthquake striking, when enough real time data is collected so that an allocation can be performed based on this data. Phase 2 includes an action-based allocation and a scheduling on building level.

Input data

- Building data: The characteristics of the building and its occupants that has been collected and 'synthetically' assigned in part A.
- Geographical hierarchy: The hierarchal and geometric structure and relation of area, sub-area and building as defined in part A.
- Action data: A list of actions that both corresponds to the level and type of training a rescue worker has completed, as well as the actions that are required to rescue people in distress for buildings of varying characteristics and damage states.

Processing the input data

Priority weight: The building data and geographical hierarchy are used to give buildings and their (sub-)areas a priority weight. The ability of the priority weight to lead to an optimal allocation depends on the accuracy of the building data which forms the basis for the priority weight.

Rescue asset and site matching: The competency of a team can be accurately assessed on the basis of the completed training certificates. An accurate matching of rescue asset should rely on the actions that a rescue asset can perform, and a rescue site requires. This matching is mostly limited to how accurately the required actions of a building are defined.

Allocation and scheduling: The goal of the allocation and scheduling is to maximise the number of lives saved, under a weighted condition this means maximising a saving score. The first two methods used for allocating in part A don't use scheduling, the last method does. A good method should include scheduling because time is an important factor to consider. Scheduling requires a lot of computational power or machine learning.

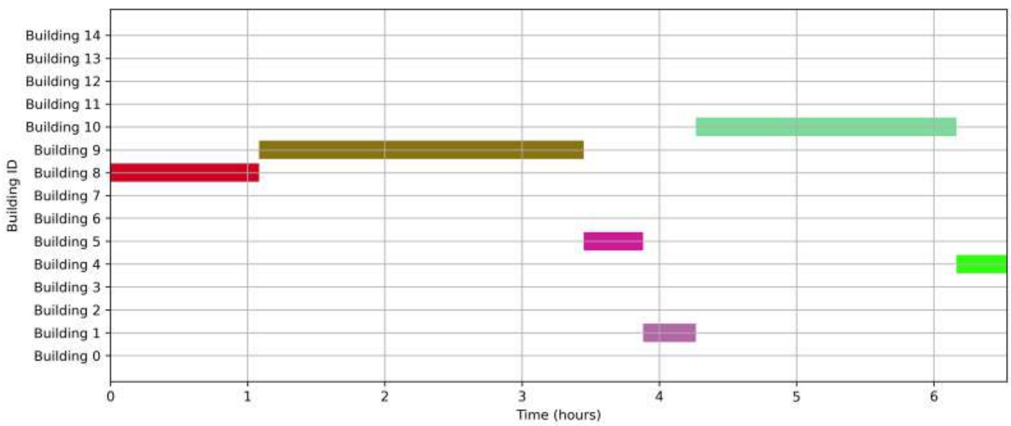


Figure 42: Building allocation schedule. Own work.

Part B: Common practice for resource allocation

Theoretical research

Global standards disaster relief

Under the United Nations' oversight, INSARAG unites over 90 nations and organizations globally, focusing on establishing worldwide standards for urban search and rescue (USAR) teams and protocols in earthquake response, outlined in the INSARAG Guidelines (INSARAG, 2020a).

This collaborative effort tries to ensure a well-coordinated and effective response to seismic events, emphasizing standardized practices and international cooperation among diverse entities involved in search and rescue operations. INSARAG, together with first responders like civil defense, local emergency services, and community first responders, plays a pivotal role in providing aid during natural disasters. The framework involves various entities, creating a coordinated approach to search and rescue operations globally, guided by standardized practices. This collaboration enhances the overall efficiency and impact of disaster response initiatives, contributing to a more resilient and organized global community in the face of seismic events.

The first responders, as shown in Figure 28, form the foundation of the framework and deliver crucial aid during the Golden Hours (first 24 hours), where survival chances are highest. National USAR teams, with their specialized skills, typically arrive on-site after six hours, strengthening the immediate response efforts. More specialized international USAR teams, equipped for complex operations, commence arrival after approximately 24 hours, providing further assistance and expertise in challenging scenarios.

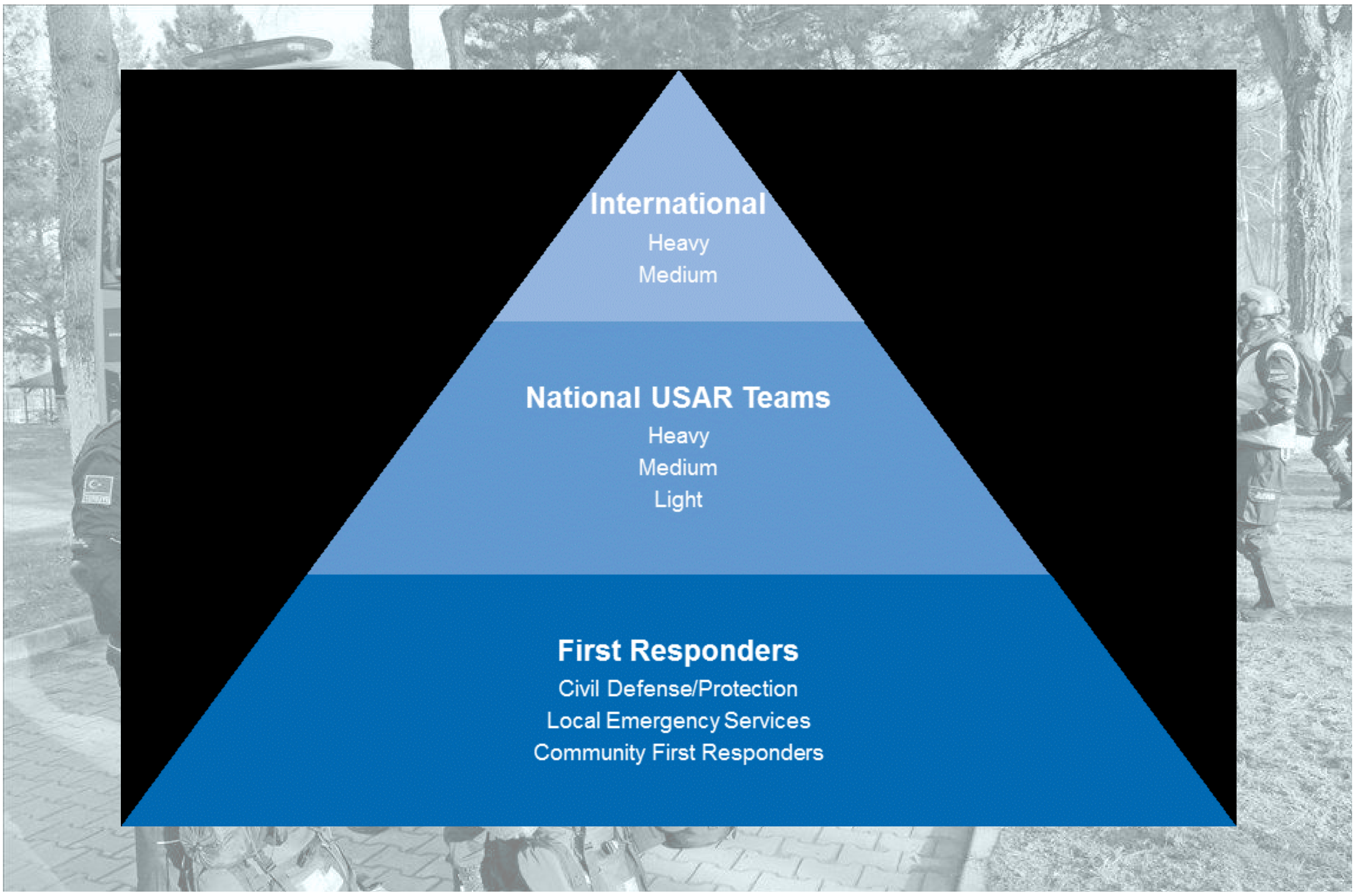


Figure 43: INSARAG SAR response framework. INSARAG (2020a)

Part B: Area classification

Theoretical research

The allocation of search and rescue resources is an intricate process that occurs at several different layers (Figure 29), each playing a crucial role in optimizing the effectiveness and efficiency of the overall response effort. The allocation layers are:

1. Worldwide --> Country
2. Country --> Sector
3. Sector --> Area
4. Area --> -Sub-Area

Creating sectors by dividing affected areas into manageable cluster enhances:

- **Operational planning:** allows for strategic resource allocation by tailoring responses to the specific needs of each sector, considering factors such as population density, infrastructure status, and terrain challenges.
- **Assignment of SAR teams**: ensures the targeted deployment of SAR teams with specialized skills and equipment to address the unique challenges of each cluster, optimizing the overall effectiveness of the response
- **Overall incident management:** facilitates organized information flow, enabling incident managers to make informed decisions and maintain situational awareness by receiving real-time updates on the status of each sector.
- **Efficient coordination:** It establishes clear boundaries and responsibilities, reducing the risk of overlapping efforts or leaving gaps in coverage, thus enhancing the overall effectiveness of SAR operations.

The size and number of sectors, areas and sub-areas depend on factors like:

- **Available resources**: Ensures that resources are distributed in a manner that aligns with the available personnel, equipment, and support.
- **The scale of the disaster**: Recognizes that the magnitude of the disaster may vary, requiring different levels of resources and coordination.
- **Geographical considerations:** Acknowledges the unique challenges posed by different terrains and locations, influencing the distribution of resources to optimize effectiveness.

It is crucial that sectorization is initiated as early in the response, ideally following a local sectorization plan. If such a plan is absent, collaboration between (inter)national organisations and Local Emergency Management Authorities (LEMA) is necessary. This approach ensures a systematic and effective response to complex disaster scenarios.

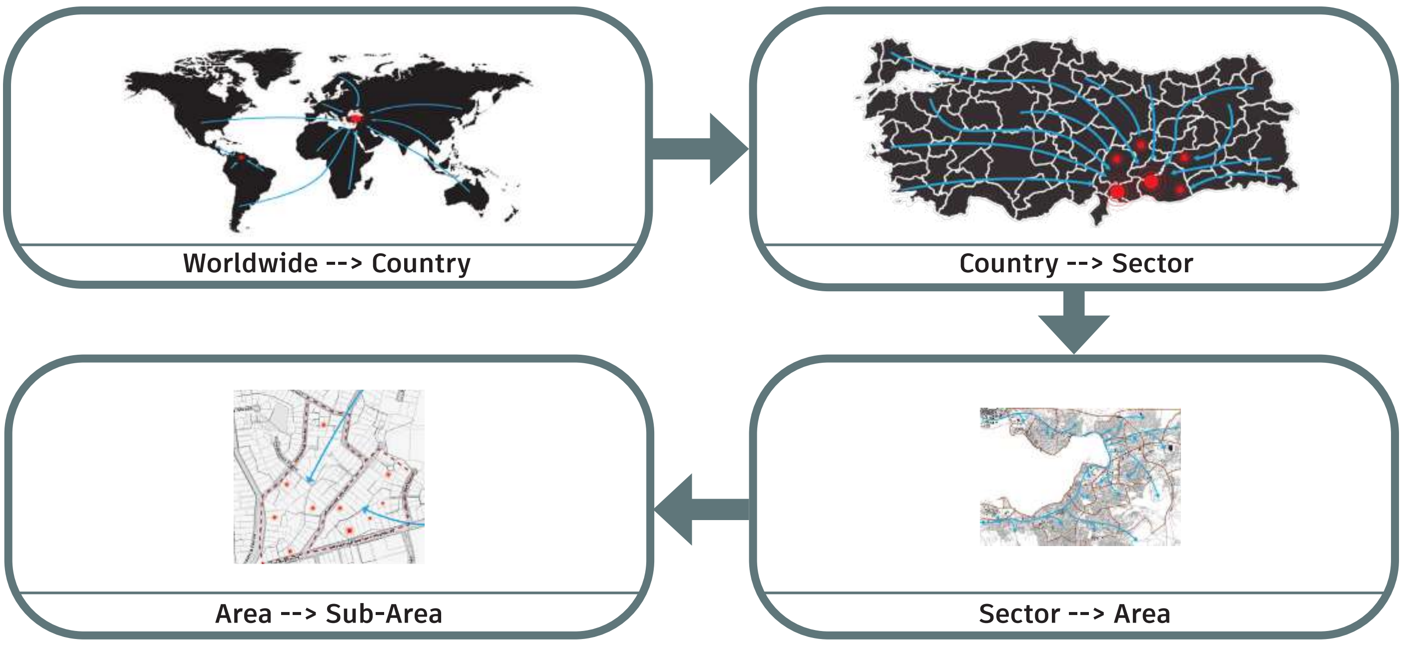


Figure 44: Levels of allocation. Own work

Part B: USAR team types

Theoretical research

Urban Search and Rescue (USAR) teams play a critical role in responding to complex emergencies and are categorized into three types: light, medium, and heavy. The requirements for these teams are outlined by INSARAG (2020a). A summary can be found in Appendix I. While these teams vary in capacity and capabilities, they consistently include the components:

- Management
- Logistics
- Search
- Rescue
- Medical

For the scope of this project, our focus will be exclusively on the rescue component. The incorporation of other components will be considered in future developments, as introducing additional elements at this stage would unnecessarily complicate our efforts to validate and establish our concept of allocating rescue resources. For the project we took into account the following data for the light, medium and heavy USAR teams:

Light USAR Teams

- Suggested personnel: 17 to 20
- Include one rescue sub-team of five rescues technicians and a team officer.
- Can work on wood, masonry, and light reinforced concrete constructions.

Medium USAR Teams

- Suggested personnel: 42
- Includes two rescue sub-team of 5 rescue technicians and a team officer.
- Capable of technical search and rescue in collapsed structures of heavy wood and/or reinforced masonry construction, including steel-reinforced structures.

Heavy USAR Teams

- Suggested personnel: 63
- Includes four rescue sub-team of 5 rescue technicians and a team officer.
- Operational capability for complex technical search and rescue operations in collapsed or failed structures, involving cutting, breaking, and breaching steel-reinforced concrete structures.

Figure 45: Heavy USAR team. USAR.NL (2023).

Part B: USAR Team skills

Theoretical research

USAR rescue technicians undergo extensive training in various specialized skills, ensuring their readiness for diverse scenarios. This multifaceted training equips USAR teams with the expertise needed to navigate complex urban environments and respond effectively to emergencies. The primary skill each rescue technician is expected to possess is structural rescue, complemented by five additional skills, as detailed on the next page, which are considered as “expertise” skills.

Each skill in the training framework corresponds to a competence level, ranging from levels 1 to 3:

- **Level 1:** At this stage, rescue technicians acquire fundamental knowledge and skills related to the specific rescue action. This level focuses on building a solid foundation, understanding basic principles, and gaining hands-on experience in executing essential tasks.
- **Level 2:** Moving beyond the basics, Level 2 involves a more in-depth and sophisticated training approach. Rescue technicians at this level enhance their proficiency by mastering advanced techniques, problem-solving, and decision-making in complex scenarios. The training emphasizes a higher degree of skill and efficiency.
- **Level 3:** This level represents the highest level of training expertise. Rescue technicians at Level 3 possess an intricate understanding of the skill, demonstrating mastery in executing the most complex and challenging actions. Training at this level involves a focus on leadership, strategic thinking, and the ability to handle unprecedented situations with a high level of competence

These competency levels for each skill correspond to a specific set of rescue actions that can be executed. As a result, each USAR team generates a list of actions it can perform, reflecting the competency levels of its team members..

Given the extensive range of rescue actions per skill, a concise overview of the three to four most important actions per competence level, per skill, has been compiled. This comprehensive list of 68 actions can be found in Appendix II for reference. The next page elaborates briefly on the six different skills.

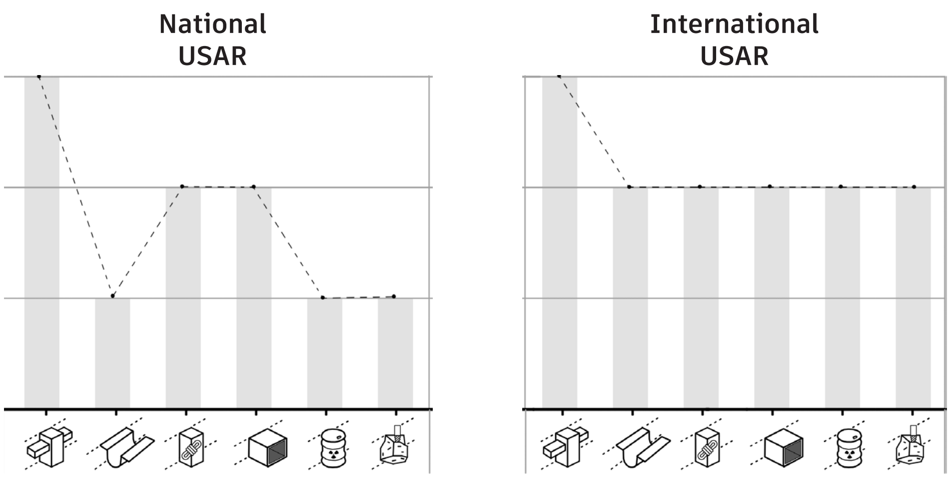


Figure 46: Example average compentence level of USAR teams. Own work

Part B: USAR Team skills

Theoretical research

1. Structural Rescue:
- Techniques for locating, accessing, and extricating victims trapped in structural collapse scenarios.
- Use of tools like concrete breakers, cutting equipment, and shoring systems.

2. Trench Rescue:
- Specialized training for rescuing individuals trapped in trenches or excavations.
- Utilizes trench boxes, airbags, and specialized shoring techniques.

3. Technical Rope Rescue:
- Techniques for safely performing rescues using ropes in elevated or challenging terrains.
- Mastery of knot tying, rappelling, and rope ascending techniques.

4. Confined Space Rescue:
- Addressing the complexities of rescuing individuals trapped in confined spaces.
- Emphasis on safety protocols, atmospheric monitoring, and specialized equipment.

5. Hazmat Rescue:
- Handling hazardous materials incidents and ensuring the safe rescue of individuals.
- Training on personal protective equipment (PPE) usage and decontamination procedures.

6. Heavy Rigging:
- Use of heavy equipment and rigging systems for complex extrication scenarios.
- Proficiency in the use of cranes, winches, and other heavy machinery.

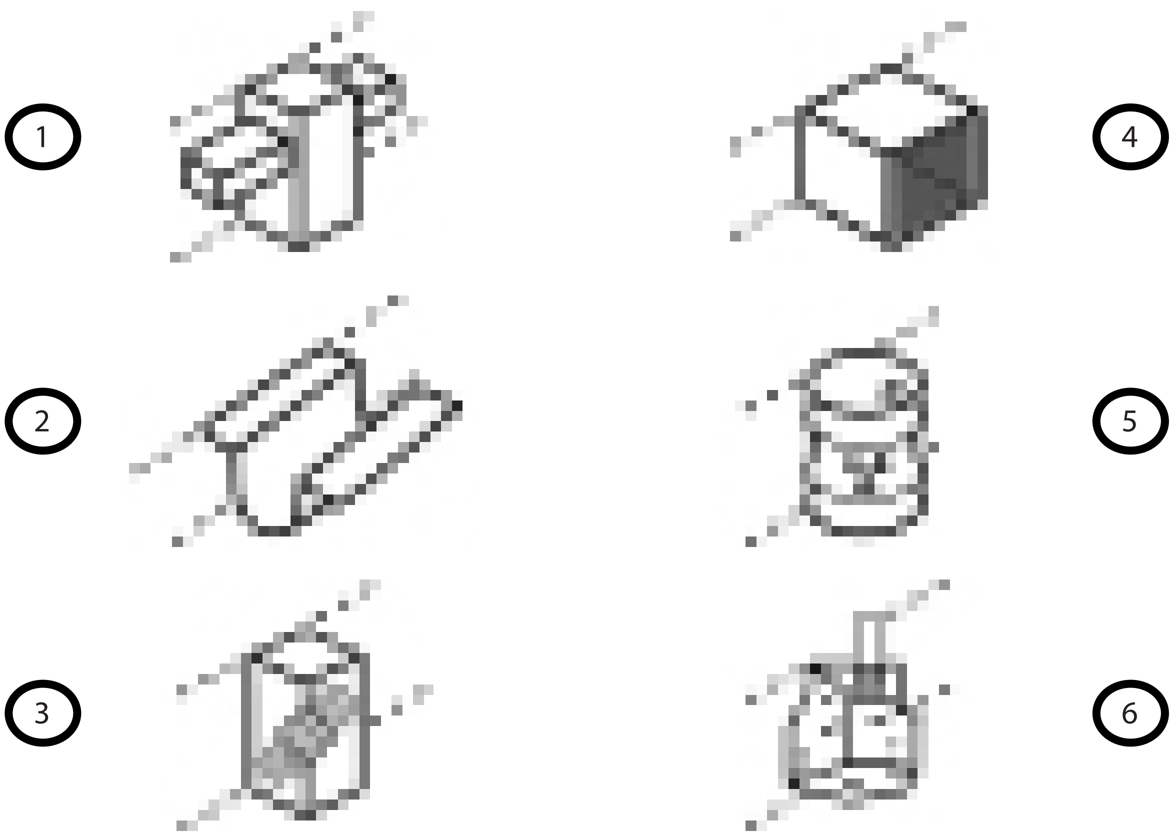


Figure 47: Rescue technician skills. Own work

Part B: Allocation models and methods

Theoretical research

In the aftermath of an earthquake, the allocation and scheduling of resources, particularly the deployment of rescue teams, play a pivotal role in mitigating casualties and minimizing damage. Effective resource management via computational methods in these critical situations demands a comprehensive study of the principles that determine allocation and scheduling process.

Principles and considerations for allocating and scheduling resources in post-earthquake circumstances:
This section outlines the fundamental principles and key considerations that guide resource allocation and scheduling strategies in post-earthquake circumstances.

1. Priority-Based allocation:

Establish a prioritization system to allocate resources based on the severity of the damage and the criticality of the affected areas. Ensure that rescue teams and essential supplies are directed first to locations with the highest risk and immediate need.

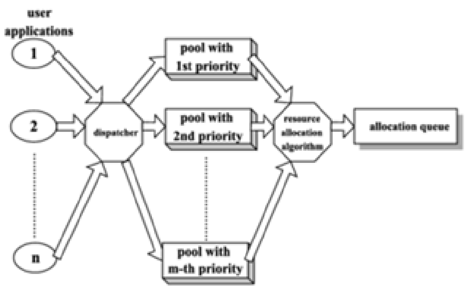


Figure 48: Priority weight approach, by Yin-Fu Huang (A priority-based resource allocation strategy in distributed computing networks)

2. Dynamic Resource Adjustment:

Implement a dynamic resource allocation system that can adapt to changing circumstances in real-time. As the situation evolves, continuously reassess the allocation of resources to address emerging priorities and challenges.

3. Geospatial Analysis:

Utilize geospatial data to identify areas with the greatest impact and optimize resource deployment. Geographic Information Systems (GIS) can assist in mapping affected regions, population density, and infrastructure damage, aiding in strategic decision-making for resource allocation.

4. Interagency Collaboration:

Foster collaboration and communication among various response agencies and organizations. Establishing a unified command structure enables efficient sharing of resources and avoids duplication of efforts. Coordination among different entities enhances the overall effectiveness of the response.

5. Adaptive Scheduling:

Develop flexible scheduling algorithms that consider the deterioration of resources. Adaptive scheduling takes into account the varying intensity of the crisis and the need for breaks to maintain the effectiveness of response teams.

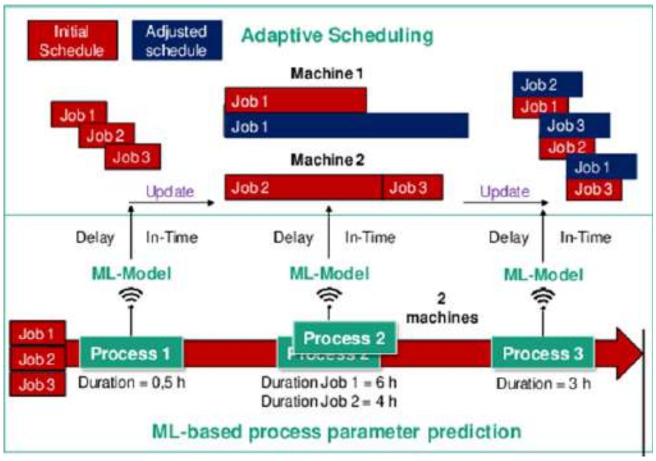


Figure 49: Adaptive scheduling using ML, by Júlia Bergmann (Adaptive scheduling through machine learning-based process parameter prediction)

6. Data-Driven Decision Making:

Leverage data analytics and predictive modeling to anticipate resource needs and potential challenges. By analyzing historical data, current conditions, and projected trends, decision-makers can make informed choices regarding the allocation and scheduling of resources, optimizing the overall response effort.

Part B: Allocation models and methods

Theoretical research

Allocation models, methods and technologies in field:
Various models can be used to optimize this process, ensuring that limited resources are distributed strategically to minimize casualties, mitigate damage, and facilitate a swift recovery.

Allocation Models:
These models provide systematic frameworks for decision-makers to distribute resources effectively. They encompass mathematical approaches, computational algorithms, and strategic frameworks tailored to address the unique challenges posed by post-earthquake scenarios.

Allocation Methods:
Methods for resource allocation delve into the practical strategies employed to implement allocation models. These range from dynamic algorithms that adapt in real-time to changing conditions, to systematic prioritization based on predefined criteria such as severity of damage, population density, and accessibility.

Allocation Technologies:
Technological advancements play a crucial role in enhancing resource allocation. From sophisticated data analytics to artificial intelligence, these technologies contribute to informed decision-making, dynamic adaptation, and improved coordination among response teams.
The combination of these models, methods, and technologies ensures that response efforts are not only swift but also optimized.

Some of the concepts studied during the literature review were:

1. Machine learning
2. Queuing Algorithm with Graph Theory
3. Linear Programming
4. Multi-skill Project Framework.

1. Machine Learning (Deep learning)
Robust decision-making, supported AI, is essential due to the complexity of disasters and the criticality and intricacy of disaster operations (Atlay et al., 2006).

Efficient disaster management is crucial for effectively addressing the scale and consequences of disasters, and in recent years, significant progress has been made in the field through advancements in machine learning (ML) and deep learning (DL).

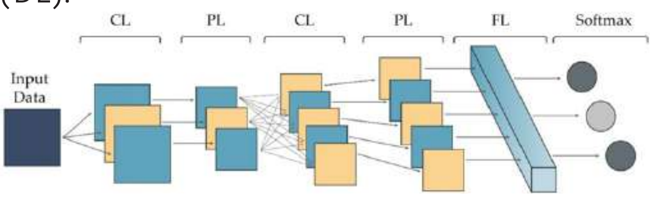


Figure 50: A CNN architecture, Linardos et al. (2022)

According to Linardos et al. (2022), the utilization of ML and DL enables the analysis of vast and complex datasets, leading to the development of predictive systems that greatly assist in disaster response. Furthermore, these techniques have facilitated the creation of practical decision-making tools that can process diverse data from multiple sources and uncover hidden patterns that would otherwise go unnoticed.

Reasons for not using the framework:
1. Data Limitations: Models heavily rely on data for training. In the context of SAR, obtaining sufficient and diverse data for training robust models can be challenging.
2. Resource Constraints: The lack of sufficient computational power and infrastructure posed significant challenges in tackling a highly complex problem.
3. Interpretability of results: ML and DL models are often considered “black boxes” because it’s challenging to interpret how they arrive at specific decisions. In scenarios, where human lives are at stake, the lack of transparency and interpretability may lead to a lack of trust.
4. Expertise with the framework: Machine learning and deep learning necessitate proficiency in model development and output interpretation. Limitations in time and expertise prevented further exploration of this framework.

Part B: Allocation models and methods

Theoretical research

2. Queuing Algorithm with Graph Theory

The queuing algorithm models the problem using graph theory, where tasks and emergency resources are represented as vertices in a bipartite graph. The edges in the graph define the allocation relationships between tasks and resources.

The objective is to achieve the maximum allocation by efficiently matching tasks with the available emergency resources.

Emergency resources encompass a variety of assets such as fire engines, task forces, USAR teams, and volunteers. The algorithm considers factors like traffic, minimum distance, accessibility, and others to optimize the allocation of these resources to different tasks.

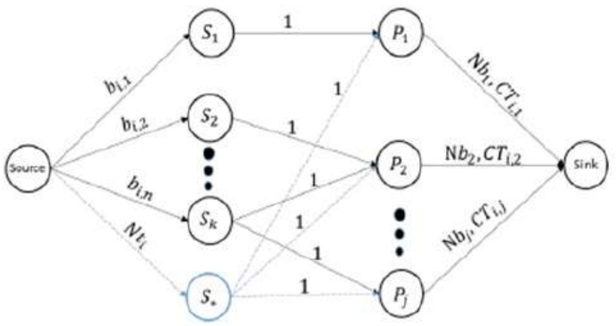


Figure 51: Flow graph for the MSPSP-PP, Polo-Mejía et al.

The algorithm employs the concept of bipartite graph matching to allocate resources effectively. Bipartite graph have two disjoint set sets of vertices, one representing tasks (t) and the other representing resources (r).

The algorithm aims to find the maximum bipartite matching, ensuring maximum flow with minimum cost using Edmond Karp's algorithm. (Kumar et al., 2017)

Reasons for not using the framework:

1. Complexity and Scalability:

The formulation of the graph logic is a detailed and complex process. In real world scenarios, especially in large-scale disasters, the computational complexity may impact the scalability.

2. Assumption of Bipartite structure:

Real-world networks can be more interconnected, leading to potential limitations in the model's representational capacity.

3. Extremely sensitive to input parameter:

The algorithms performance is sensitive to input parameters and the weights assigned to the network. This may cause inaccuracies and biases leading to suboptimal allocation.

3. Linear Programming

Linear programming is a mathematical tool that can be applied to optimize resource allocation and scheduling problems. Bodagi B. et al., states in a paper on "Solving multi-resource allocation and location problems in disaster management through linear programming" that such problems can be solved using integer and mixed integer linear programming solvers.

In simple cases the problem can be described as a linear or convex problem through integer programming while complex scenarios like disaster require mixed integer linear programming. Mixed-integer linear programs involve variables that are integers, making optimization more challenging, and there is no guarantee of obtaining an optimal solution in some cases.

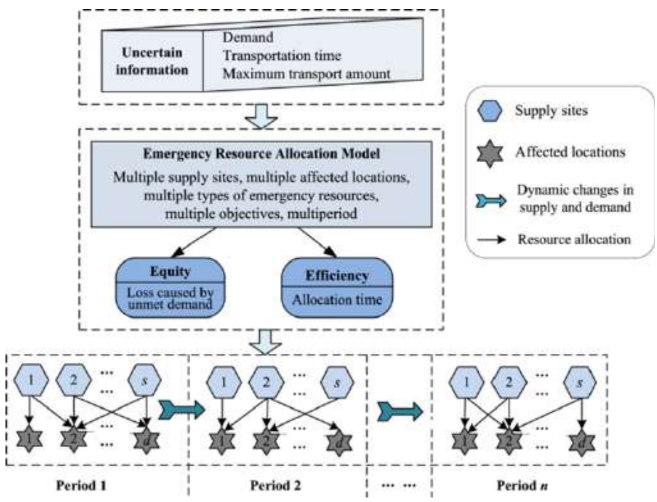


Figure 52: Research framework of multiperiod equitable and efficient allocation of emergency resources under uncertainty, by Wang, Y. et al. (Multiperiod Equitable and Efficient Allocation Strategy of Emergency Resources Under Uncertainty)

Part B: Allocation models and methods

Theoretical research

The objective function in LP would aim to maximize the efficiency of resource allocation, considering factors such as the availability and
capabilities of different types of resources, the severity of emergencies in various geographical zones, and the time constraints associated with rapid response. Constraints would be introduced to address resource limitations, interagency collaboration requirements, and the dynamic nature of the post-disaster situation. This approach ensures that the limited resources are strategically distributed to areas with the greatest need, taking into account the varying severity of emergencies and the urgency of response times.

Reasons for not using the framework:

1. Complexity of the model:
LP models can become very complex, especially when dealing with a large number of variables, and constraints. If there is limited data, a simpler heuristics or rule based approach might be more practical.

2. Assumption of linearity:
LP assumes that the relationship between variables is linear which is not always accurate and sometimes fails to capture the complexity of the scenario. If the relationships are highly nonlinear, other optimization techniques or simulation models might be more appropriate.

3. Limited consideration of uncertainty:
LP models typically assume that all parameters are known with certainty. In the aftermath of an earthquake, uncertainties and variability in data are inevitable. If the level of uncertainty is high, probabilistic or stochastic optimization methods may be more suitable.

4. Multi-skill Project Framework

This is a problem approach which can be used where there is a set of regulations that requires the presence of a group of [doers] having a set of well-defined competencies and skill for the execution of an activity. It is based on CPU scheduling algorithms defining different tasks into categories like preemptive and non preemptive tasks. The core hypothesis of multi skill scheduling framework states: "When allocating resources it assumes that all the resources in an activity are non preemptive; meaning, once started, an activity must run continuously until its completeness." (Polo-Mejía et al.)

This hypothesis doesn't always hold true especially in case of disasters where priorities are continuously changing and there are multiple constraints with n-level complexity. For these reasons we further explored frameworks that were based on partial preemptives. This leads to division of all the actions that can be performed by the rescue teams and the teams themselves into 3 categories:

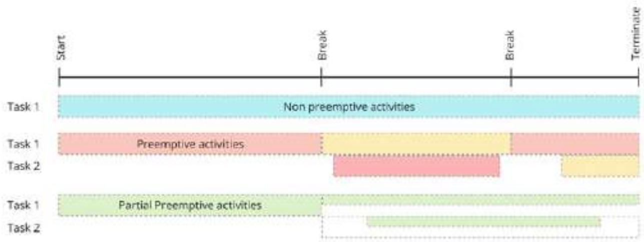


Figure 53: ime relation with activities, own work

Non preemptive resource and activities:
This category is for activities where resources are required and will be employed for the entire duration of the operation. Eg. Emergency Medical Teams are required on site for the entire duration of rescue for higher level rescues.

Partial preemptive resource and activities:
The ability to interrupt or reallocate some, but not all, of the resources in a team. This allows certain aspects can continue without interruption. Eg. K9 Search teams where the teams can subdivide and distribute to other high priority zones without interrupting the main rescue work.

Preemptive resource and activities:
For activities where all resources can be terminated or transferred mid process if the need arises. Resources are moved completely. Eg. Fire Fighting Team where the teams can move from one site to another even though the entire job on that demand site has not been completed

This framework works very well with the disaster scenario as it acknowledges the fluid nature of the disasters. It can efficiently adapt to the changing priorities.

Reasons for not using the framework:

1. Rigidity in Skill Allocation:
The framework categorizes activities into non-preemptive, partial preemptive, and preemptive, which may lead to a rigid allocation of skills. In dynamic disaster scenarios, the required skills might change rapidly, and a fixed categorization may limit adaptability.

2. Lack of building action database:
Due to data sharing and privacy concerns information regarding different building actions and their association with various damage states could not be gathered. Without base data the problem becomes extremely complex and difficult to work with in a very large scenario.

3. Complexity in Implementation:
Implementing a framework based on CPU scheduling algorithms can be complex and resource-intensive, particularly in real-time disaster response scenarios. The need for continuous monitoring and adjustment could introduce challenges in implementation.In many cases the complexity of implementation might outweigh the benefits.

4. Limited Applicability to Certain Tasks:
The framework might not be suitable for all types of rescue tasks. Some activities may not neatly fit into the defined categories of non-preemptive, partial preemptive, or preemptive, leading to suboptimal resource allocation for certain tasks.

Part B: Scheduling models and methods

Theoretical research

Scheduling models, methods and technologies in field:
Scheduling is an important part of allocating resources as it helps maximizing the impact of limited resources within a set duration of time to minimize repercussions of the disaster.

Scheduling Models:
Various scheduling models available are part of temporal scheduling models, resource-task assignment models or dynamic models. These models focus on optimizing the timing of various response activities by considering urgency of tasks and availability of resources while keeping in mind the evolving nature of the emergency.

Scheduling Methods:
Methods for resource scheduling take into consideration various approaches and strategies like systematically prioritize tasks with available resources. Using heuristic approaches also help in giving real time, quick and practical solutions which are invaluable in disaster situations.

Scheduling Technologies:
Technological advancements play a crucial role in enhancing resource allocation. From sophisticated data analytics to artificial intelligence, these technologies contribute to informed decision-making, dynamic adaptation, and improved coordination among response teams.

The combination of these ensures a coordinated, adaptive and data-driven emergency response. Some of the concepts studied during the literature review were:

1. Constraint programming (IBM CPLEX Optimization studio, Pyschedule and Google OR-Tools)
2. Agent based models (AnyLogic)
3. Network flow models

1. Constraint programming

Constraint programming is a declarative programming model for solving combinatorial problems with complex constraints. By creating a descriptive model with variables, constraints and objective functions we can use optimization tools like CPLEX or pyschedule to find optimal solutions. This allows for the formulation of complex scheduling problems and provides efficient algorithms to solve them.

CPLEX (IBM ILOG CPLEX Optimization studio) is an optimization tool to ensure efficient allocation in a time sensitive sequential format. First the objective functions are defined in this case it can be maximise live saved or maximise area covered or minimise operation time. Next task is to define decision variables, parameters and constraints like task assignment, team availability, time windows and priorities. A model type is selected like MIP and the problem is solved. There are various other solvers that can be used like CBC, Gurobi, etc. depending on the problem type.

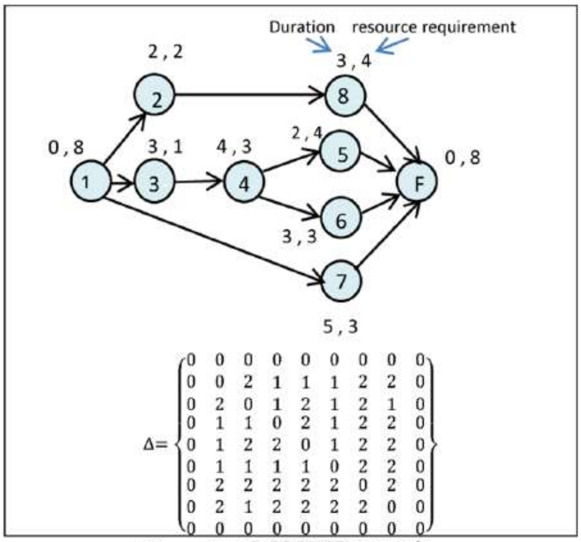


Figure 1 : a RCPSPTT example.

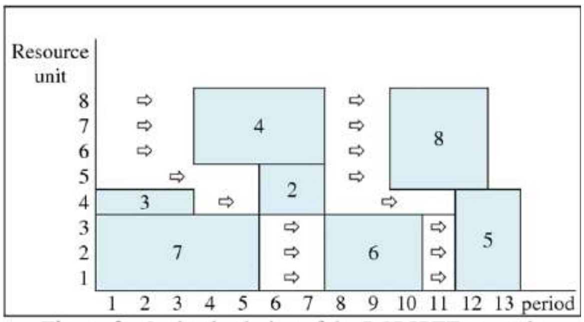


Figure 2: Optimal solution of the RCPSPTT example

Figure 54: a RCPSPTT example, by Kadri et al. (Resource Constrained Project Scheduling Problem with sequence dependent Transfer Times : The single mode case)

Part B: Scheduling models and methods

Theoretical research

Pyschedule is a light-weight python library for resource constrained scheduling problems. It generates a scenario and creates assets representing rescue teams, types of teams and other rescue assets. It also defines jobs that corresponds to tasks or assignments that have to be done. Lastly it tries to capture limitations or dependencies like precedence, priority, delay cost and travel times.

Reasons for not using the framework:

1. Complexity of task:

Formulating the problem and configuring a constraint problem especially with CPLEX can be complex, requiring expertise in mathematical programming. It also has a steeper learning curve for users that are unfamiliar with this model of optimization

2. Dependency on modelling skills:

The effectiveness of constraint programming is often equivalent to the quality of the problem model. In cases of limited data and unclear relationships, the results may not be very accurate.

3. Suitability:

In the context of pyschedule the problems have to be simpler and deal with linear constraints which was not the case in our situation. It is also difficult to scale up the pyschedule model.

2. Agent based models

Agent-Based Models (ABM) involve simulating the actions and interactions of individual entities, or agents, within a system. In the context of search and rescue team scheduling for buildings, ABM could represent the behavior of individual rescue teams and other relevant entities within the affected area.

ABM is models with multiple components like agents to represent individual entities in the system such as buildings, rescue sub teams, etc. The environment is representative of the physical characteristic of the site like road network and damage state. There are rules that govern the interaction and the emergent behavior is recorded.

Reasons for not using the framework:

1. Computational complexity:

ABM can become computationally intensive, especially when simulating a large number of agents and complex interactions in a dynamic environment. In real-time emergency scenarios, computational complexity may hinder the quick decision-making required for effective search and rescue operations.

2. Real time adaptability:

In search and rescue operations, the situation can evolve rapidly, requiring immediate adjustments to team assignments. ABM may not be agile enough to accommodate these changes effectively.

3. Lack of optimality:

The model does not guarantee optimal resource allocation may not be the best fit. Hybrid approaches that combine the strengths of ABM with more computationally efficient techniques like optimization models (e.g., MIP, CP) might be more practical in ensuring both accuracy and speed in the resource allocation process.

3. Network flow models

A Network Flow Model is a mathematical representation of the flow of resources or entities through a network of interconnected nodes and edges. In the context of search and rescue team scheduling for buildings, a

Network Flow Model might be used to optimize the allocation of resources (rescue teams) to various locations (buildings) in a way that minimizes overall costs or maximizes efficiency.

Part B: Scheduling models and methods

Theoretical research

The model in network flow is described with nodes and edges representing buildings and their interconnectivity. There are flow variables that help in determining flow of resources through the network. Similar to CPLEX this is also modelled with an objective function and constraints relating to capacity and flow conservation constraints (balance of resources).

Reasons for not using the framework:

1. Inability to capture time dynamics:
Timing is very crucial in search and rescue operations. Network flow models don't adequately capture time-dependent factors such as urgency of tasks and deterioration rates of different injury classes. Due to lack of consideration for changing conditions this might affect the optimal deployment of teams over time.

2. Limited consideration of spatial constraints:
Network flow models sometimes oversimplify spatial constraints, leading to suboptimal solutions when dealing with complex data like, multiple degrees of damage, injury classes, etc. Network flow models might not inherently account for uncertainty, making them less adaptable to the dynamic and unpredictable nature of search and rescue operations.

3. Resource heterogeneity:
Rescue teams and members have a diverse set of skills and capabilities. The model often struggles to represent the heterogeneous nature of rescue teams and their specific competencies required for different tasks within a building.

Part B: Problem description

Theoretical research

Problem description:
In this section we will delve into key components and constraints that shape the optimization of resource allocation and scheduling problem for post earthquake rescue operations.

1. Objective:
The main goal of the decision support tool is to provide the control room with a range of solutions derived from both current and anticipated data. The aim is to maximise the number of lives saved during rescue operations.

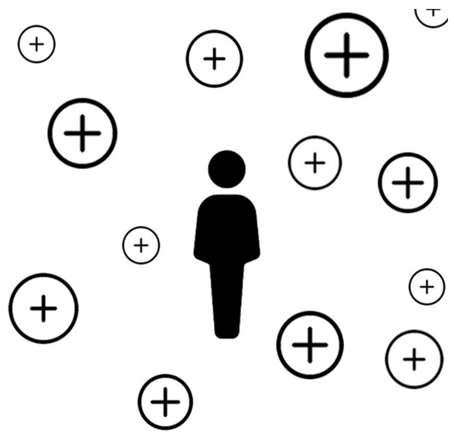


Figure 55: Primary goal to maximise lives saved, own work

In order to maximize the efficiency and effectiveness of rescue operations, our secondary goal is to ensure a targeted and swift response. This entails not only strategically deploying available resources to areas with the highest urgency but also meticulously optimizing the schedule of rescue teams to minimize response time.

By concentrating on the efficiency and effectiveness of utilizing resources, particularly the specialized skill sets embodied by rescue teams, our aim is to create a proactive and adaptive approach. This focus enables us to save lives with agility and forms the bedrock of our goal to enhance the resilience and responsiveness of rescue operations.

2. Key Components:
This part will talk about the various components that form the background of a search and rescue allocation and scheduling problem. As the situation is very dynamic and has a lot of uncertainties,it is necessary to break it down into distinct variables to encompass the breadth of the situation.

Resources:
Resources encompass a broad spectrum, including personnel, supplies, and equipments. Each type of resource plays a crucial role in post-earthquake rescue operations.

Understanding the types and availability of resources is fundamental to the effective allocation and scheduling of resources. Different resources have varying capabilities and limitations, and optimizing their deployment requires a detailed understanding of their roles and functionalities.

Geographical zones:
The affected area is divided into distinct geographical zones to account for variations in damage and urgency. Each zone in our case an area with multiple sub areas, represents a unique set of challenges and requirements for rescue operations.

Figure 56: Geographical zoning of Gaziantep, own work

Geographical zoning allows for a targeted and strategic approach to resource allocation. It recognizes that the impact of an earthquake is not uniform across the affected area, and resources need to be directed where they are most urgently needed.

Part B: Problem description

Theoretical research

Emergency levels:
Emergency severity levels categorize the severity of emergencies within each geographical zone. This categorization considers factors such as damage states, injury severity, risk levels and occupancy type. Severity levels help prioritize resource allocation based on the urgency of the situation.

Assigning severity levels allows for a dynamic and adaptive response. Different zones may experience varying degrees of emergency, and
allocating resources based on severity ensures that the right type of resource is allocated to the right zones.

Time factor:
Time constraints acknowledge the dynamic and time-sensitive nature of post-earthquake scenarios. Response times are critical, and the framework considers factors such as the evolving nature of emergencies, changing conditions on the ground, and the need for rapid decision-making.

Incorporating time constraints emphasizes the need for swift and adaptability in resource allocation and scheduling. The framework recognizes that delays can have significant consequences, and optimizing response times is paramount to the success of rescue operations.

3. Constraints:
There are number of constraints and limitations in a post disaster situation and it is crucial to identify the relevant limitations to appropriately model the problem.

Resource limitations:
This constraint addresses the finite availability of resources, including personnel, supplies, and equipments. The challenge is to optimize the deployment of these limited resources to areas with the greatest need.

The constraint reflects the scarce nature of resources during disaster response. Efficient allocation becomes crucial to ensure that each resource is utilized effectively to maximize its impact on saving lives and aiding recovery.

Interagency collaboration:
Successful disaster response often involves collaboration between various rescue agencies and organizations. This constraint considers the capabilities, resources, and response strategies of different entities. Coordination is essential to avoid duplication of efforts and working in areas that best match their capabilities.

Interagency collaboration is critical for leveraging collective resources effectively. This constraint acknowledges the need for coordination between different organizations involved in post-earthquake rescue operations.

Dynamic nature of situation:
This constraint emphasizes the need for adaptability in resource allocation and scheduling strategies to respond effectively to evolving circumstances.

Earthquake aftermaths are characterized by uncertainty and unpredictability. The constraint reflects the necessity for a flexible and adaptive model that can adjust resource allocation and scheduling decisions in real-time.

Time constraints:
Time is a critical factor as it is imperative to save lives. The need to minimize the overall response time, including the time taken for resource deployment and the initiation of rescue operations.

Part B: Problem description

Theoretical research

Table 9.2 Optimization Problems Categorized by Structure of Objective Function and Constraints and Nature of Decision Variable

Structure of the Objective Function (OF) and/or Constraints	Nature of the Decision Variable (DV)			
		Discrete		
	Continuous	Integer	Binary	Mixed
Linear	Continuous-variable linear programming (CV-LP)	Integer Linear Programming Programming (ILP)	Binary Linear (BLP)	Mixed Linear Programming (MLP)
Nonlinear	Continuous-variable nonlinear programming (CV-NLP)	Integer Nonlinear Programming (INLP)	Binary Nonlinear Programming (BNLP)	Mixed Nonlinear Programming (MNLP)

Figure 57: Optimization Problems Categorized By Structure Of Objective Function And Constraints And Nature Of Decision Variable

4. Decision Variables:

In the formulation of the problem model, diverse variables are considered to determine the output. These decision variables, integral to the optimization process, fall into distinct categories based on their nature: binary, discrete, or continuous. The classification of these variables help in crafting a mathematical representation that accurately reflects the complexities of resource allocation and scheduling in post-earthquake circumstances.

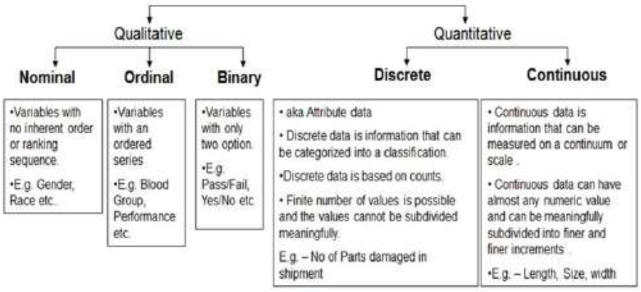


Figure 58: six_sigma_data_types, by six sigma institute

Sites to be served (Rescue demand):

This variable represents the geographical sites or zones that needs rescue. Each site corresponds to a specific area, and the decision variable involves determining the severity of damage and the consequent rescue demand. Each sites should receive different priority in terms of resource allocation and rescue team deployment.

For each demand_site, a binary decision variable x_i can be defined, where x_i=1 indicates that the site is selected to be served, and xi=0 implies exclusion.

Resources to be allocated:

This variable represents the resources available that can be allocated to different demand sites. The decision involves determining the quantity and type of resources to be sent to each site based on its specific needs and the severity of the situation.

Continuous decision variables Y_{ij} can be assigned to represent the quantity of resource R_j (where j is the type of resource) allocated to site S_i. These variables collectively form the resource allocation matrix for distribution of resources across different sites.

Sequence of rescue:

The sequence of rescue defines the order in which different sites are attended to. This decision variable involves determining the priority sequence for deploying rescue teams and allocating resources to various sites. The sequence is influenced by factors such as the severity of emergencies, and the potential for further escalation of the situation.

Binary decision variables Z_{ik} is used to indicate whether site S_i is served during time period T_k (Z_{ik}=1) or not (Z_{ik}=0).

Time to complete the operations:

This variable represents the time required to complete a demand site and the entire rescue operation. It involves determining the optimal schedule and coordination of activities to minimize the time needed to address the emergency situations.

$T_i \in T$ where T represents the total time required to complete the entire rescue operation. T_i is a continuous decision variable that can be used to represent the time taken for each specific activity or travel time between sites. The summation of all the time taken for each site and the buffers represent T.

Part B: Adopted approach

Theoretical research

Overview of the adopted approach:
The framework of the adopted approach falls under heuristic or metaheuristic models specifically priority or rule based. A heuristic is a problem-solving approach or methodology that uses practical and intuitive methods, often employed to find a good, but not necessarily optimal, solution.

Priority-based systems often involve assigning levels of importance or preference to different elements or tasks. Rule-based systems utilize a set of predefined rules or conditions to guide decision-making. This suggests a problem-solving or decision-making strategy that relies on practical and intuitive methods, by incorporating prioritization or predefined rules to guide the process.

Heuristic offer flexibility in decision-making. This means that the approach may adapt to different scenarios. The method is particularly valuable when dealing with complex problems where finding an optimal solution is challenging. Their ability to explore and navigate solution spaces efficiently makes them suitable for problems with numerous variables and constraints.

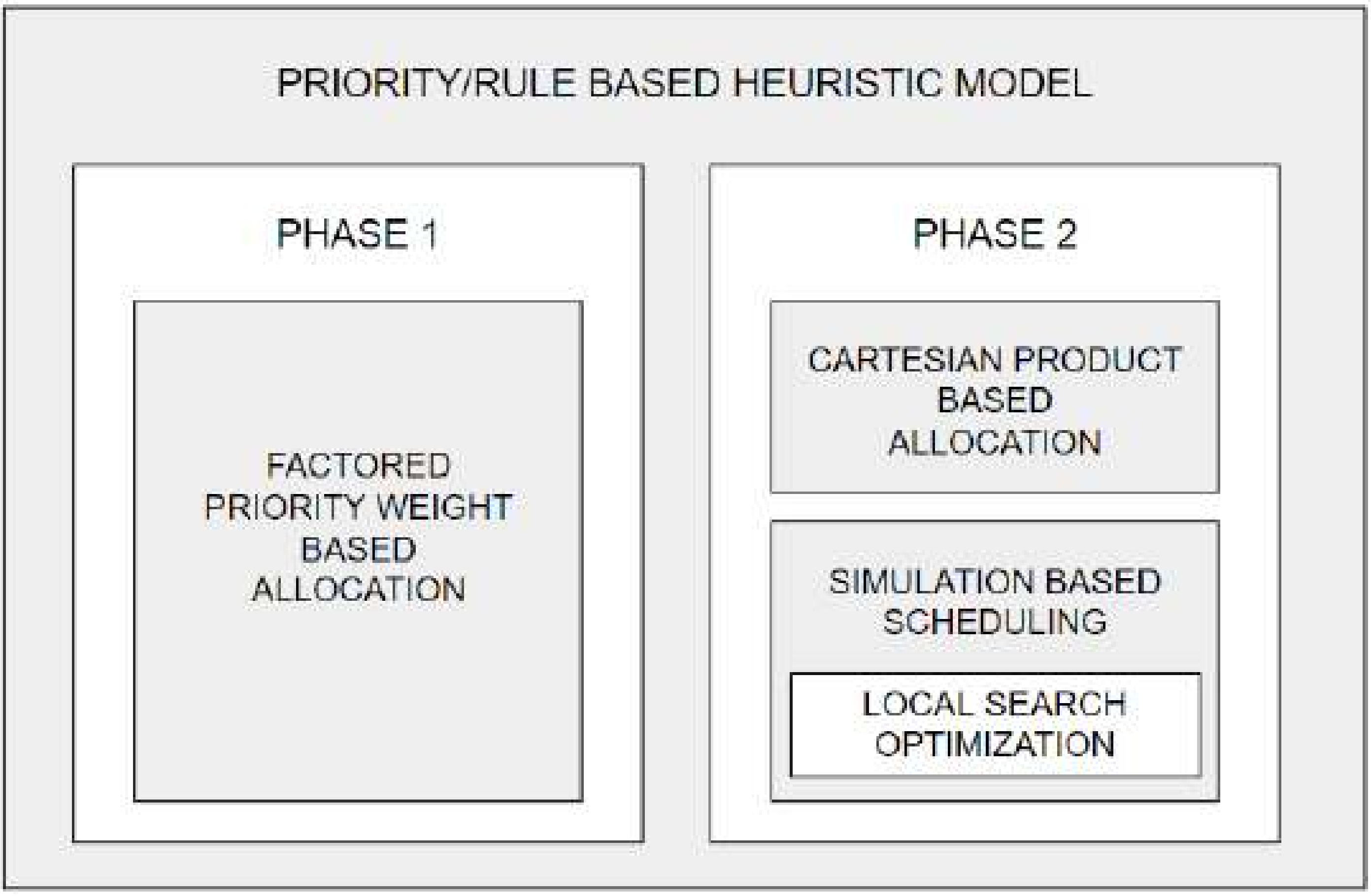


Figure 59: Framework for allocation and scheduling processes

Part B: 2 Phase approach to allocating resources

Theoretical research

After a seismic event such as an earthquake, the rapid and effective deployment of rescue resources is important to save maximum lives. However in the early hours after the disaster, there are numerous challenges that need to be addressed. This structured methodology aims to optimize the utilization of available resources, taking into account the evolving nature of the emergency and the need for swift, targeted responses.

Reasons for a Phased approach:

1. Lack of detailed information

In the initial stages of an earthquake, information about damages and specific rescue requirements is often limited. A phased approach allows for adaptive strategies as more data becomes available.

2. Data validation

The phased approach allows validation of data from predictive analysis via on site assessment with drones, satellites and search teams. This validation process is vital for effective resource allocation.

3. Movement & dispatch of rescue resources

The rescue resources aren't dispatched all at once. The first rescue starts with local volunteers and responders followed by task forces and then USAR teams.

4. Time criticality of injuries

The urgency of addressing time-sensitive injuries necessitates a systematic response. Phasing the allocation process enables prioritization, directing resources to locations where immediate intervention can maximize the number of lives saved.

5. Competency and capabilities of available resources

Understanding the strengths and limitations of available resources is crucial. The phased approach allows for a strategic alignment of competencies, ensuring that each rescue team is assigned tasks that match their skills, thereby optimizing overall effectiveness.

Overview of the Phased approach:

The whole process of allocation and scheduling is divided into 2 phases based on data availability, resource availability and maximising the primary goal of live saved. This phased approach outlines a strategic and organized response to earthquake impacts, particularly in the context of Urban Search and Rescue (USAR) operations. Breakdown of each phase:

Phase 1: Factored weight method

1. Time Frame:

0 to 12/24 hours

2. Objective:

The objective is to address immediate rescue needs before USAR teams arrive by utilising available volunteers and local teams.

3. Key elements:

- The information is limited and based on a predictive model
- Weighted priority rating approach to allocate sub-teams
- Algorithmic matching of sub-area requirements with team competency scores.
- For local teams and volunteers focus on zones with minimal risk and higher clearance chances due to low damage.
- Recon team is conducting a detailed area-wide assessment for precise information.

Phase 2: Action based method

1. Time Frame:

After 12/24 hours

2. Objective:

Allocation of resources based on detailed understanding of the situation at building level to maximise efficiency of resources.

3. Key elements:

- The sites have been assessed and the control room has more detailed information for precise decision-making.
- Allocations become more precise, aligning with required actions and team member competencies.
- Emphasis on matching resources with specific demands.
- Targeted approach for assigning teams with appropriate skills to specific sub-areas leading to optimization of resources.

Part B: 2 Phase approach to allocating resources

Theoretical research

Phase 1: Factored weight approach
The initial stage commences immediately following the earthquake impact and spans approximately 12 to 24 hours. During this phase, information is limited, and only volunteers, task forces, and local teams are actively engaged in rescue efforts. USAR teams have not yet arrived on-site, prompting the utilization of a weighted priority rating approach to allocate sub-teams to different areas, aligning with the rescue demand.

The success of the first phase relies entirely on the anticipated damage states and severity classes of injuries determined in part A analysis. This information aids in narrowing down the search space for teams, directing volunteers and local teams to zones with minimal risk. These are also zones with higher clearance chance due to low damage which in return improves the lives saved rate.Employing a priority weight scheme assigned to each building, the algorithm matches sub-area requirements with the overall competency score of the team. Sub-areas exceeding this score are eliminated, and the team is assigned to the highest priority area within its competence range.

Phase 2: Action based approach
Following the initial 12 to 24 hours, the recon team conducts a comprehensive area-wide search and assessment. This critical phase provides the control room with a detailed understanding of the situation at the building level, enabling the identification of specific actions needed for effective rescue and building clearance. During this stage, allocations become more precise, aligning with the required actions and the competency levels of the assigned teams. This targeted approach ensures that teams with the appropriate skills are assigned to specific sub-areas, optimizing resource management and utilization.

The action-based methodology emphasizes the importance of accurately matching resources with the demands of the situation. This approach enables the creation of a structured framework where teams are strategically allocated to minimize the loss of life and reduce downtime, leveraging their skill levels effectively. By aligning competencies with the specific tasks at hand, this phase aims to enhance overall operational efficiency, creating a well-organized setup that maximizes the impact of rescue efforts.

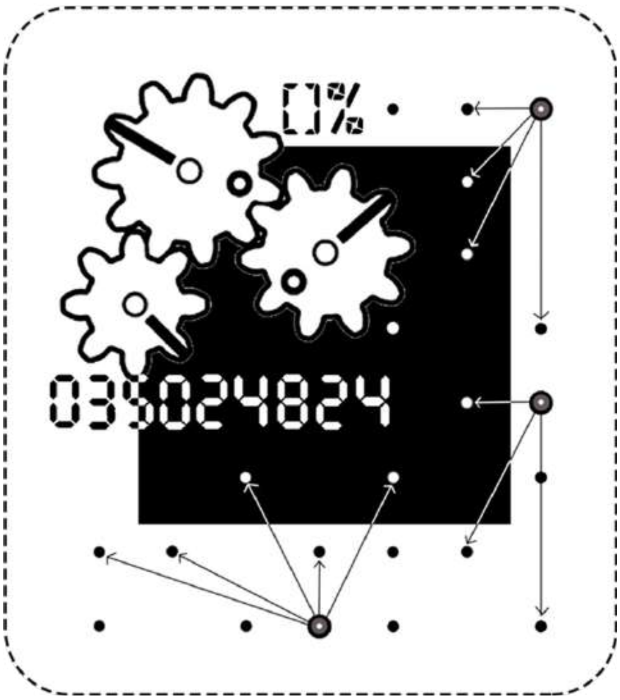


Figure 60: Factored weight based approach (Phase 1), own work

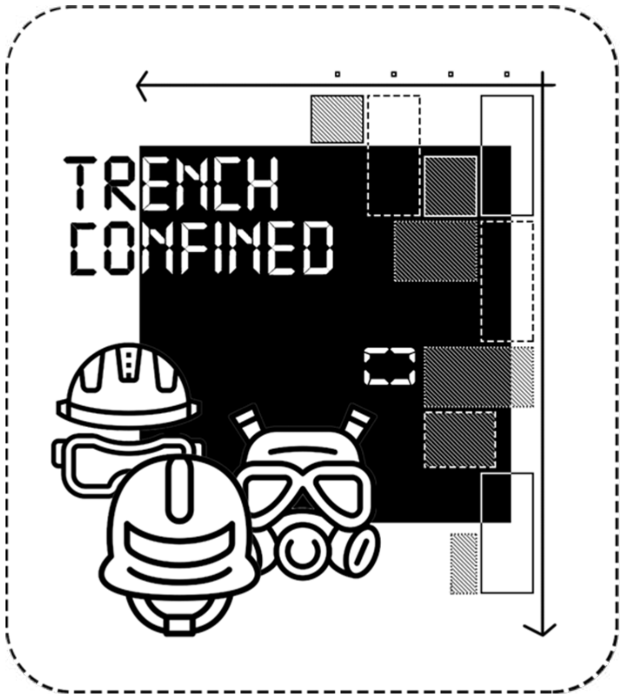


Figure 61: Action based approach (Phase 2), own work

Part B: Adopted approach

Theoretical research

Approach for allocation of rescue teams:
The allocation process follows a two-phase algorithmic approach. We have tried to create a custom variation of priority based heuristics. In Phase 1, the focus is on immediate response, sorting and assigning sub-teams based on competence and priority. Phase 2 introduces a more comprehensive evaluation, factoring in efficiency scores and prioritizing based on a combination of competence and specific area needs.

The process involves a combination of sorting, filtering, and iterative refinement to allocate rescue teams based on specific criteria, including competence, priority, safety, and efficiency. The process incorporates aspects of prioritization, competence evaluation, and iterative adjustments, making it a customized solution rather than a direct implementation of a well-known algorithm or simulation technique.

The approach is practically feasible as it systematically addresses immediate needs (Phase 1) while also considering overall efficiency and optimization factors (Phase 2). The iterative nature allows for continuous adjustments based on real-time information, making it adaptable to dynamic situations. The approach incorporates optimization through the use of priority weights, efficiency scores, and iterative refinement.

The combination of these factors ensures that the most competent teams are assigned to areas with the highest priority and potential impact.

Thus the proposed approach provides a structured and adaptive method for allocating rescue teams in disaster response scenarios. By combining immediate needs assessment with a more comprehensive evaluation of team competence and overall efficiency, it aims to optimize resource utilization and response effectiveness in dynamic and challenging environments. The iterative refinement ensures that the allocation remains responsive to evolving conditions, making it a robust for this approach.

Key components:

1. Priority weight

Generating the priority weight scheme for the buildings was extremely crucial to determine the situation and the type of team required. It takes into consideration damage state probabilities, risk level, injury severity and occupancy at the time of earthquake.

Figure 62: Priority weights distribution, own work

2. Site demand

The demand on site refers to the set of actions required to clear a building. These actions are based on the damage state, building typology and building height. Each site has a specific set of actions requiring different levels of expertise. The sum of all the site demands gives the area and sub area demand which is used to determine the type and quantity of teams that will be assigned to it.

3. Team competency

There are various types of teams ranging from USAR teams to organised volunteers. Each team consists of multiple sub teams as described in the previous chapters. Each sub team has a set of members that can undertake certain tasks of certain level at a certain speed. Each sub team is therefore given a competency score that describes the maximum demand and areas it can rescue.

Part B: Adopted approach

Theoretical research

Approach for scheduling of rescue teams:
Based on the theoretical research, complexity of the problem and constraints like expertise and time, we decided to approach the problem from a custom simulation-based scheduling algorithm. This algorithm is tailored for disaster response scenarios (specifically earthquakes), aiming to find the most effective sequence of building rescues.

This algorithm falls under the category of simulation-based optimization or heuristic methods. Specifically it can be labelled as a Monte Carlo simulation approach to explore different sequences of building rescues and evaluate their performance based on predefined criterias. Unlike taking the brute-force approach which would involve exhaustively trying all possible combinations we decided to use randomization and simulation to explore a subset of possible solutions and find a good or optimal solution. This approach was suitable in this case because finding the exact solution is such dynamic situations is computationally infeasible and very time consuming.

This simulation based approach provides a practical and effective approach for solving complex problems in situations where the solution space is vast and evaluating all possibilities is not feasible. We also try to use optimization algorithms after the best sequences are generated to check if they can improve the results. The optimization algorithms that we tried were local search optimization and simulated annealing.

Modelling the problem and assumptions:
The problem at hand involves scheduling rescue teams for disaster response, specifically in earthquake scenarios. In this particular problem we have a list of buildings that have to cleared as a result from the previous phase along with the type of sub team. There were some assumptions to better model the problem given the limitations:

1. We only consider the scheduling for a single USAR sub team while in reality there is a group of different teams working in and across a subarea, moving in and out at different timestamps.

2. Due to lack of data on such sequence of actions in a building and the fuzzy logic behind damage state and actions correlation we decided to assume that the team assigned can complete all the actions in the building and the rescue time incorporates that time.

3. Our focus is to find the best possible sequence to save maximum possible people in least amount of time. As resources are used or spent, their efficiency decreases leading to higher idle time

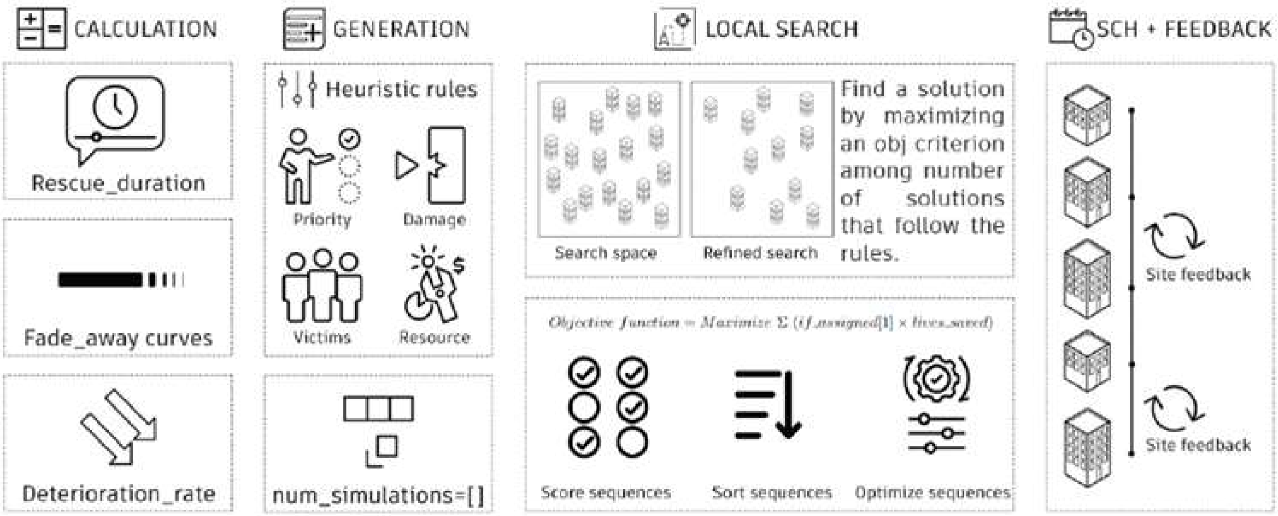


Figure 63: Factored weight based approach (Phase 1), own work

Part B: Adopted approach
Theoretical research

This deterioration is again not a part of the model but we have tried to find ways to incorporate it which can be researched in the future.

The next section discusses the model in detail breaking it down into several parts and categories.

Key Parameters:
The key parameters considered in the model include building information (such as damage state, height, area, and initial injury severity) and the team assigned for rescue operations (heavy, medium, or light).

1. Building information
Building variable: Each building is represented by a binary variable X_i, indicating whether it is included in the rescue sequence or not. 1, if building i is in the sequence, 0 otherwise.

It also has several predefined characteristics defined from previous steps and analysis:
{'building_id', 'building_area', 'building_height', 'damage_state', 'injury_distribution'}

Subarea representation: Buildings are part of subareas, and X_i is a member of subarea k.

$$X_1, X_2, X_3 \dots X_N \in \text{Subarea}_k$$

Where N is the number of buildings in subarea k.

Rescue Sequence: Buildings are organized in sequences S_j, where N is the total number of buildings.

$$X_1, X_2, X_3 \dots X_N \in S_j,$$

2. Rescue asset
Rescue Asset Variables: When defining rescue assets in the context of this search and rescue model, it considered rescue subteam as a rescue asset R_k, assigned to subarea k. Here we have 3 types of rescue subteams = {'heavy', 'medium', 'light'}, each with different competencies.

Time Relationship: As a rule of thumb, the heavy USAR teams have higher competency in actions then medium followed by light teams. This affects their rescue times. We thus create a dictionary to define the time relationship between rescue and these teams.

Time_relationship = {'heavy': 1, 'medium': 1.25, 'light': 1.4}

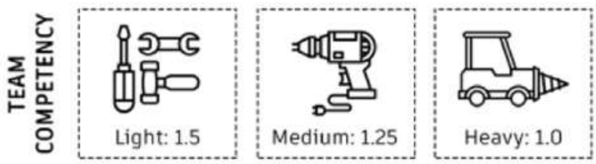


Figure 64: Time relationship with teams, own work

Note: Due to lack of a well defined data set on relation between actions and time in relation to teams, the current time_relationship dictionary is not the most accurate representation and in future development it would likely improve the results to create a score based on the track record of the team in previous situations.

3. Time period
Time period is an extremely important function in the model as rescue operations are time sensitive. To recreate the rescue operation there is start_time and end_time. There is also a variable named current_time which will be continuously updated as the sequence moves from one building to another keeping track of time passing. This will become significant when calculating other functions and parameters like people alive at time of arrival and the overall rescue time.

Start Time Condition:
current_time = start_time
This condition ensures that the sequence starts at the specified start time.

End Time Condition:
current_time ≤ end_time
This condition ensures that the rescue operations do not exceed the predefined end time.

Part B: Adopted approach

Theoretical research

Time Passing Condition:
$current\_time_{i+1} = current\_time_i + rescue\_time_i + buffer\_time$

This condition updates the current time as the sequence moves from one building to another. Here, $rescue\_time_i$ is the time taken to rescue the i-th building, and buffer_time is an additional time for travel and uncertainties that were not considered.

4. Time function and fade away curve

The time function here refers to the mathematical formulation of rescue duration for a person in each building. This depends on several factors like building_height, building_area and damage_state.

$$Rescue\_duration = (1.6 * Damage\_state) + (2.1 * building\_height \wedge 0.5) + (0.01 * building\_area \wedge 0.5)$$

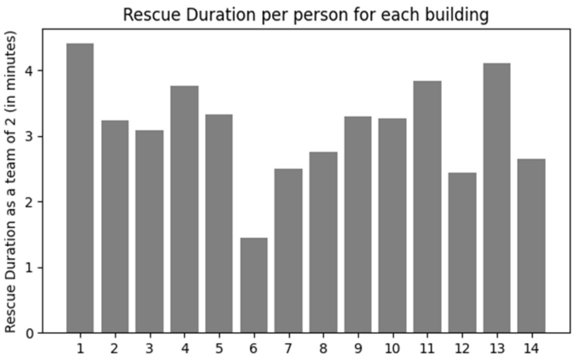


Figure 65: Rescue duration for each person in the building

This is calculated for every building. There are certain issues in this approach which will be discussed later in the following chapters.

The time period is also dependent on the fade away curve as explained in Part A. It is the deterioration curve of an injury type depending on the severity of injury, duration and deterioration rate. This curve influences the number of people alive at the current_time.

$$fade\_away = ((injury\_severity \wedge (1 / det\_rate)) - (t / duration)) \wedge det\_rate$$

The rescue_time function calculates the rescue time for each building based on the start time (current_time), the time to save each life (Rescue_duration), and the fade away function.

Steps to calculate rescue_time:
- Initialization at X_1, $current\_time_{X1} = 0$
- Calculate fade_away at $current\_time_{X1} = 0$
- Calculate people_alive (PA_i) based on injury class and fade_away
$PA_{X1} = Injury\_class_{X1} [m] * fade\_away_{X1} [m]$
- Calculate rescue time for the building
$rescue\_time_{X1} = PA_{X1} * rescue\_duration_{X1}$
- $current\_time = rescue\_time_{X1}$, used for next building and repeat.

5. Building scoring system

A scoring system is developed to assess the performance of each sequence. Each life saved is awarded a point based on the injury_class and negative point for each life not saved.

$$Total\_score_{Sj} = \sum((PA_{Xi} [m] * points\_saved [m]) - (A_{Xi} [m] - PA_{Xi} [m] * points\_not\_saved [m])$$

Objective function:

The objective is to find the most effective sequence of building rescues, considering the dynamic nature of disaster response scenarios. The primary objective function involves maximizing a score, computed based on the number of people saved and the severity of injuries.

Sequence S is a permutation of indices of the buildings. Objective function f(S) is defined as the total score achieved by rescuing the buildings in the given sequence. The total score of f(S) is calculated as the sum of individual building score:

$$f(S) = \sum g(X_i)$$

where $g(X_i)$ is the score for rescuing the i-th building in the sequence. Therefore, the objective function f(S) represents the total score achieved by rescuing the buildings in the given sequence, taking into account the initial and final states of each building and the points assigned for saving or not saving people in different severity classes. The optimization problem aims to find the sequence of building rescues that maximizes this total score.

Constraints:

1. Time Constraints

The scheduling must be completed within a specified end time ($current\_time_{final} \leq end\_time$) or if there is no one alive in the subsequent buildings, $PA_i = 0$.

2. Team Competency

The rescue time for each building depends on the assigned rescue team's competency (heavy, medium, or light). Mathematically the teams competency is multiplied to rescue_time to get the final rescue time.

3. Building Dependencies

The order of building rescues is influenced by the severity of damage, with priority given to severely damaged buildings.
$Priority(X_i) \geq Priority(X_j)$

Process and Optimization:

This initial step to appropriately structure the data is crucial for extracting relevant information and streamlining the subsequent calculations. The next step involves computing the rescue duration per person.

In preparation for a more extensive analysis, the number of simulations is defined, establishing the scope and scale of the subsequent evaluations. This dynamic approach allows for a comprehensive exploration of potential outcomes and their associated variables.

Subsequently, each simulated sequence is subjected to a detailed analysis, considering both the time taken for rescue and the overall score of the rescue operation. This dual assessment provides a holistic perspective, considering both efficiency and effectiveness in the evaluation of simulated scenarios. The sequences are sorted for further examination.

Using a local search optimizer to improve the quality of the given solution (sequence) iteratively by exploring neighboring solutions. If the score of the new generated sequence is higher it takes that as the new benchmark for further iterations.

These selected sequences are visualized through a Gantt chart, offering a comprehensive and intuitive representation of the chronological aspects of the rescue operations. This visualization not only highlights the temporal aspects of each sequence but also aids in identifying critical stages and potential bottlenecks in the rescue process

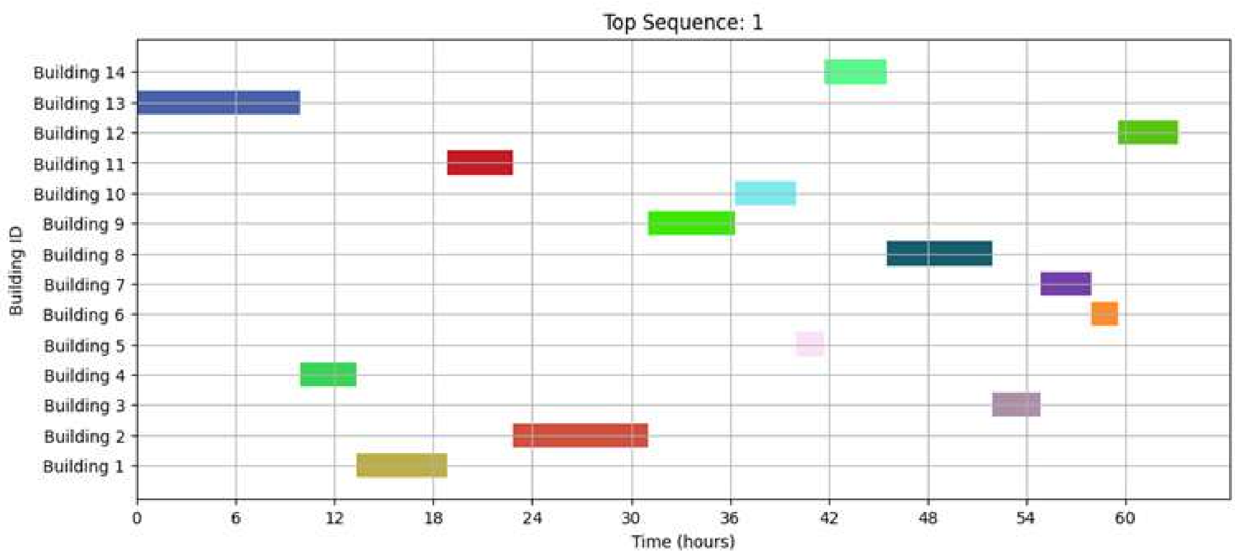


Figure 66: Example of a generated sequence, own work

Part B: Adopted approach

Theoretical research

Overall, this structured analytical approach, from data transformation to visualization, provides a robust framework for understanding and optimizing rescue operations in complex scenarios.

Setbacks faced:

1. Finding precise solutions is challenging due to the computational infeasibility and time-consuming nature of the task. Striking a balance between exploration (randomization), and exploitation(optimization), can be complex.

2. Unfortunately, the local search algorithm did not yield favorable results, with no to little improvement observed in the solution set. This could be due to oversimplification of the problem or the algorithm being trapped in a local maximum.

Results:

The goal is to enable HQ to select the most suitable plan based on the specific circumstances. The dynamic nature of earthquake, it is imperative to maintain a continuous feedback loop from the field for precise site data to make adjustments.

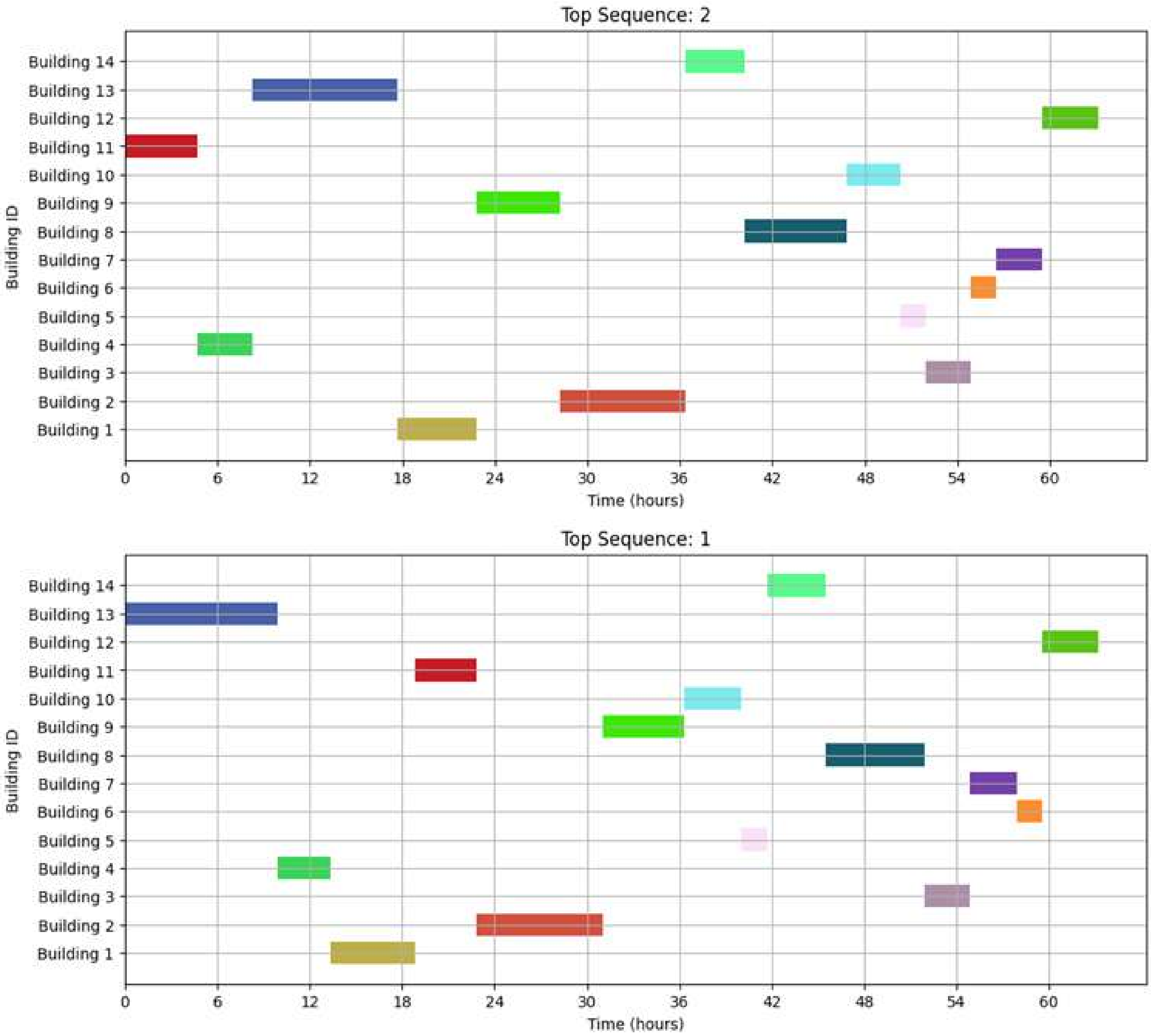


Figure 67: Example of a generated sequence, own work

Part B: Synthetic data available resources

Overview of data creation: teams, sub-teams and team

Considering that we lacked access to real resource databases, it was crucial to create a synthetic resource database as resources constitute the foundation of our tool. In pursuit of this, we crafted a synthetic set of resources designed for various types of teams. Drawing upon the INSARAG framework, our goal was to build a dataset that would simulate real-world scenarios, thereby ensuring the strength and practicality of our resource allocation approach.

Limit scope
However, given the broad scope of the entire INSARAG framework, we will focus exclusively on generating rescue components, setting aside considerations for other components such as management, logistics, and medical. This selective approach is essential to avoid unnecessary complications in validating and establishing our concept of allocating rescue resources.

Team creation
The configuration will proceed as follows: each type of team will be allocated a specific number of sub-teams and team members, tailored to the requirements of that particular team type. Furthermore, considering the distinct training standards associated with each team type, competency levels will be assigned to team members based on weighted averages related to the specific team type.

Local authorities
Recognizing that local authorities often aspire to achieve an INSARAG certificate, often of a lower degree, we will extend the application of the INSARAG framework to include local authorities. Given their lower certificates and, consequently, reduced levels of training, they will be assigned with lower competency weights to reflect their specific capabilities.

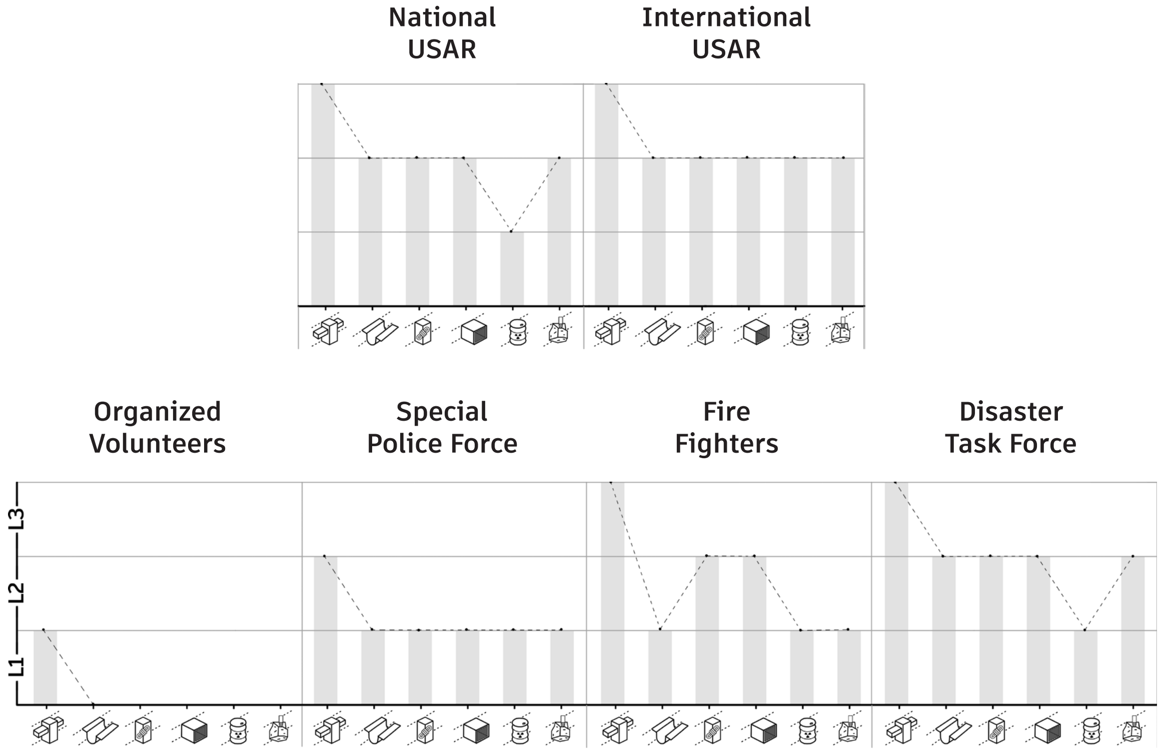


Figure 68: Avarage compentence levels per team type. Own work

Part B: Synthetic data available resources

Overview of data creation: teams, sub-teams and team

In the process of generating different teams, sub-teams, team members, and determining the competency levels for each team member, the following rules have been applied:

Heavy USAR Team
- 4 sub-teams
  - 5 rescue technicians
  - 1 team leader
- Team leader highest level of training
- Capable of executing all rescue actions
- Average structural rescue competency level: 3
- Average expertise skill competency levels: 2

Medium USAR Team
- 2 sub-teams
  - 5 rescue technicians
  - 1 team leader
- Team leader possesses the highest level of training
- Able to execute almost all rescue actions
- Average structural rescue competency level: 2
- Average expertise skill competency levels: 1

Light USAR Team:
- 1 sub-team
  - 5 rescue technicians
  - 1 team leader
- Team leader has a high level of training
- Unable to execute heavy rigging
- Average structural rescue competency level: 2
- Average expertise skill competency levels: 1

Disaster Task Force
- 1 sub-team
  - 5 rescue technicians
  - 1 team leader
- Team leader has a high level of training
- Unable to execute heavy rigging and hazmat
- Average structural rescue competency level: 1
- Average expertise skill competency levels: 1

Fire Fighters
- 1 sub-team
  - 5 rescue technicians
  - 1 team leader
- Team leader has a moderately high level of training
- Unable to execute heavy rigging and hazmat
- Average structural rescue competency level: 1
- Average expertise skill competency levels: 1

Special police Forces
- 1 sub-team
  - 5 rescue technicians
  - 1 team leader
- Team leader moderate level of training
- Unable to execute heavy rigging, confined space and hazmat
- Maximum structural rescue competency level: 1
- Very low chance a team member has a competency level 1 for an expertise skill

Organized Volunteers
- 1 sub-team
  - 4 volunteers
  - 2 team leaders
- Team leader moderate level of training
- Volunteers have no expertise skills
- Volunteers are only able to execute limited tasks from the structural rescue competency level 1

Part B: Synthetic data rescue actions

Overview of data creation: linking actions to damage state, building height & typology

In the second phase, characterized by an action-based approach, we will establish connections between sub-teams and sub-areas by aligning the executable actions of a sub-team with the required actions of all buildings in a sub-area.

Executable actions of a sub-team.
The executable actions of a sub-team refer to a collection of actions that the team can perform, based on the competency levels of its members across all skills. These actions are derived from the training framework outlined by INSARAG, where specific actions corresponding to each skill's competency level are covered in the team's training program. Thus, once we have generated the competency levels for a team member, this can easily be translated to a list of actions that the team member is able to execute. Combining the actions of all team members of a sub-team, results in a list of actions the sub-team is able to execute.

Required rescue actions for a building.
Establishing the required rescue actions for a sub-area involves defining all necessary steps to rescue individuals in distress within that specific sub-area. Given the challenges in acquiring the essential data for creating these types of lists, we created a database (Figure 54, appendix III) which links actions to building characteristics based on:

- Damage state
- Typology
- Height

This database is constructed through the application of case studies and leveraging our structural knowledge, although it has not undergone validation. As such, it merely functions as a synthetic tool, enabling the generation of a diverse list of necessary actions, allowing the generation of an final output which approaches reality.

In practice, these action lists should be continually updated in real-time by a combination of sources, including satellites, drones, assessment squads, and other SAR channels. This dynamic approach ensures that the rescue strategy remains adaptable and responsive to evolving conditions on the ground.

						Structural Rescue												Trench Rescue											
Building Class	material_1_code	material_2_code	lat_load_code	height_code	Damage State	A	B	C	D	E	F	G	H	J	K	L	M	A	B	C	D	E	F	G	H	J	K	L	M
concrete frame, infill panels	CR	CR	LFINF	HBET:1-3	3	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	3	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	3	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Concrete Frame, structural infill	CR	CR	LDUAL	HBET:1-3	3	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	3	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	3	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Concrete Walls	CR	CR	LWAL	HBET:1-3	3	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	3	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	3	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Unreinforced Masonry, Rubble Stone	MUR	STRUB	LWAL	HBET:1-3	3	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	3	0	1	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	3	0	0	0	0	0	1	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Unreinforced Masonry, Clay Brick	MUR	CL	LWAL	HBET:1-3	3	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	3	0	1	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	3	0	0	0	0	0	1	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Unreinforced Masonry, Hollow Concrete Blocks	MUR	CBH	LWAL	HBET:1-3	3	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	3	0	1	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	3	0	0	0	0	0	1	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Unreinforced Masonry, Adobe	MUR	ADO	LWAL	HBET:1-3	3	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	3	0	1	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	3	0	0	0	0	0	1	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Timber	W	W	LWAL	HBET:1-3	3	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	3	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	3	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Steel	S	S	LFM	HBET:1-3	3	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	3	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	3	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Construction site	CS	CS	LFM	HBET:1-3	3	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0
				HBET:4-6	3	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0
				HBET:7-	3	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0

Figure 69: Partial overview correlation building charecteristics and SAR actions . Own work

Part B: Flowchart

This part refers to the Search and Rescue problem and can be divided into two parts: Phase 1 Allocation, and Phase 2 Allocaion + Scheduling

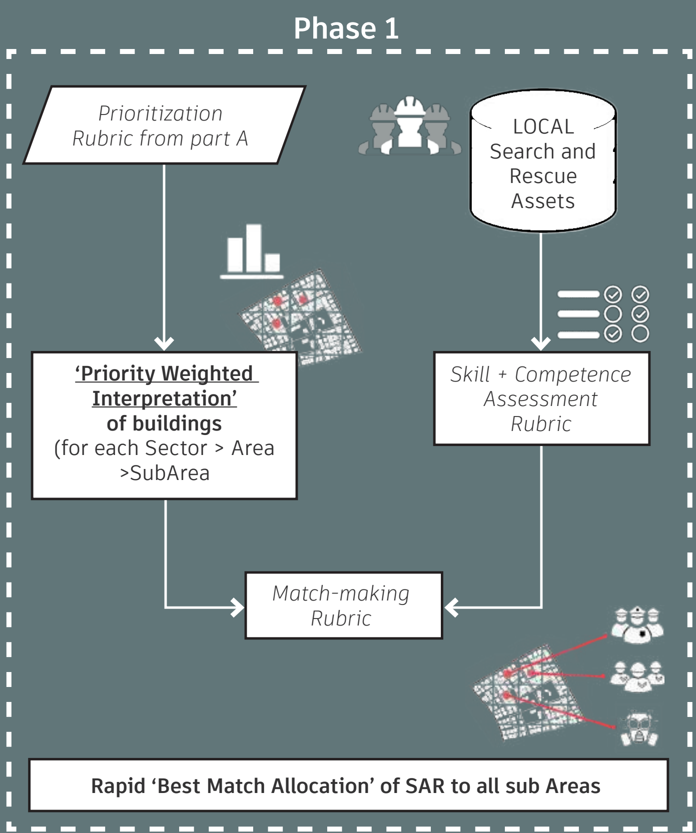
Phase 1:
-The priority weighted ranking of buildings is prepared fro the data from part A

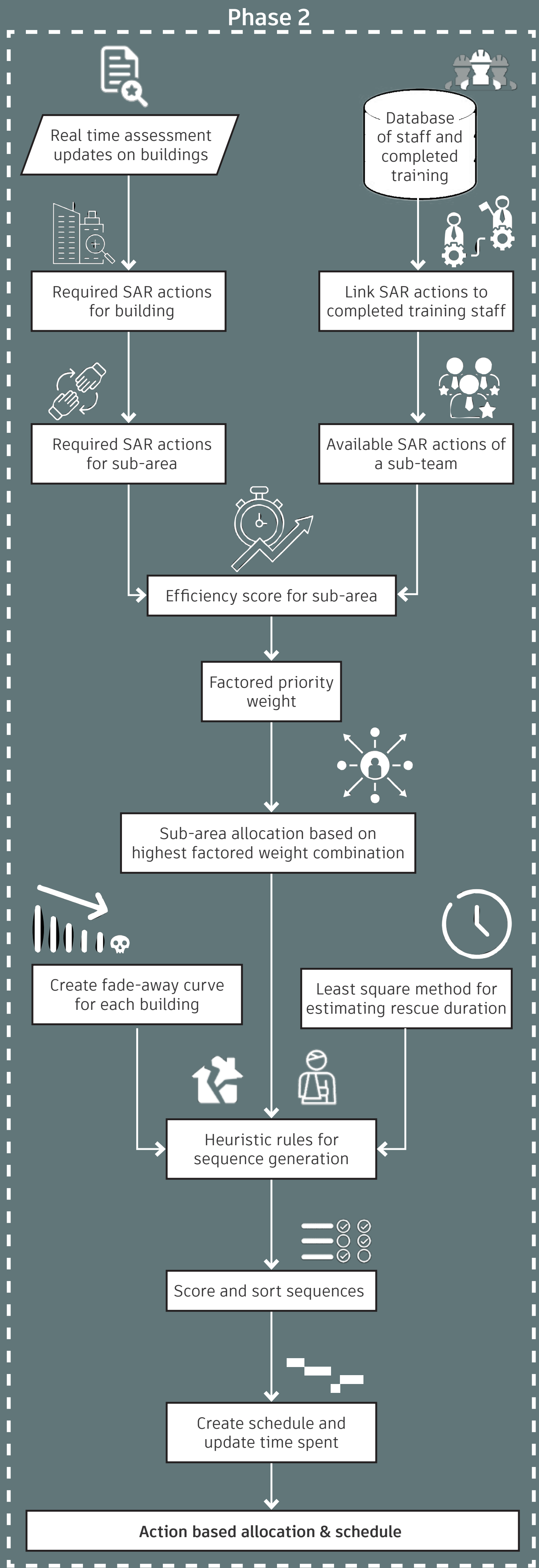
- The data of available local Search and Rescue Assets (police, volunteers etc), is collected and teh asset skills are simplified into a competence score that is used to make an allocation based on 'Rapid Best Match' between teams and Areas>Sub Areas.

-Meanwhile, real time data about BUilding Damage and injury profiles is collected for Phase 2 allocation.

Phase 2:
The allocation up to sub area level is done similar to phase 1, except the necessary 'actions' to clear specific buildings, is also matched with the capacity for the 'action' among asset members

The exact schedde (sequence) in which each team shall visit the set of buildings in its sub area is done based on an optimization- Maximising no. of lives saved, while minimizng time required to do so.





Part B: Class definitions: Team

Code & flowchart logic

This class describes a search and rescue team. The general attribute is:

- Team ID

The attributes relating to other search and rescue classes are:

- Team type, describes if the team is a USAR heavy, light, or medium team, a taskforce, fire fighter, police, or volunteer team.
- Sub-teams, describing the sub-teams that are part of this team.

Function: Add sub-team

1. Add a sub-team object to the team object's list of sub-teams.
2. Set the sub-team's team type to be the same as the team's team type.

<table>
<tr><th>Team</th><th>Sub-team</th><th>Team member</th></tr>
<tr><td rowspan="12">Team ID: 0
Team type: Medium</td><td rowspan="6">Sub-team ID: 0</td><td>Team member ID: 0</td></tr>
<tr><td>Team member ID: 1</td></tr>
<tr><td>Team member ID: 2</td></tr>
<tr><td>Team member ID: 3</td></tr>
<tr><td>Team member ID: 4</td></tr>
<tr><td>Team member ID: 5</td></tr>
<tr><td rowspan="6">Sub-team ID: 1</td><td>Team member ID: 6</td></tr>
<tr><td>Team member ID: 7</td></tr>
<tr><td>Team member ID: 8</td></tr>
<tr><td>Team member ID: 9</td></tr>
<tr><td>Team member ID: 10</td></tr>
<tr><td>Team member ID: 11</td></tr>
<tr><td rowspan="6">Team ID: 1
Team type: Task force</td><td rowspan="6">Sub-team ID: 2</td><td>Team member ID: 12</td></tr>
<tr><td>Team member ID: 13</td></tr>
<tr><td>Team member ID: 14</td></tr>
<tr><td>Team member ID: 15</td></tr>
<tr><td>Team member ID: 16</td></tr>
<tr><td>Team member ID: 17</td></tr>
<tr><td rowspan="6">Team ID: 2
Team type: Volunteer</td><td rowspan="6">Sub-team ID: 3</td><td>Team member ID: 18</td></tr>
<tr><td>Team member ID: 19</td></tr>
<tr><td>Team member ID: 20</td></tr>
<tr><td>Team member ID: 21</td></tr>
<tr><td>Team member ID: 22</td></tr>
<tr><td>Team member ID: 23</td></tr>
</table>

Figure 70: Teams table. Own work.

Part B: Class definitions: Sub-team

Code & flowchart logic

This class describes a search and rescue sub-team, belonging to a larger search and rescue team. The general attribute is:

- Sub-team ID

The attributes that relate to other search and rescue classes are:

- Team type, describes if the team is a USAR heavy, light, or medium team, a taskforce, fire fighter, police, or volunteer team.
- Team, describes the team which this sub-team is a part of.
- Team members, describes the team members that are a part of this sub-team.

Another set of attributes are related to the allocation of search and rescue assets to rescue sites:

- Servable damage states, describes the damage states that the sub-team is allowed to clear based on the sub-team's team type.
- Phase 1 competence, describes how competent the sub-team is.
- Remaining time, describes how much time the sub-team has until phase 1 ends, it starts with 24 hours.
- Action counts, describes how many members of the sub-team can perform different actions in the form of a dictionary.
- Servable sub-areas, describes which sub-areas the sub-team can clear based on their skillset.
- Servable buildings, describes which buildings the sub-team can clear based on their skillset.

Team	Sub-team	Team member
Team ID: 0 Team type: Medium	Sub-team ID: 0	Team member ID: 0
		Team member ID: 1
		Team member ID: 2
		Team member ID: 3
		Team member ID: 4
		Team member ID: 5
	Sub-team ID: 1	Team member ID: 6
		Team member ID: 7
		Team member ID: 8
		Team member ID: 9
		Team member ID: 10
		Team member ID: 11
Team ID: 1 Team type: Task force	Sub-team ID: 2	Team member ID: 12
		Team member ID: 13
		Team member ID: 14
		Team member ID: 15
		Team member ID: 16
		Team member ID: 17
Team ID: 2 Team type: Volunteer	Sub-team ID: 3	Team member ID: 18
		Team member ID: 19
		Team member ID: 20
		Team member ID: 21
		Team member ID: 22
		Team member ID: 23

Figure 71: Teams table. Own work.

Part B: Class definitions: Sub-team

Code & flowchart logic

- Sub-area, describes the sub-area which the sub-team is currently allocated to.
- Sub area priority, describes the factored priority score of the sub-area which the sub-team is currently allocated to.

Function: Add team member

1. Input a team member object.
2. Add the team member to the list of team members that are a part of this sub-team.
3. Set the sub-team of the team member to be this sub-team.
4. Set the team of the team member to be this sub-team's team.

Function: Assign sub-area

1. Input a sub-area object.
2. Set this sub-team's sub-area to be the input object.
3. If this sub-area is not none, set the sub-area's sub-team to be this sub-team object.

Function: Calculate action counts

1. Create an empty dictionary.
2. Get the available actions for each team member in the sub-team.
3. For each of the available actions add it to the dictionary with a count of 1 or increase the count by 1 if it is already in the dictionary.
4. Set this sub-team's action counts to be the created dictionary with action counts.

<table>
<tr><th>Team</th><th>Sub-team</th><th>Team member</th></tr>
<tr><td rowspan="12">Team ID: 0
Team type: Medium</td><td rowspan="6">Sub-team ID: 0</td><td>Team member ID: 0</td></tr>
<tr><td>Team member ID: 1</td></tr>
<tr><td>Team member ID: 2</td></tr>
<tr><td>Team member ID: 3</td></tr>
<tr><td>Team member ID: 4</td></tr>
<tr><td>Team member ID: 5</td></tr>
<tr><td rowspan="6">Sub-team ID: 1</td><td>Team member ID: 6</td></tr>
<tr><td>Team member ID: 7</td></tr>
<tr><td>Team member ID: 8</td></tr>
<tr><td>Team member ID: 9</td></tr>
<tr><td>Team member ID: 10</td></tr>
<tr><td>Team member ID: 11</td></tr>
<tr><td rowspan="6">Team ID: 1
Team type: Task force</td><td rowspan="6">Sub-team ID: 2</td><td>Team member ID: 12</td></tr>
<tr><td>Team member ID: 13</td></tr>
<tr><td>Team member ID: 14</td></tr>
<tr><td>Team member ID: 15</td></tr>
<tr><td>Team member ID: 16</td></tr>
<tr><td>Team member ID: 17</td></tr>
<tr><td rowspan="6">Team ID: 2
Team type: Volunteer</td><td rowspan="6">Sub-team ID: 3</td><td>Team member ID: 18</td></tr>
<tr><td>Team member ID: 19</td></tr>
<tr><td>Team member ID: 20</td></tr>
<tr><td>Team member ID: 21</td></tr>
<tr><td>Team member ID: 22</td></tr>
<tr><td>Team member ID: 23</td></tr>
</table>

Figure 72: Teams table. Own work.

Part B: Class definitions: Sub-team

Code & flowchart logic

Function: Calculate phase 1 competence

1. Define the phase 1 competence weights for each action type. The types are structural, trench, rope, confined space, hazmat, and rigging.
2. For each of the sub-team's team members, multiply their competence in each of the action types with the corresponding phase 1 competence weight.
3. Sum up all of the competences of each team member and save this in a phase 1 competence variable.
4. Set the phase 1 competence of the sub-team to be the calculated phase 1 competence variable.

Team	Sub-team	Team member
Team ID: 0 Team type: Medium	Sub-team ID: 0	Team member ID: 0
		Team member ID: 1
		Team member ID: 2
		Team member ID: 3
		Team member ID: 4
		Team member ID: 5
	Sub-team ID: 1	Team member ID: 6
		Team member ID: 7
		Team member ID: 8
		Team member ID: 9
		Team member ID: 10
		Team member ID: 11
Team ID: 1 Team type: Task force	Sub-team ID: 2	Team member ID: 12
		Team member ID: 13
		Team member ID: 14
		Team member ID: 15
		Team member ID: 16
		Team member ID: 17
Team ID: 2 Team type: Volunteer	Sub-team ID: 3	Team member ID: 18
		Team member ID: 19
		Team member ID: 20
		Team member ID: 21
		Team member ID: 22
		Team member ID: 23

Figure 73: Teams table. Own work.

Part B: Class definitions: Team member

Code & flowchart logic

This class describes a search and rescue team member, part of a sub-team. The general attribute of this class is:

- Sub team member ID

The attributes that relate to other search and rescue classes are:

- Team type, describes if the team is a USAR heavy, light, or medium team, a taskforce, fire fighter, police, or volunteer team.
- Sub-team, describes the sub-team that the team member is a part of.
- Team, describes the team that the team member's sub-team is a part of.

The next attributes relate to the competency of the team member. The competency is assigned randomly with a weighted distribution based on the team member's team type. Except for the team leader(s), one team member (two for volunteers), which has a set training level in each of the rescue types based on the team member's team type:

- Competence structural, describes the level of training the team member has achieved in the structural rescue type.
- Competence trench, describes the level of training the team member has achieved in the trench rescue type.
- Competence rope, describes the level of training the team member has achieved in the rope rescue type.
- Competence confined space, describes the level of training the team member has achieved in the confined space rescue type.
- Competence hazmat, describes the level of training the team member has achieved in the hazmat rescue type.
- Competence rigging, describes the level of training the team member has achieved in the rigging rescue type.

<table>
<tr><th>Team</th><th>Sub-team</th><th>Team member</th></tr>
<tr><td rowspan="12">Team ID: 0
Team type: Medium</td><td rowspan="6">Sub-team ID: 0</td><td>Team member ID: 0</td></tr>
<tr><td>Team member ID: 1</td></tr>
<tr><td>Team member ID: 2</td></tr>
<tr><td>Team member ID: 3</td></tr>
<tr><td>Team member ID: 4</td></tr>
<tr><td>Team member ID: 5</td></tr>
<tr><td rowspan="6">Sub-team ID: 1</td><td>Team member ID: 6</td></tr>
<tr><td>Team member ID: 7</td></tr>
<tr><td>Team member ID: 8</td></tr>
<tr><td>Team member ID: 9</td></tr>
<tr><td>Team member ID: 10</td></tr>
<tr><td>Team member ID: 11</td></tr>
<tr><td rowspan="6">Team ID: 1
Team type: Task force</td><td rowspan="6">Sub-team ID: 2</td><td>Team member ID: 12</td></tr>
<tr><td>Team member ID: 13</td></tr>
<tr><td>Team member ID: 14</td></tr>
<tr><td>Team member ID: 15</td></tr>
<tr><td>Team member ID: 16</td></tr>
<tr><td>Team member ID: 17</td></tr>
<tr><td rowspan="6">Team ID: 2
Team type: Volunteer</td><td rowspan="6">Sub-team ID: 3</td><td>Team member ID: 18</td></tr>
<tr><td>Team member ID: 19</td></tr>
<tr><td>Team member ID: 20</td></tr>
<tr><td>Team member ID: 21</td></tr>
<tr><td>Team member ID: 22</td></tr>
<tr><td>Team member ID: 23</td></tr>
</table>

Figure 74: Teams table. Own work.

Part B: Class definitions: Team member

Code & flowchart logic

Function: Get available actions

1. Get the available actions for the competency that the team member has in each of the rescue types and save it in variables. The available actions for a given competency are stored in the competency action dictionary.
2. If the team member's team type is volunteer and the team member is not one of the team leaders, the team member only gets the 'safe access and egress' and 'casualty assessment and basic medical care' as available actions.
3. Create an available actions dictionary where the available actions can be stored and organised by each rescue type.
4. For all team members other than the regular volunteers, the available actions for their competency level are stored in the available actions dictionary.
5. Also add the available actions for the competency level below the competency level of the team member to the available actions dictionary.
6. Return the available actions dictionary.

Structural Rescue	Level 1	Size-up and Scene Safety Casualty Assessment and Basic Medical Care Shoring and Stabilization (Basic) Safe Access and Egress
	Level 2	Advanced Scene Assessment Advanced Medical Care and Triage Advanced Shoring Techniques Complex Casualty Extrication
	Level 3	Command and Coordination Multiple Collapse Points Advanced Shoring and Heavy Machinery Urban Search and Rescue (USAR) Techniques
Trench Rescue	Level 1	Scene Assessment and Safety Hazard Recognition Casualty Assessment and Basic Care Trench Shoring and Stabilization (Basic)
	Level 2	Advanced Hazard Recognition Advanced Shoring and Trench Box Systems Casualty Packaging and Extrication Equipment Operation
	Level 3	Incident Command and Coordination Multiple Casualties and Complex Trench Configurations Technical Trench Rescue Integrate with Other Disciplines
Technical Rope Rescue	Level 1	Knot Tying Anchor Systems Ascending and Descending Rigging and Mechanical Advantage
	Level 2	Advanced Knot Tying Complex Rope Systems Difficult Access Confined Space Rope Rescue
	Level 3	Dynamic Environments Rope-Based Confined Space Rescue Advanced Anchoring and Rigging

Confined Space Rescue	Level 1	Confined Space Hazard Assessment Safe Entry and Exit Retrieval Systems and Equipment Air Monitoring and Ventilation
	Level 2	Advanced Confined Space Entry Specialized Confined Space Equipment Air Monitoring and Ventilation (Advanced) Advanced Patient Care
	Level 3	Complex and Hazardous Incidents Leadership and Incident Command Integration with Other Disciplines
Heavy Rigging Rescue	Level 1	Equipment Familiarization Basic Rigging Techniques Safe Operation Safety Protocols
	Level 2	Advanced Equipment Operation Complex Rigging Configurations Load Handling and Balance Safety Risk Management
	Level 3	High-Risk Scenarios Coordination and Incident Command Integrate with Other Disciplines

Figure 75: Competency action dictionary. Own work.

Part B: Functions: Calculate the priority weight

Code & flowchart logic

1. Input a list of areas object.
2. For each building in the areas, calculate the priority weight.
3. For each sub-area in the areas, update the priority weight.
4. For each area, update the priority weight.

Figure 76: Priority weights. Own work.

Part B: Functions: Allocate teams to areas

Code & flowchart logic

1. Input the area objects and the number of teams of different types that need to be distributed between the areas.
2. Define the number of people per team.
3. Calculate the total number of people among the areas.
4. Calculate the sum of the priority scores of the areas.
5. Calculate the number of people required per priority weight.
6. Calculate the number of people required per area.
7. Sort the area by number of people required.
8. Allocate a team of the most competent team type to the area with the greatest number of people required.
9. Subtract the number of people required in the area with the number of people in the allocated team.
10. Resort the area by number of people required.
11. Repeat the allocation until there are no teams left.

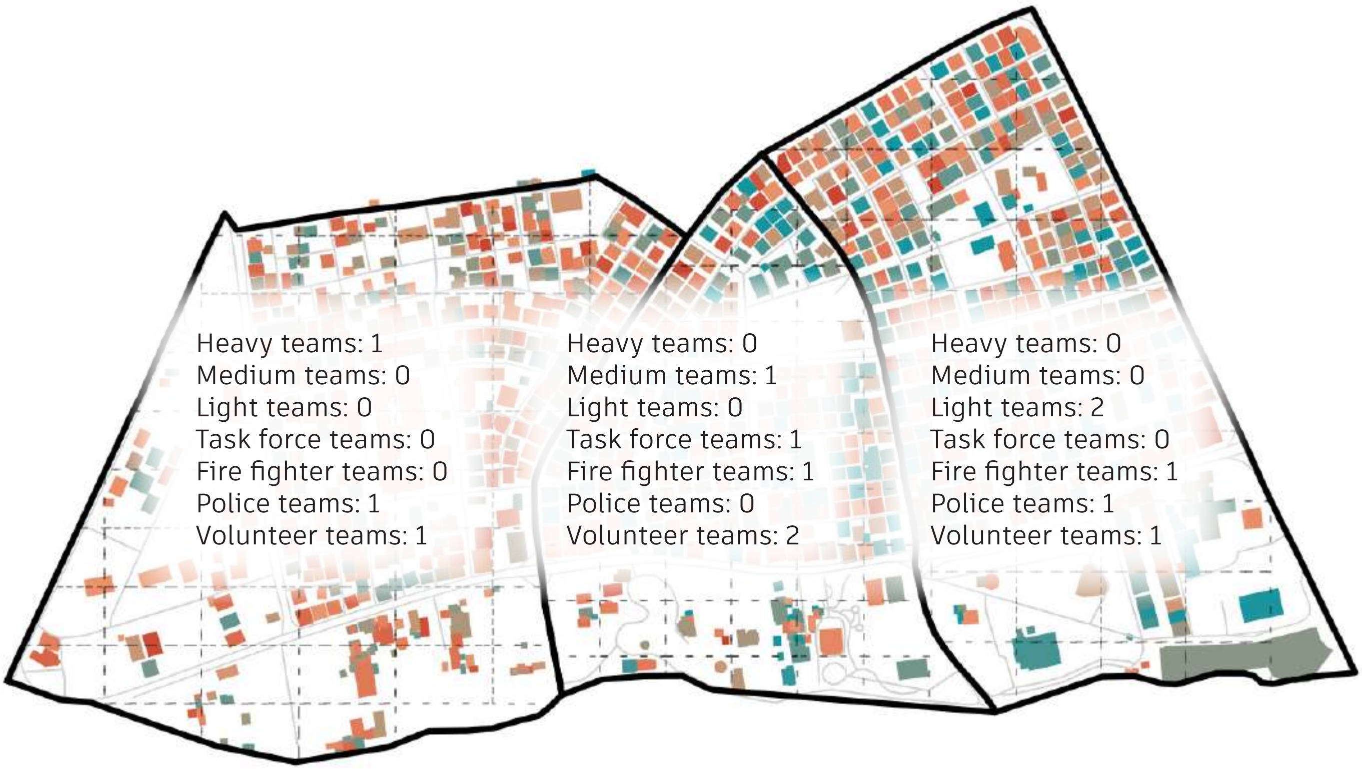


Figure 77: Teams allocated to areas. Own work.

Part B: Functions: Create teams

Code & flowchart logic

1. Input the area.
2. Create the number of team objects of a type that are allocated to the area.
3. Create the number of sub-team objects that are in a team of that type and associate the objects with each other.
4. Create the number of team-member objects that are in a sub-team of that type and associate the objects with each other.
5. <u>Calculate the action counts for each sub-team in the team.</u>
6. <u>Calculate the phase 1 competence for each sub-team in the team.</u>
7. Repeat for remaining team types.

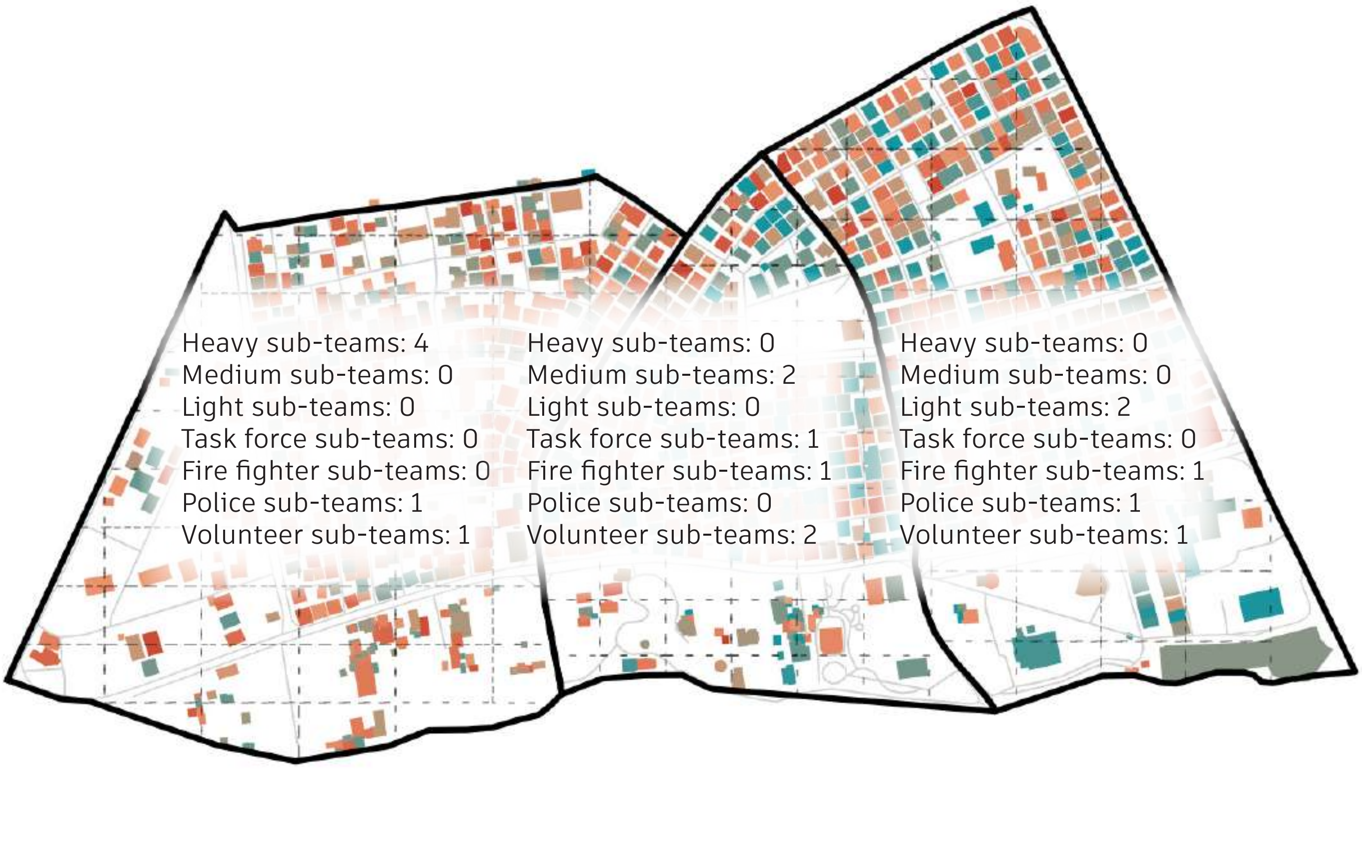


Figure 78: Created sub-teams in areas. Own work.

Part B: Functions: Allocate sub-team to sub-area: phase 1

Code & flowchart logic

1. Input the area.
2. Sort the sub-teams based on their phase 1 competence.
3. Filter the areas' sub-areas out that are set as cleared.
4. Filter the sub-areas out that don't have any buildings in them which aren't safe or don't have any buildings which are in a damage state that can be served by the most competent sub-team.
5. Calculate a new priority weight for the filtered sub-areas based only on the buildings which are in a damage state servable by the most competent sub-team.
6. Sort the filtered sub-areas based on their new priority weights.
7. Assign the highest priority sub-area to the most competent sub-team.
8. Set the servable buildings to cleared and the sub-area to cleared if all the unsafe buildings have been cleared.
9. Subtract the time it takes to clear the servable buildings in the sub-area from the remaining time of the sub-team, which starts with 24 hours.
10. Repeat the process for the sub-team with the most remaining time, or the most competent sub-team if sub-teams have the same remaining time.

Figure 79: Allocation of sub-teams in phase 1. Own work.

Part B: Functions: Allocate sub-team to sub-area: phase 2

Code & flowchart logic

1. Input the area.
2. Filter the areas' sub-areas out that are set as cleared.
3. For a sub-team in the area, filter the sub-areas out that don't have any buildings in them which aren't safe or don't have any buildings which are in a damage state that can be served by the sub-team.
4. For each of the filtered sub-areas, calculate the sum of the people that can perform an action for each action required in the area.
5. Use this sum of action counts to assign an efficiency score to the sub-team for a specific sub-area.
6. Calculate a new priority weight for the filtered sub-areas based only on the buildings which are in a damage state servable by the most competent sub-team.
7. Multiply the new priority weight with the efficiency score for the sub-area, to get a factored priority weight which ranges from 0,5 to 2 times as great as the unfactored new priority weight.
8. Create a dictionary for all the servable sub-areas with their corresponding factored priority weight and another one for all the servable buildings with their corresponding factored priority weight.
9. Sort the dictionaries based on the factored priority weight.
10. Save both dictionaries as attributes of the sub-team.
11. Repeat step 2 through 10 for all remaining sub-teams.
12. Make a new list which includes the sub-area dictionaries for each sub-team, but is only as long as the amount of sub-teams in the area. Because a lower scoring sub-area will never be assigned to a sub-team.
13. Create all the possible combinations for

Figure 80: Factored priority weight for sub-team 0. Own work.

Part B: Functions: Allocate sub-team to sub-area: phase 2

Code & flowchart logic

1. assigning a sub-team with a sub-area of their shortened dictionary.
2. Filter out the combinations where multiple sub-teams area assigned with the same sub-area.
3. For each combination, add up the factored priority weights for the sub-team-sub-area pairs to get a combination score.
4. Assign all sub-teams to their corresponding sub-areas of the combination with the highest combination score.
5. Set the buildings which are servable to cleared for all the sub-areas of the best combination.

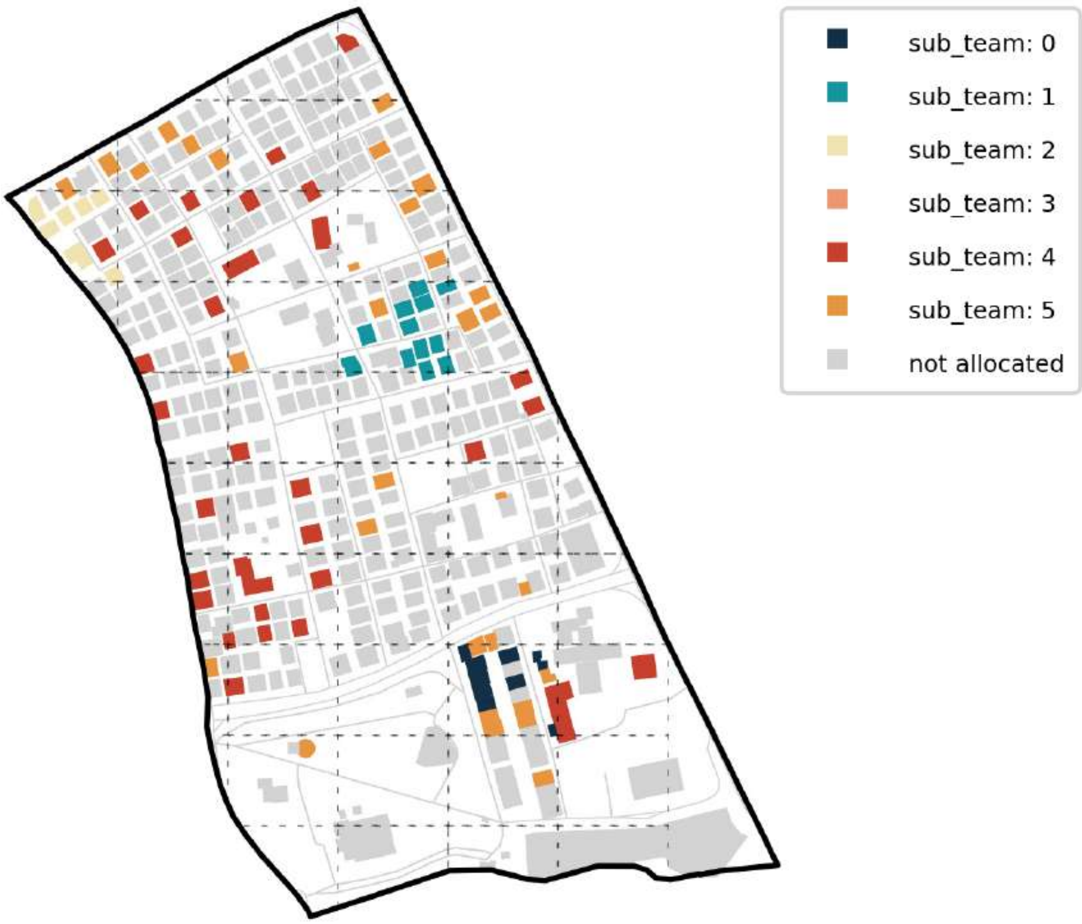


Figure 81: Allocated buildings of sub-teams after phase 1 and phase 2. Own work.

Part B: Functions: Calculate fade away

Code & flowchart logic

1. Define all the hyper parameters like duration, injury_severity and deterioration rate.
2. Create an empty placeholder to store fade_away rate for each injury_severity.
3. Create a for loop to find fade_away rate for each severity at ‘t’ point of time.
4. Use the following fade_away function= ((injury_severity ^ (1 / det_rate)) - (t / duration)) ^ det_rate.
5. Append the values to fade_away list.

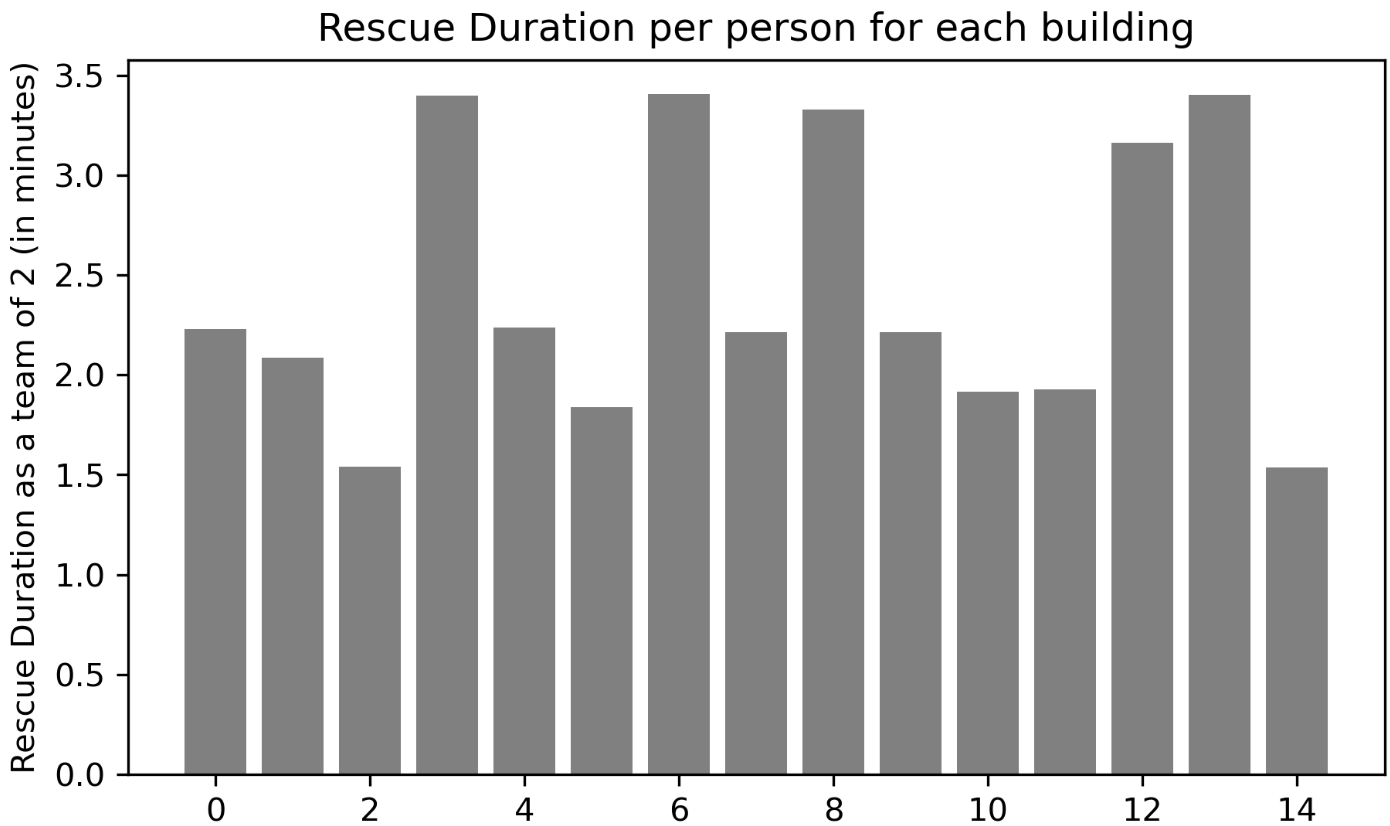


Figure 82: Rescue duration per person for each building. Own work.

Part B: Functions: Calculate rescue duration

Code & flowchart logic

1. Create an empty dictionary to store rescue_time for each building (building: rescue time).
2. Extracting ‘Building_Id’, ‘Building_Height’, ‘Building_Area’ and ‘Damage_State’ from the list of building dictionaries.
3. Calculate the rescue_time based on a predefined mathematical formulation.
4. Based on the team assigned the overall rescue time differs based on competency.

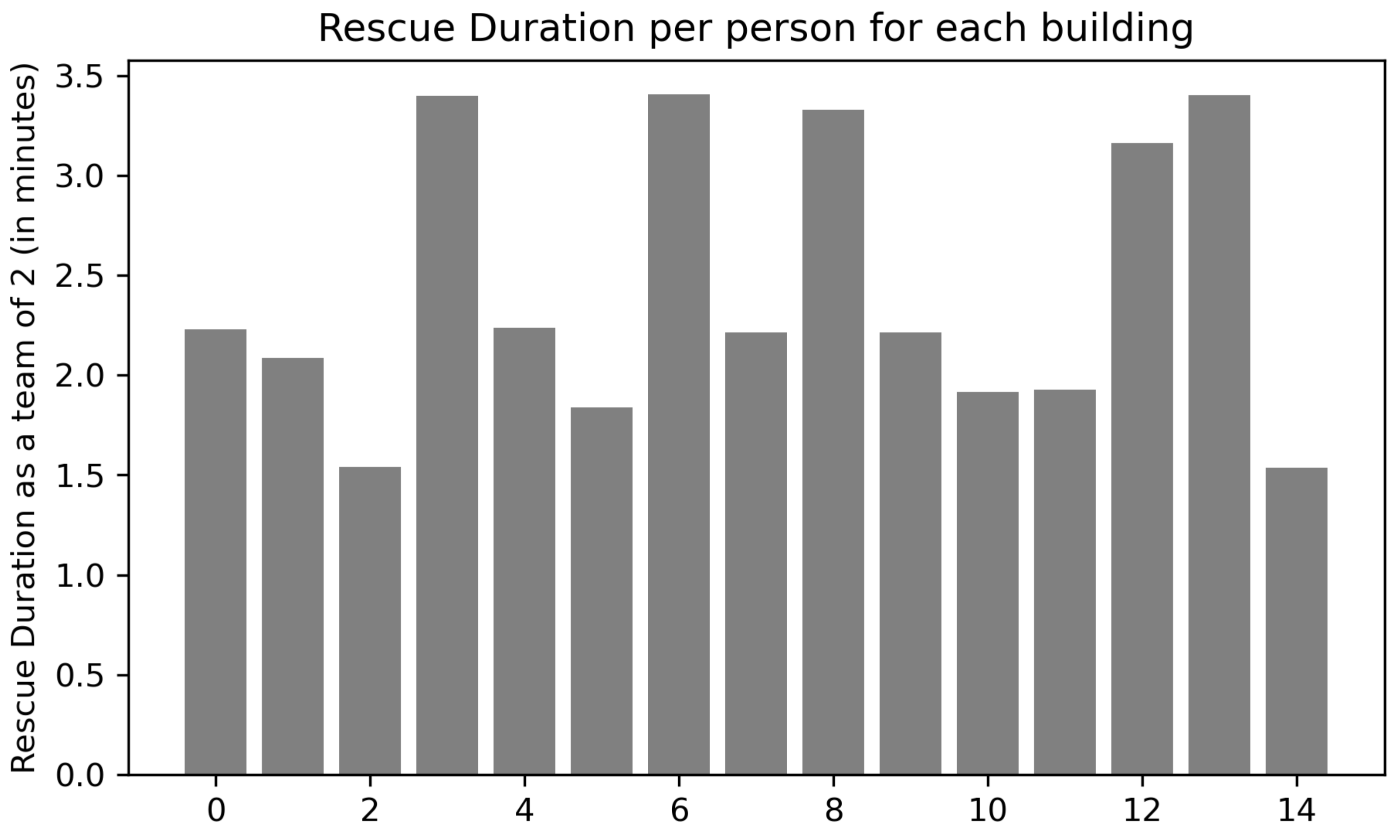


Figure 83: Rescue duration per person for each building. Own work.

Part B: Functions: Calculate rescue time

Code & flowchart logic

General description on building scheduling for a sub team

1. Convert the geodataframe to a dictionary with selected attributes.
2. Calculate rescue duration per person and visualise in a bar chart.
3. Define number of simulations.
4. Generate simulations by calling the function generate_building_sequences.
5. Analyse each sequence through rescue time taken and the score of rescue.
6. Sort the sequences and visualise top 5 sequences in gantt chart.

Function

1. <u>Call the calculate_fade_away function.</u>
2. Calculate the fade away at current_time i.e. start time of a building operation.
3. Import building_id and injury_severity for a specific building from the building dictionary.
4. Set up total_rescue_time, total_rescued and people_alive.
5. Loop through every injury severity in initial count to calculate the number of people alive based on the injury class and fade_away values
6. <u>Call the Rescue_duration function.</u>
7. Calculate the rescue time based on the number of people alive.
8. Add buffer time if the building is scheduled.
9. Update the current time for the next building.
10. Repeat for all buildings in the sequence.

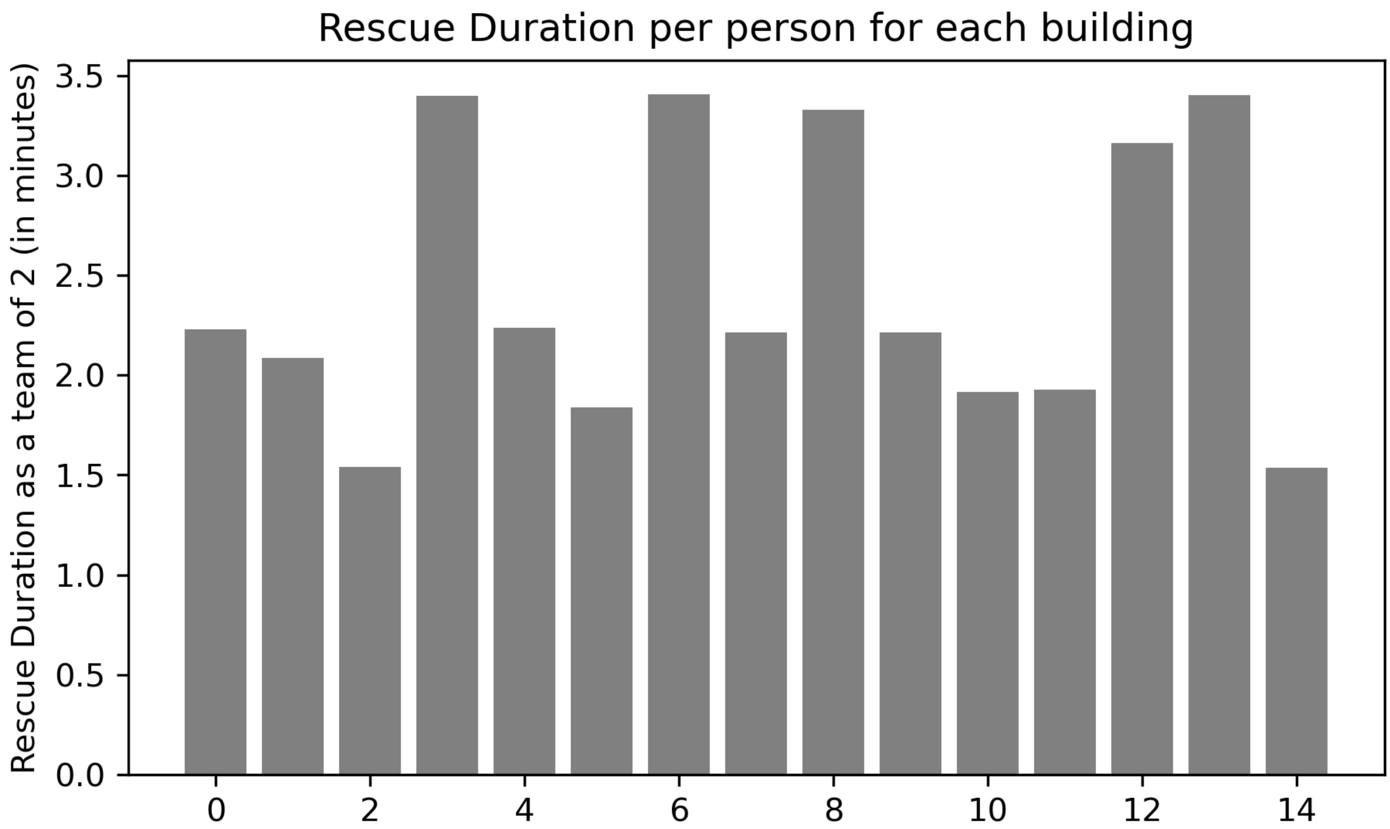


Figure 84: Rescue duration per person for each building. Own work.

Part B: Functions: Generate sequence

Code & flowchart logic

1. Define rules for sequence generation, in this case damage state and priority rating.
2. Create an empty placeholder for sequences generate.
3. Loop through every building in the imported list of sub area buildings and create random sequences by shuffling within domain rules.
4. Add the sequence to the list of sequences.

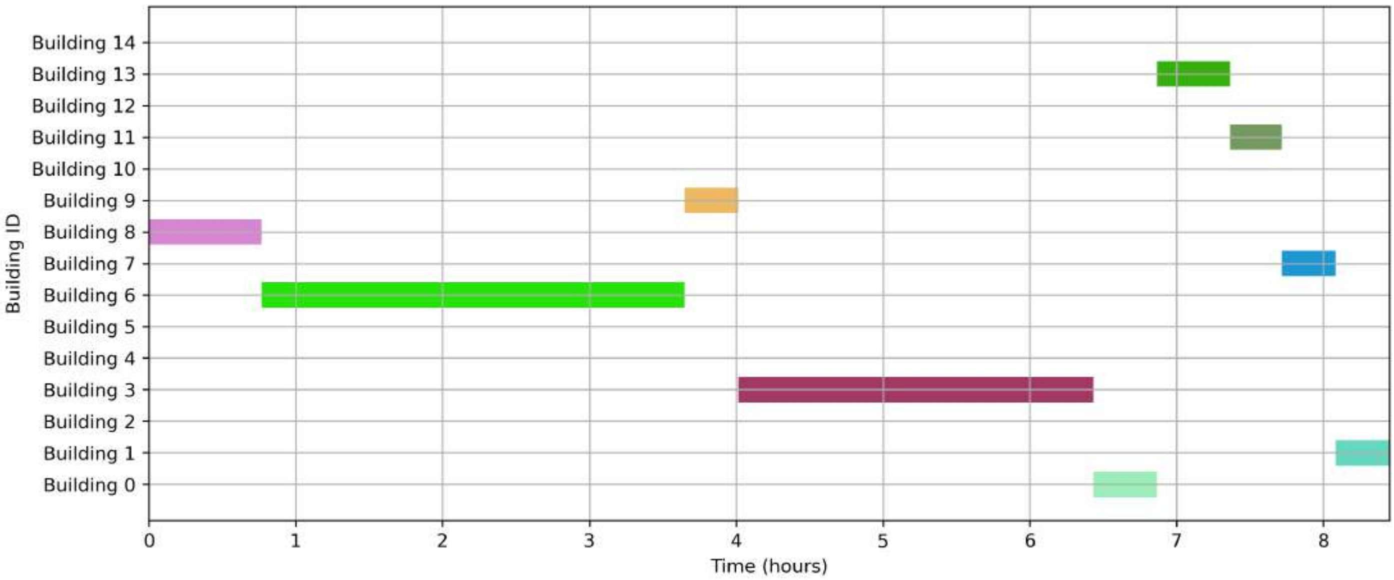


Figure 85: Generated sequence. Own work.

Part B: Functions: Calculate score

Code & flowchart logic

1. Define the points for each injury class based on whether saved or not saved.
2. Create an empty placeholder for the points achieved.
3. Loop through each severity and see people saved and not_saved.
4. Calculate the score achieved for the sequence.

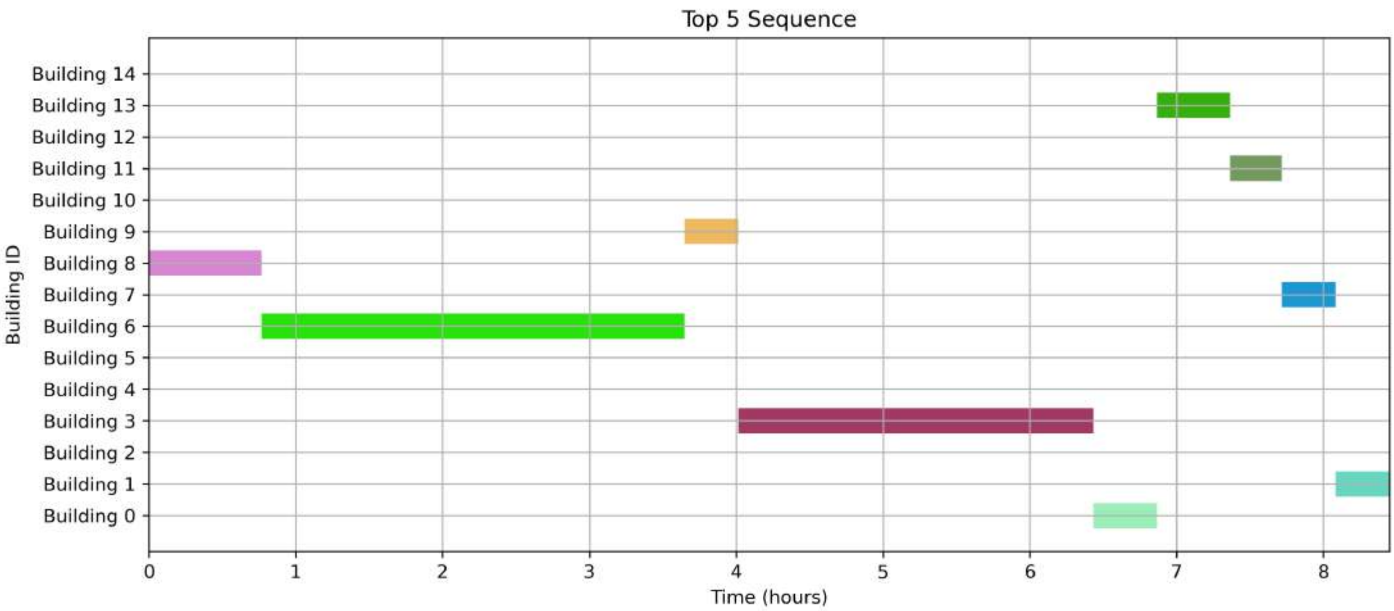


Figure 86: Generated sequence. Own work.

Part B: Risks & uncertainties

Identified risks and uncertainties with probable methodology to deal with it

Risks and uncertainties:

1. Lack of Data Validation:
The initial phase of the allocation process relies entirely on simulation results derived from Part A analysis. In real-world scenarios, this methodology may pose risks, potentially leading to the deployment of teams to unsuitable locations or overlooking buildings erroneously classified, thereby jeopardizing team safety.

2. Time and Rescue Function:
The time function, concerning the duration to rescue a person in a specific damage state, currently lacks consideration for crucial factors such as injury severity, building typology, and the dynamic nature of site conditions. Numerous parameters continually influence the function, making it susceptible to inaccuracies.

3. Fade Away Curve:
The existing approach to the fade away curve is grounded in an experimental model linking injury types with damage states and time. Certain logical assumptions in this model require further research. This generalized approach does not account for individual variations in the way people are affected by the same injury under different conditions.

4. Clustering of People in the Same Injury Group:
The current algorithm assumes that individuals within the same injury group are clustered together, presuming a uniform time or rate for saving each person in that group. In reality, the spread is dynamic, and rescue times vary among individuals within the same group.

5. Unforeseen Changes on Site:
In a disaster scenario, the most significant factor is the continually changing dynamics on site. The situation evolves over time periods, necessitating a robust system capable of updating and adapting to the changing scenarios involving the site, teams, and resources. Eg. risk of secondary disasters, or critical rescue process.

Proposed methodology to deal with risks and uncertainties:

1. Time (Buffer)
To mitigate the risk associated with the time function's lack of consideration for critical factors, a time buffer is introduced. This buffer will account for the dynamic nature of site conditions, injury severity, and building typology. By incorporating an adjustable time margin, the system can adapt to unforeseen changes, providing a safety net for potential inaccuracies in the initial time estimates. In reality it is a dynamic input that should adjust itself real-time.

2. Feedback loop
Implementing a feedback loop is crucial for continuous improvement and adaptation. The system will be designed to gather real-time data during rescue operations. This information will be used to refine and optimize the time function and other parameters, ensuring that the model evolves based on actual performance and changing conditions. Regular feedback loops will enhance the system's accuracy and responsiveness over time.

3. Resource depreciation factor
Recognizing the dynamic nature of resources during disaster scenarios, the proposed methodology involves accounting for resource depreciation over time. This includes considering factors such as fatigue, equipment wear, and changing availability. By integrating resource depreciation into the allocation process, the system can better anticipate and manage resource limitations, thereby improving the overall efficiency and effectiveness of rescue operations.

4. Data collection and train future models
To address the lack of data validation, a robust data collection strategy should be proposed. Real-world data from ongoing operations will be continuously gathered and analyzed. This data will not only validate the simulation results from Part A but also serve as the foundation for training future models. By incorporating real-world data, the system will become more resilient to uncertainties and better reflect the complexities of diverse scenarios.

Part B: Thoughts that didn't make the project

Thoughts that could not be implemented

There were a few topics that were not included in the final process due to lack of time, model complexity, computational power and skill set. Some of the key ideas were:

1. The allocation for phase 2 should be based on multiple allocations and sequences optimised via the individual schedules but the complexity did not allow us to use this approach. We also considered exploring advanced optimization techniques for phase 2 allocation, such as machine learning algorithms, to enhance the accuracy of the allocation process.

2. We also wanted to investigate the use of collaborative scheduling algorithms that enable multiple teams to work concurrently, promoting efficiency and minimizing idle time. We could have also explored visualization tools or simulations to represent the inter-sector movement between teams, providing the headquarters with a clearer understanding of the overall project flow.

3. We wanted to create an action level sequencing within buildings but due to lack of data and training models its was not possible to create such detailed sequencing models. We were considering using advanced modeling techniques, such as reinforcement learning or deep learning, to create more detailed action-level sequencing within buildings. This could help in capturing complex dependencies and optimizing the workflow. In future we can collaborate with domain experts to gather additional data and insights that can contribute to the development of more accurate sequencing models.

4. There was a possibility to investigate the possibility of integrating real-time data into the scheduling process, allowing for dynamic adjustments based on changing conditions or unexpected events. We also thought of exploring the use of IoT (Internet of Things) devices and sensors to capture real-time information on resource utilization, enabling a more responsive and adaptive scheduling system such as scanning, satellite, drones, etc.

5. We had originally planned to develop a user-friendly interface for stakeholders to interact with the scheduling system, facilitating better communication and collaboration among team members. We could've implemented features that allow users to easily understand and customize scheduling parameters, and create an adaptable scheduling environment.

6. We understand that disaster scenarios are extremely dynamic and we wanted to incorporate risk assessment tools and strategies within our framework to identify potential bottlenecks or challenges in advance, enabling proactive mitigation measures. This can be done by develop contingency plans and scenario analyses to address uncertainties and unexpected events that may impact the project.

Conclusion / Reflection

Dashboard design

Vision & homepage

Vision

For this tool, our ultimate vision revolves around the creation of a comprehensive dashboard, specifically designed to offer a centralized hub of crucial insights for all parties involved in search and rescue operations. The dashboard is designed to empower control rooms, offering the essential tools and information necessary for the optimal allocation and scheduling of search and rescue resources. Our objective was to create a user-friendly interface guided by the principles outlined in this report, efficiently displaying the most relevant Key Performance Indicators (KPIs) for each topic. Striking a balance, it is crucial not to overwhelm users with excessive data, ensuring that the presented information remains focused and actionable.

Homepage

The dashboard features a homepage that allows users to retrieve building data sets by selecting the country and territory that has been hit by the earthquake. Additionally, users can select an earthquake profile as a reference or upload their own profile for analysis.

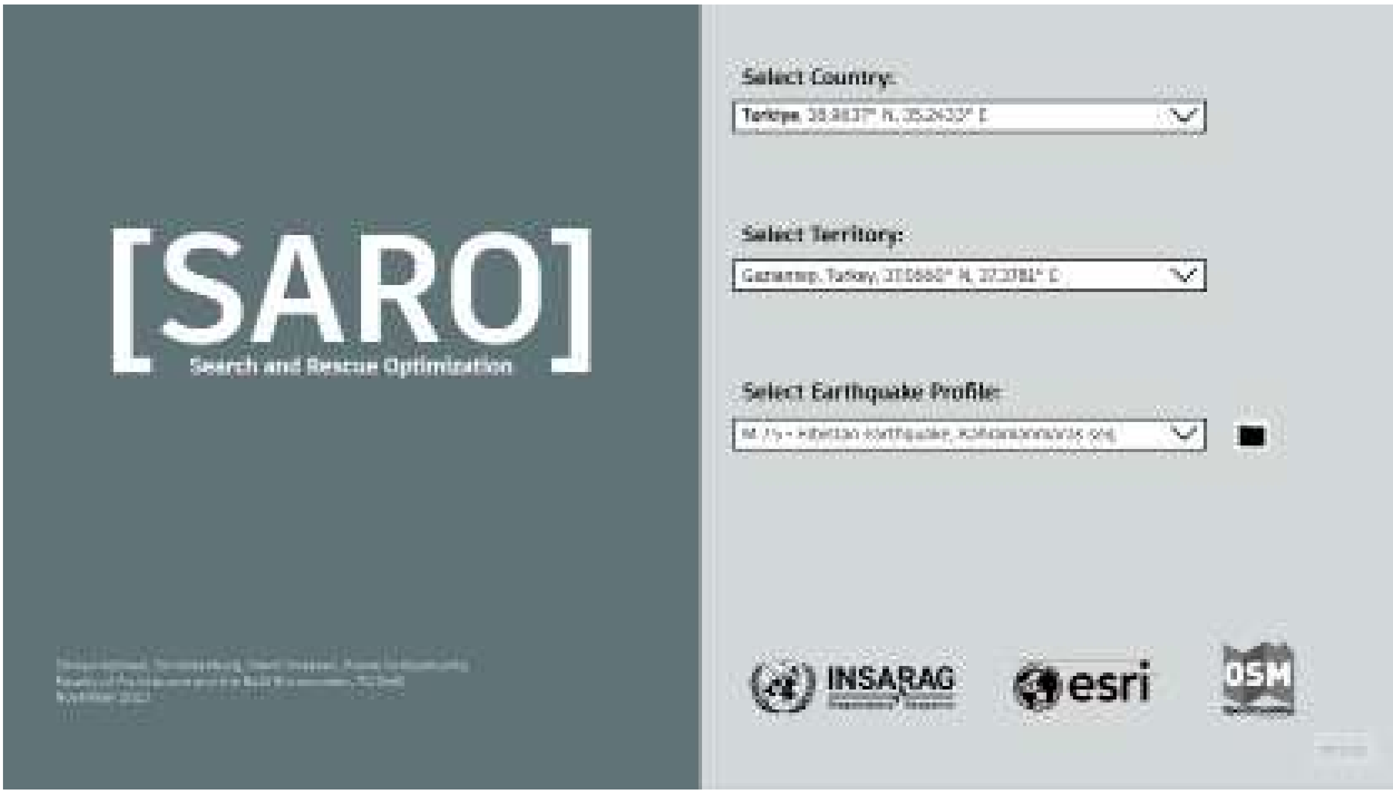


Figure 87: UI design: Dashboard page. Own work

Dashboard design

Standard layout & vulnerability analysis

Standard setup dashboard
The upper section of the dashboard always displays the primary dataset upon loading from the homepage. This area presents essential information such as:

- Time elapsed since the earthquake occurred
- Date
- Key Performance Indicators (KPIs) pertaining to rescued, deceased, or missing individuals
- KPIs related to the overall worksite

Additionally, the header facilitates navigation between the four main tabs:

- Vulnerability Analysis
- Team Management
- SAR - First Phase
- SAR - Second Phase

Vulnerability analysis
In this dedicated tab, users have the flexibility to choose a specific area, sub-area, and vulnerability parameter, which are then visually represented on a map. Clicking on a particular building within the map provides detailed results for the chosen vulnerability analysis parameter. Users can select from the following options:

- Damage states
- Occupancy populations (at event time)
- Injury profile (predicted)
- Injury profile (Real Time)
- Map- Building Categories
- Map- Construction Material Type

Damage states
In the example shown in Figure 73, the parameter of damage state is shown. On the right, damage state data is shown of the entire area . Once a building is selected, the predicted damage states are shown with the aligning fragility curves.

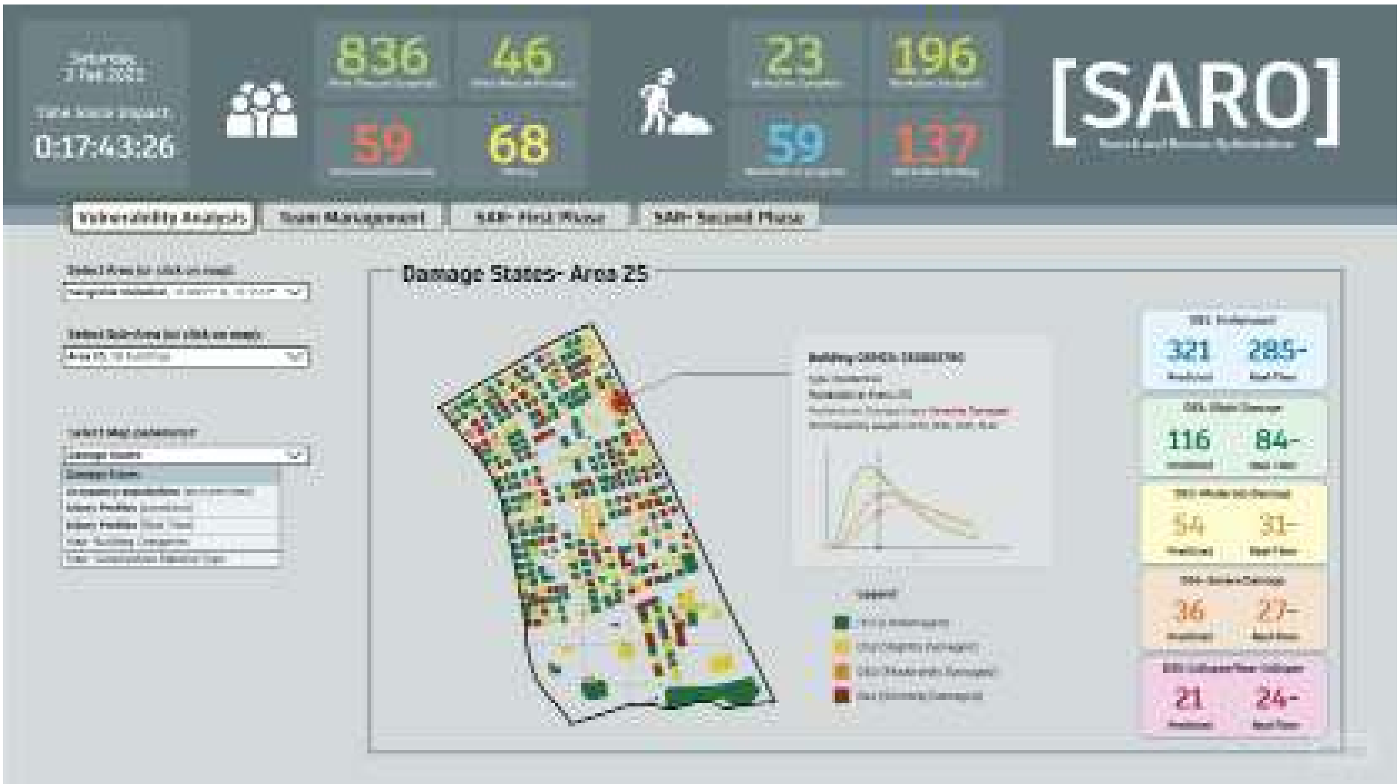


Figure 88: UI design: Vulnerability analysis damage state. Own work

Dashboard design

Vulnerability analysis

Injury profile

Figure 74 shows the vulnerability parameter of the injury profiles. Given that each building has four distinct injury profiles, the presentation of this parameter is rendered in a 3D map with stacked bar charts. This visual representation compared to a 2D map proves beneficial for grasping not just the severity relationships among all four profiles for a particular building but also for placing them within the context of the surrounding area. On the right, injury profile data is shown of the entire area

This map also allows to click on buildings and retrieve data which is specific for that building.

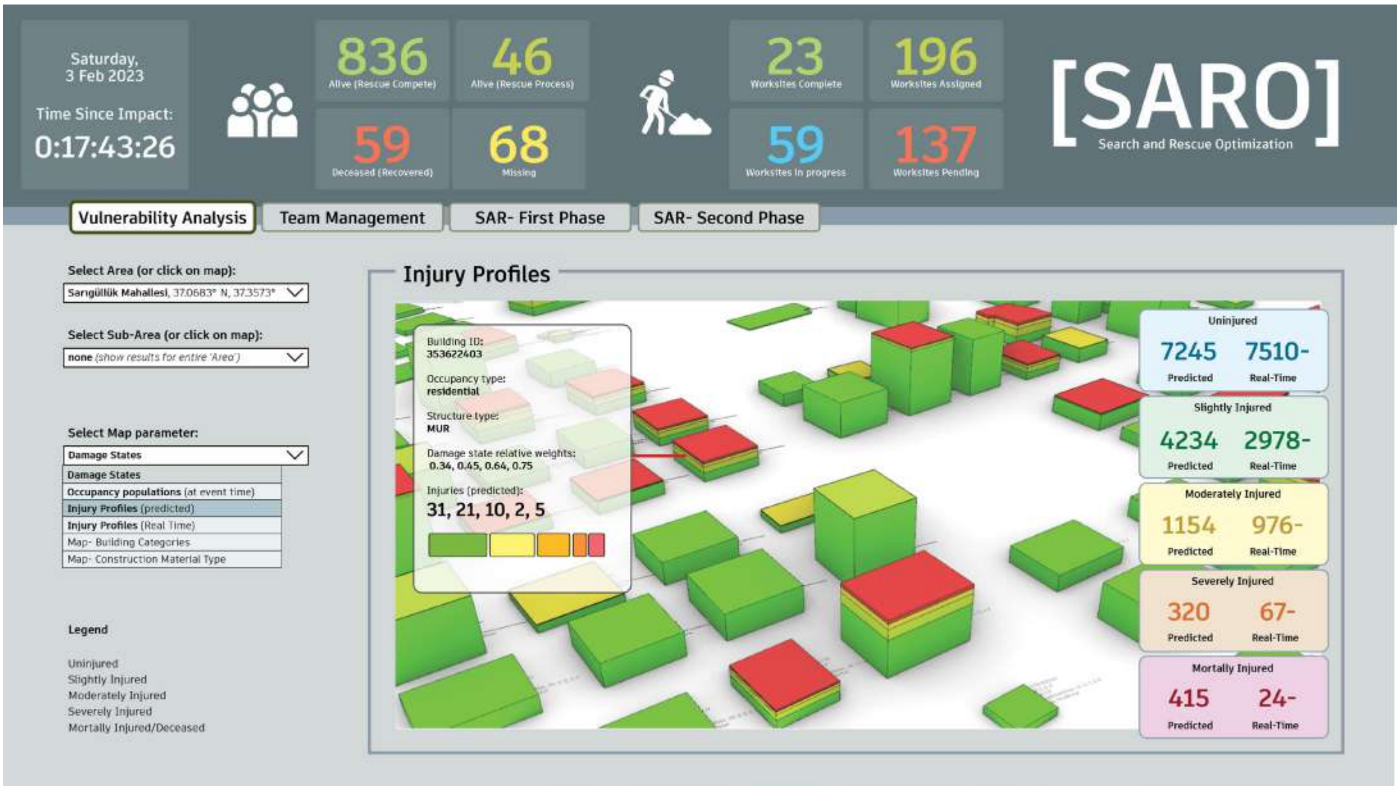


Figure 89: UI design: Vulnerability analysis injury profile. Own work

Dashboard design

Team management & SAR Phase 1

Team management

This tab facilitates the management of teams within a designated area, initiating the Phase 1 allocation process. Figure 75 illustrates the capability to add teams and subsequently allocate them to a specific area. Furthermore, users can retrieve an overview displaying the teams currently allocated to the selected area.

SAR- First phase

Once all the teams have been configured in the Team Management tab, users can navigate to the SAR - First Phase tab (Figure 76) to access data related to the planning of sub-teams. Selecting a sub-team reveals its current location and provides insights into the projected planning for the sub-areas it is assigned to cover.

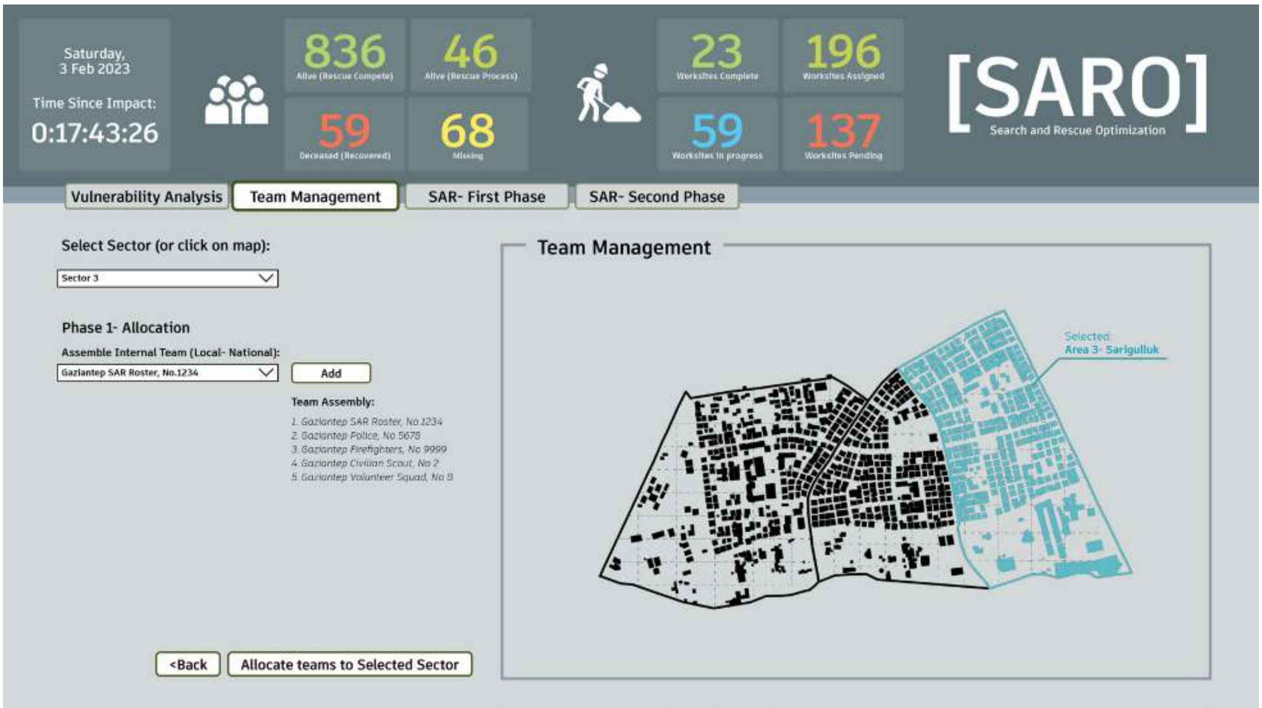


Figure 90: UI design: Team management. Own work

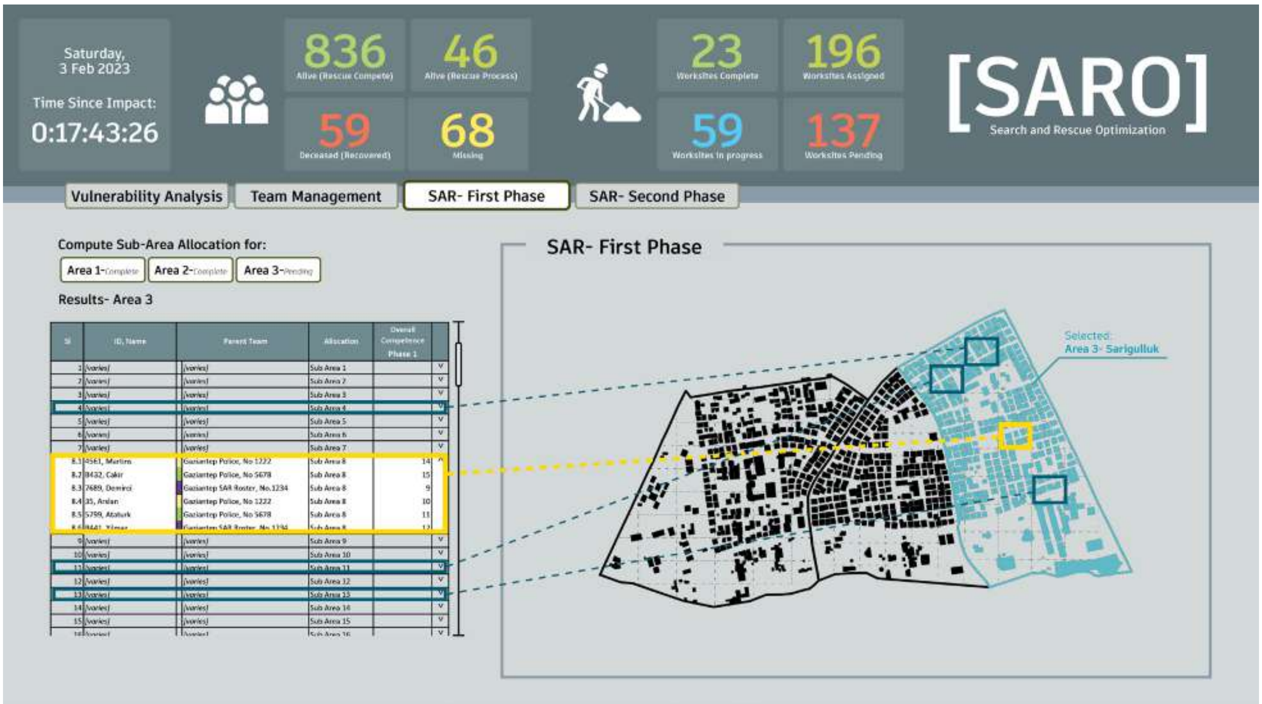


Figure 91: UI design: SAR- First Phase. Own work

Dashboard design

SAR- Second phase

The second phase tab (Figure 77) offers a comprehensive dashboard for a specific sub-area. Below the map, detailed information about the status of all buildings is presented. On the left, data is provided concerning the sub-team allocated to the area. Clicking the “Check Schedule” button allows for a more in-depth view of the schedule, shown in Figure 78.

Figure 92: UI design: SAR- Second phase. Own work

Figure 93: UI design: Dashboard page. Own work

Group reflection: Data accessibility

Collection, storing and sharing

While some of the required input data was publically accessible for our tool, our ability to obtain it has been hindered by:

- limited data-sharing practice
- paywalls
- usage restrictions
- privacy concerns
- language barriers

Therefore, many improvements have to be made in data accessibility and sharing practices, such as implementing open data initiatives, reducing paywalls, and addressing privacy concerns to enhance the tool's effectiveness and responsiveness in disaster scenarios. Overcoming these obstacles will allow for more comprehensive and accurate information, ultimately leading to better-informed decision-making during critical phases of disaster response.

Furthermore, it's essential to recognize that this issue extends beyond our project. Improved data accessibility has for example the potential to foster the development of innovative initiatives dedicated to providing vital assistance during disaster situations.

> "Enhanced data accessibility not only benefits our tool but also has a positive impact on the entire field of disaster response and recovery".

This, in turn, promotes more effective and coordinated efforts aimed at saving lives and minimizing harm during emergencies, benefiting the **performance, economy, and social consensus** of Turkey (Figure 79).

Figure 94: Advantages public data sharing. Own work.

Group reflection: Future Improvements

1. Data Accesibility

Due to the unavailability of data, significant efforts were dedicated in our search for essential data to required for the development of our tool. We conducted thorough online searches, attempted to establish communication with companies, and even engaged with members of the Gaziantep municipality. While the municipality indicated the potential availability of the data we sought, the data they provided was insufficient for our purposes. As a result, a substantial portion of our project's time was directed towards creating synthetic data.

Throughout our project, we encountered multiple obstacles that substantiate the need for enhanced data accessibility. Therefore, we would like to reflect and consider how it could have been utilized if the required data had been available for the following topics:

1. Building characteristic information
2. Data validation
3. Enhancing Predictive Scheduling

1. Building characteristic information

For calculating damage states, we required data related to building characteristics, such as building typology, height, lateral load resistance system and seismic code compliance. Since we couldn't acquire this data, we generated synthetic data based on general distribution data of these characteristics .

> "As this is an essential input for our tool to predict damage states, a future collaboration has to be implemented with parties who own the data, preferably with the government agencies."

2. Data validation

Speaking to the municipality of Gaziantep, we know that data exists about what damage state a building entered after the big earthquake that hit Turkey.

> "Data of damage states and building characteristics could be used for validating and enhancing the accuracy of our proposed models, thus enabling subsequent improvements and refinements."

While the municipality did provide us with the damage states of the buildings, they did not provide the corresponding building characteristic data. Consequently, we had to generate this data based on regional statistics, which, in turn, hindered our ability to validate any correlation between damage states and building characteristics.

3. Enhancing Time Predictions

Accurate scheduling of rescue operations relies on determining the speed at which a life can be saved. This number likely relies on the skill of the rescue asset, the size and material of the building, the damage state, and the injury of the victim itself.

To provide this time definition, we tried to make an equation and derive the constants using a least square method, feeding in artificial 'empirical' data, primarily serving as a proof of concept. But it is only about 65% accurate. We dont know yet what the nature of proportionality is between these variables and the time function. More research is required.

To realize this, we propose a collaboration with SAR organizations such as INSARAG, known for meticulously documenting official rescue operations. Their data offers valuable insights into the relationships between building conditions, resource needs, time invested, and lives saved.

Group reflection: Future developments

> "This data holds the potential to develop an more accurate predictive model. This model could establish connections between damage states, rescue actions, team competence, and time requirements, significantly boosting the efficiency of resource allocation and scheduling."

G

Gaps between Conceptualized and the Real product:

1. Developing an accurate model for predicting the number of individuals trapped based on building characteristics, damage states and building typology requires further research.

2. The project currently employs a two-phased allocation approach. The setup involves a clear distinction between phase 1 and phase 2. Phase 1 heavily depends on predictive modeling for damage states and injury profiles, while phase 2 relies on real-time updates for action requirements. However, this transition is not as static as we designed it to be. In practice, these phases need to be integrated as a dynamic, interconnected whole where data from both phases informs and adapts to each other, allowing for a more flexible and responsive approach. This integration will better reflect the complex and changing nature of real-world situations.

3. The possibility of secondary disasters in buildings is not considered and this factor can add a lot of uncertainty and risk in buildings

4. The correlation between rescue assets and equipment, particularly heavy riggin equipment, is not considered.

5. This workflow can also be used for the allocation of human resources other than search and rescue resources.

Group reflection: Process developments

Progression project definition

The first three weeks are less of relevance for us as a group as they were centered around individual explorations where we had not interacted as a collective of four.

Week 3-6 (20/9 – 11-10)
On the day of choosing the topics, we all discovered our shared interest in 'facilitating community cooperation and support' as we all felt it could significantly enhance earthquake response. Despite our lack of experience in this domain, we collectively felt the urge to explore new territory, embarking on a journey where the outcome was uncertain. At this point, we all expressed our expectations, agreeing to pursue a complex topic with a primary emphasis on exploration and personal development of knowledge and computational skills. While acknowledging the high-risk nature of our choice, we were determined to embrace the challenge, recognizing that even a less-than-ideal outcome could offer valuable learning experiences.

However, faced with the group size limit of 2-3 people and our group comprising four members, we reached a consensus to adopt a decision support system (D.S.S.) as our common topic which could allow us to closely collaborate on the same tool if we chose different topics. Over the next two weeks, our focus was on finding our specific topics within the D.S.S. framework.

Two primary ideas emerged for the decision support system: 'water infrastructure repair' and 'search and rescue.' Unaware of the complexity of these topics at the time, we began exploring both independently. In hindsight, this long exploration process was necessary for us to make a well-thought-out decision. However, it set us back significantly, and it wasn't until after the proposal that we finalized our choice in week 5 to pursue the topic of 'search & rescue' with all four members as it had more potential, more data available and it sufficient complexity.

In our pursuit of search and rescue, we divided the process into two parts. Part A centered on predictive Building & Context Assessment, while Part B focused on allocating and scheduling rescue resources based on the findings of Part A. At the time, this division appeared to be the most logical approach to align with the overarching vision we had for the tool. These distinct components not only facilitated a systematic and comprehensive exploration of search and rescue, but also enabled us to conduct independent research, allowing for a better understanding of the complex world involved in optimizing response strategies.

Week 6-10 (11/10 – 10/11)
After the mid-term, we received feedback highlighting a concern we were already aware of: the absence of a structural component in part A. Instead of attempting to force an ill-fitting component into a project section where it didn't naturally belong, our approach was to consolidate our efforts into one comprehensive project. Several reasons supported this decision: the structure of our project involved numerous interrelated topics, making it near impossible to establish a clear distinction between two evenly divided parts. Additionally, our intense collaboration throughout the entire course made it feel as though we were a cohesive group of four, even though,on paper we were designated as a group of two.

Reviewing the collaborative endeavors mentioned earlier, it becomes evident that both before and especially after the midterm, a substantial amount of our collective time was dedicated to discussions. These discussions became necessary as we joint our research efforts to align every detail of the project. At times, we drifted from the overarching goal of establishing our framework, delving into minor details that were interesting on their own, but less of importance in the project's primary objectives. However, despite the

Group reflection: Process developments

Progression project definition

occasional sense of these discussions being unnecessary, we acknowledge its vital role in enhancing our understanding of the project as we approached its finalization. It allowed us to develop an intricate level of detail into a project of such broad scope, ultimately contributing to the depth and comprehensiveness of our final work.

Moreover, these discussions resulted in crucial enhancements to our framework. For instance, during week 8, we engaged in a two-day discussion marathon on how to address the (computational) demands for our allocation and scheduling. It became evident that our initial approach was impractical, leading us to explore alternatives which resulted in the development of our two-phased allocation framework.

In summary, the journey from the initial exploration of our shared interest in community cooperation to the finalization of a comprehensive search and rescue framework has been both challenging and rewarding. The process of group collaboration, intense discussions, and continuous refinement has not only improved our understanding of the subject matter but has also strengthened our collaborative skills. As a group, we are proud of the final outcome and recognize the invaluable lessons learned during this intense and valuable experience.

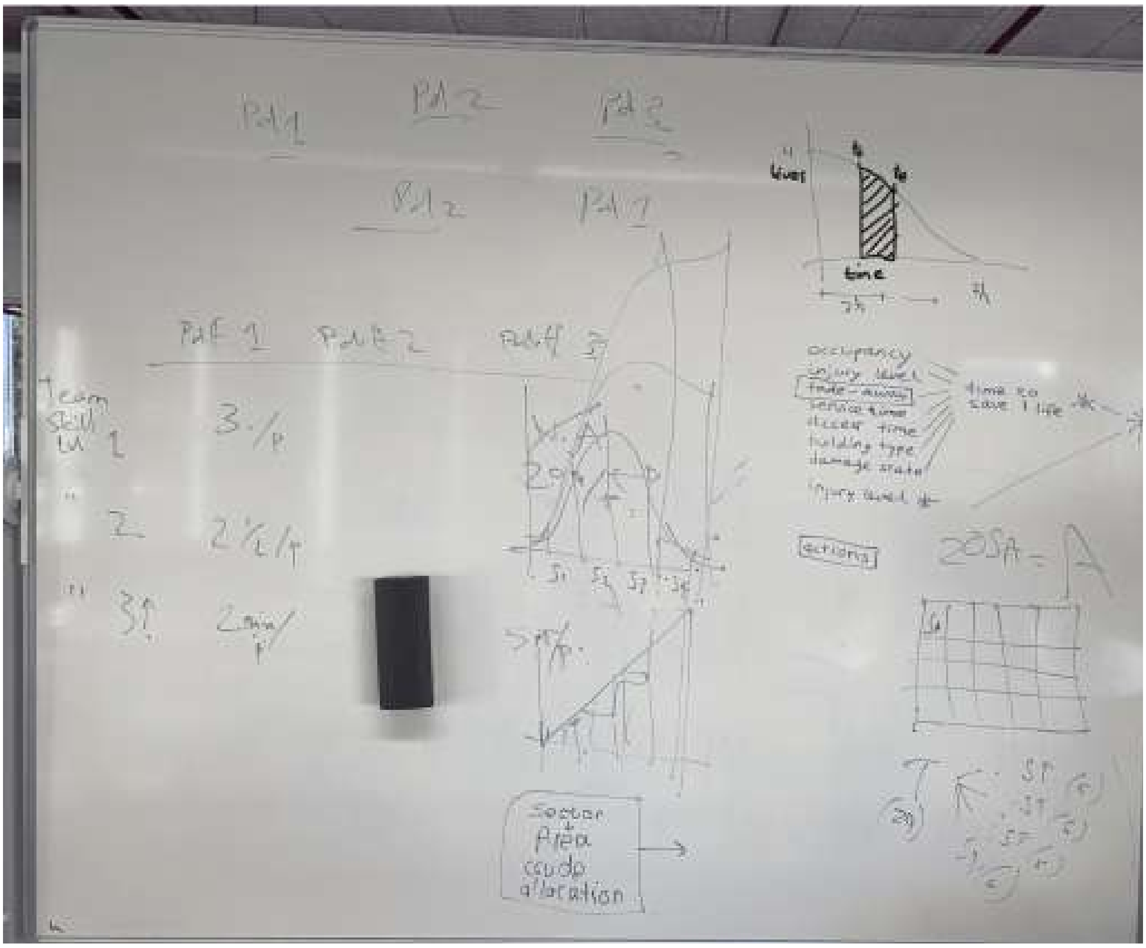


Figure 95: Sketches from discussions. Own work.

Group reflection: Process developments

Progression project definition

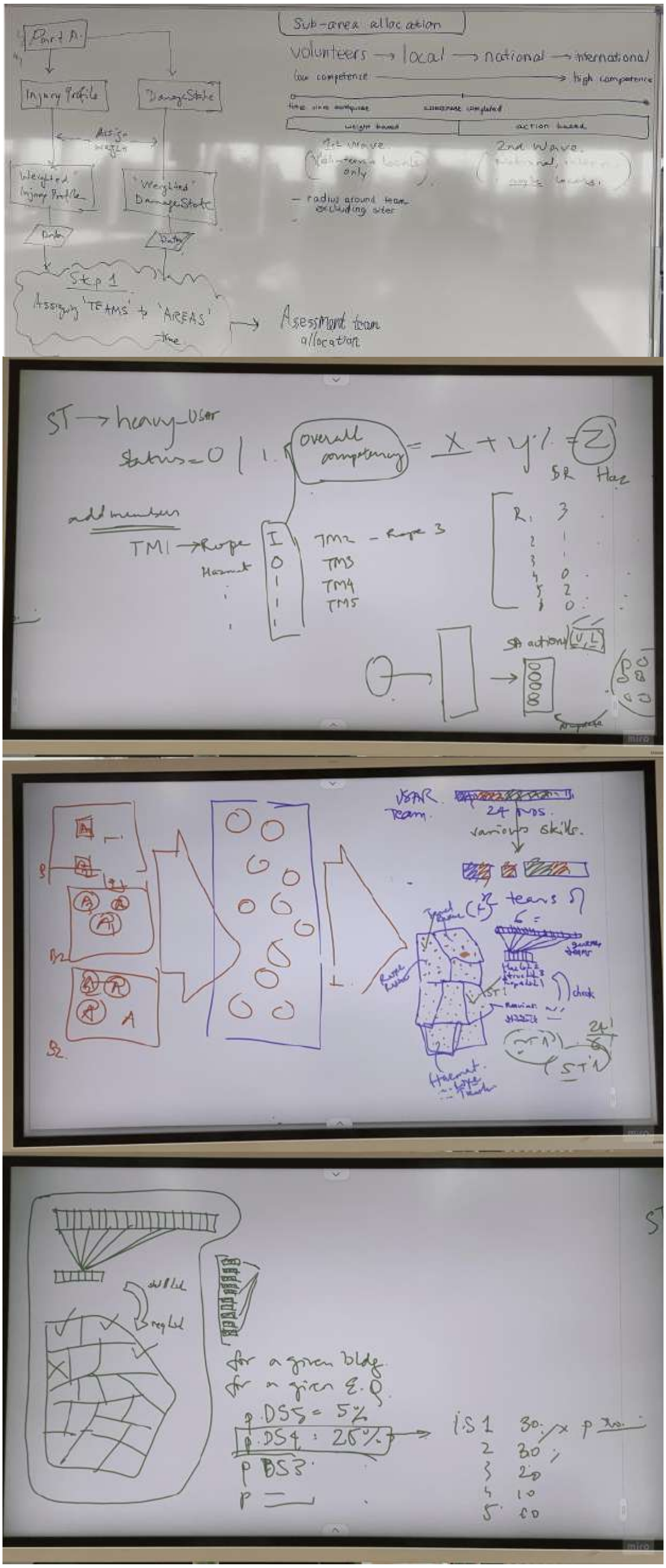


Figure 96: Sketches from discussions. Own work.

Individual reflection

Shreya Kejriwal

Respoonsibilities:

-Part A- Research on Injuries and Damage State Correlations and Fadeaway Curves
- Search and Rescue agency research
- Research on search and rescue optmization problems
-Code for action based allocation and sequencing problem

The CORE project had a very interesting approach to combine multiple disciplines like building technology and data science to explore new possibilities. The project has been an invaluable asset to my personal growth, especially through the enriching experience of collaborating with a diverse group of individuals. Working alongside people from different backgrounds has provided me with fresh perspectives and pushed me to challenge my own biases, ultimately expanding my knowledge and understanding. This process has underscored the significance of effectively communicating my thoughts and experiences on specific topics. By articulating my insights clearly and concisely, I had to ensure that my teammates share the same understanding and vision.

One of the most valuable lessons we learned during the project was the importance of adaptability. Our research and design problem was intricate and complex, with numerous unknown and foreign variables. As we progressed, we encountered unforeseen obstacles that required us to make adjustments in our approach. However, our team demonstrated remarkable flexibility and the ability to pivot, ensuring that we never lost sight of our ultimate goal. Through regular discussions and a commitment to continuous learning, we were able to update our beliefs and knowledge based on new information.

The integration of coding with architecture in the overall project scheme was particularly captivating for me. I was able to learn python and many of its libraries in detail. The opportunity to attend various lectures and receive guidance allowed me to acquire new skills and techniques, further enhancing my abilities in both coding and structural dynamics.

As I reflect on the CORE project, it becomes evident that its impact extends far beyond the tangible outcomes. The complete process of decisions and discussions to look at information beyond our comfort zone was an amazing experience.

Engaging in the CORE project was a unique experience that brought together building technology and data science, exploring new ideas. This collaboration significantly contributed to my personal growth, exposing me to diverse perspectives and challenging my preconceptions. Communicating effectively became crucial as I worked with people from different backgrounds.

A key takeaway was the importance of adaptability. Dealing with complex challenges and unforeseen obstacles, our team learned to adjust our approach while staying focused on our goal. Regular discussions and a commitment to learning allowed us to adapt to new information and refine our strategies.

The blend of coding and architecture in the project was particularly interesting. I enjoyed working on allocation and scheduling algorithms, delving into mathematical concepts related to time uncertainties. Attending lectures and receiving guidance enriched my skills in coding and structural dynamics.

I did some initial research for part A but as the project progressed I was personally more involved in the research part of Part B, focusing on allocation and scheduling algorithms. Working with the scheduling and optimisation algorithm was a little challenging to begin with as there were a lot of new terminologies and parameters. Overall it was nice learning curve.

Reflecting on the CORE project, its impact goes beyond tangible outcomes. It involved redefining and critical thinking, considering the complexity of problems, and addressing ethical considerations.

Individual reflection

Pavan Sathyamurthy

Responsibilities:

-Research: Structural Dynamics
-Research: Risk, Exposure and Vulnerability
-Modelling
- Collaborative work with Bo on linking rescue actions to: building typology and height, and damage state
- Research: simulating time factor for saving lives is SAR operations using LSM
-Code for Part A: importing OSM data, applying synthetic building attributes and preparing damage profile extimates and injury profile estimates

The CORE project has, for me, been the most interesting project in my master program so far for several reasons. Here are some of my key thoughts:

Course Structure and course theme: I agree with the course structure this year. Particularly the python introduction was crucial and very useful for us to break into the process of using coding. Some more (non compulsory) coding exercises could perhaps be added.

I do feel though, that the actual working on the project had to be done in very limited time, due to the lectures in the first weeks. This is crucial for students to understand the problem of earthquake disasters of course. FOr me this either means that CORE should be a longer course, or that the studio theme could be less technical. Seismic science, structural dynamics, and disaster management at higher levels is quite new territory to a Building Technology student, and all three together, along with the explorations of new computational tools, may have been a lot.

Having said that, the recent final exhibition seems to suggest that the students all rose up very well to the challenge and produced some exceptional works in my opinion.

Choosing the SARO project: With this one, we went completely ambitious, and at times were lost in the complexity, with days of group discussions trying to dissect the problem of SAR. In week 3, we agreed that we were all okay choosing a difficult, unfamiliar topic. If the exploration ended it failure, we were ready to accept it as we got to learn something new. It was a risky decision, to disregard the thoughts about good grades or having a finished final product by end of quarter.

Choosing between learning exercises and creating new knowledge: By week 4 or 5 it became apparent to me that the workflows and tools i was working on, particulary for part A, were already developed tools by others, like those used by HAZUS-MH, Openqake engine, or the ESRM python code. In that sense, what iw as doing was already done before, and probably better. I decided to pursue it anyway becuase it was my best chance of understanding the science behind damage prediction and Hazard analysis. It was also the way i could learn Python,, by trying to prepare my own program that does vulnerability and exposure analysis.
This way i dont think i have contributed any new knowledge, particularly with Part A. It is mainly an educational experience.

I think the original contribution from SARO was in trying to combine risk assessment with Search and Rescue programs. This highlighted the various correlations and we have tried to show this in our report. The project perhaps also highlights several key voids in data and knowledge, as reference for anyone who tries to attempt such a project in future.

Side Projects started and Discontinued: As mentioned earlier, the technical complexity and unfamiliarity with seismic design and structural dynamics was quite formidable. I recognize the time spent trying to navigate many research papers and even attempting to read Anil Chopra's Dynamics of Structures. (Needless to say, i coldnt finish it in this quarter).

A lot of this was only possible to navigate becuase of the guidance of Dr Charalampos Andriotis and Dr Simona Bianchi, who in meeting were actually teaching me the necessary theory to do the risk assessment.

From the point of view of my personal education, this was a great step, but oce again, whereas it was a lot of learning for me, i could not create any new knowledge.

Approach to Computational tools: This was my first experience with using programming

Individual reflection

Pavan Sathyamurthy

languages, adn tis project has helped me underrstand the power and potential of it. Part B, in particular absolutely demanded this approact, so the project choice was ideal for it.

I do feel like my learning curve needed to be very steep and i was writing specialized code using several libraries.. writing code without understanding all of the basics. I knew this because the errors kept confounding me, and the library documentantion was also difficult to comprehemd at times. I think i would have preferred a more structured and slow pace for myself and ideally learnt more coding before CORE started.
I also learnt what tools to use when and am happy with the combination of excel, python, OSM and Rhino/Grasshopper that we used in this project, and we used the tools for what they were well suited for. (most of this project could perhaps also be done in grasshopper and ghpython for example, and i was tempted to...but that would be much less efficient.)

I do think i missed the opportunity of Object Oriented Programming though. The code for part A uses a mechanism treating buildings and earthquakes as objects, but all of the following computations were output as columns that i appeneded to a dataframe, which were then read for the next steps throught list comprehension. The correct way to do this would be to program all of the computations as methods and functions in the class definitions so the building objects have the computational results assigned to them. Learnings for next time.

Remarks on the Groupwork:
I must say I am fortunate to have again had a really good team to work with this quarter. Each member was hardworking, strong in thoughts, and most importantly, we shared the same appetite for where we wanted to explore with this project, and the willingness to discover a dead end. Brent was instrumental in guiding me with the programming when I was stuck. Bo helped me with the creating the correlations between Building and Casualties with SAR- also to mention he directed and edited the remarkable promo video we made for SARO, and Shreya broke down the complex computation and mathematics of solving the optimization problems for the allocation and scheduling problem. And most importantly we did not shy away from the sometimes overwhelming complexity of the project- and just spent hours discussing until we got to the plan forward.

I do not think i could have managed this project without this particular team, and I express my gratitude to them.

Finally I express gratitude to Serdar, Juan and the whole teaching staff of the CORE studio... along with all of the guest lecturers, who made it possible to tackle such a project as this.

Individual reflection
Brent Smeekes

Responsibilities:
- Explorative research on 'mortality prediction in building collapse',
- Importing buildings, sub-areas, areas and adding to those classes.
- Creating classes for teams, sub-teams, team members.
- Writing code for allocating to areas.
- Setting up the create teams code.
- Writing code for allocation phase 1.
- Writing code for allocation phase 2.
- Creating maps as output of program.
- Collating all team memers code to create the 'MasterCode'

During the start of the course, I didn't learn a lot from the coding workshops because I already had some programming experience. I did learn some of the basics of earthquakes and how to design having earthquakes in mind. The lectures weren't enough for me to get a good understanding of how to analyse earthquakes, but enough for me to understand the possibilities of earthquake research. This helped me to decide on topics for the project that I thought would be interesting for me, but also for the community in this field of research.

It was the 'Recovery and Resilience in the Aftermath of the 2023 Earthquakes in Turkey' lecture by Nazil Aydin that sparked the idea to work on critical infrastructure repair. Besides sparking this idea, this lecture was very valuable in general. It really solidified the fundamentals and terms that were used in earthquake research, it would have made other lectures easier to understand if this lecture had come first.

When the team building was happening on the 20th of September, I had planned to work with a group of 4 on risk analysis, the probability of failure for a given building. I'm happy that the groups had to be broken up because the size changed. In retrospect it might have been better to only let us know about the details of teambuilding on the day itself to prevent premature teambuilding from happening. The breaking up of the groups allowed me to pursue the topic of recovery of critical infrastructure which I was actually fascinated by.

Around week 4 I did some research on 'mortality prediction in building collapse'. The papers I read were a good starting point, but I struggled to find the exact information I was looking for. I chose to focus my efforts on programming and Pavan took the research over. I think it was important that there was someone in charge of organizing the code, making sure that the information from different people was connected. However, I do wonder if this was the reason that I chose to steer away from the research aspect.

To sum up, I really enjoyed this project and course and I think I learned a lot. I had an amazing team, everyone with different expertise's, and I think I learned something from everyone. In the future I want to challenge myself to better integrate research and programming in my process.

Individual reflection
Bo Valkenburg

Responsibilities:

- Explorative research about resources related to search & rescue operations.
- Explorative research about common practice of search & rescue operation.
- Developing resources framework for teams, sub-team, team members, compentency levels and rescue actions
- Writing code for rescue resources framework
- Collaborative work with Pavan on linking rescue actions to: building typology and height, and damage state
- Editing video for exhibition
- Setup & compiling of report

To be fully honest, before CORE started, I was quite hesitant about my choice for the course as I had limited knowledge about the computational aspects of Building Technology. This resulted from extending my first year of the master's program over two years and not selecting computational courses as electives, thereby excluding myself from any computational course. With this in mind, CORE marked a fresh start for me. Luckily, this hesitance quickly swifted towards embracing the chance to comprehend the complexities of computational aspects in Building Technology. The coursework not only provided essential coding skills but also developed a new appreciation for the field of work.

Reflecting on the course, the initial three weeks were crucial for me as a complete coding beginner. The crash courses effectively covered the basics, and I really appreciated the well-delivered theoretical aspects. However, throughout the rest of the course I came to recognize that coding isn't solely learned through theory as it heavily relies on practical exercises. To enhance these crash courses, I would like to suggest incorporating additional hands-on exercises, for a more comprehensive learning experience It varied from day to day; on some occasions, there were plenty of exercises to practice on a given topic, while on others, there weren't enough.

Regarding the overall course timeline, I believe it was well-structured. The initial three weeks, in particular, were beneficial as we were introduced to the wide spread of topics and engaged in Python crash courses. However, there were instances when the lecture topics delved deeply, making them challenging to grasp. Consequently, I would appreciate adjustments where lectures aimed more at being exploratory rather than focusing on intricate details.

Also, I felt like the mid-term should have been scheduled a week later than it was. There were only two weeks between the proposal and mid-term, limiting the time for substantial progress. In contrast, the final stretch between the mid-term and the final exhibition was four weeks, providing ample time for preparation.

In conclusion, I want to express my gratitude to my groupmates as I really enjoyed this course with them. They truly demonstrated their competency across a broad set of skills, from which I was able to learn and benefit. Furthermore, our collective commitment to getting the detail right, necessitating extensive discussions, significantly facilitated the success of all our contributions. With that said, I can

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Appendix I: Resources USAR teams

Light USAR team

3.4.2 Light USAR Teams

A Light USAR Team comprises the five components required by the INSARAG Guidelines (Management, Logistics, Search, Rescue and Medical). Light USAR Teams have the ability to conduct technical search and rescue operations in collapsed structures of wood, masonry, and light reinforced concrete construction. The Light team will also have the capacity to conduct rigging and lifting operations. Light USAR Teams will be similar in technical skills to Medium and Heavy USAR Teams. Light teams will be capable of completing a search and rescue to ASR3 on worksites. A Light USAR Team suggested personnel is between 17 and 20 personnel, with the ability to deploy one person to INSARAG support (UCC/RDC) for the duration of the deployment. The Team's logistics component will be capable of establishing a Base of Operations (BoO) including shelter, sanitation, tool repair, feeding, and hygiene arrangements.

A Light USAR Team:

- Is required to have the capacity to work on a single worksite.
- Is required to have the capability for search dogs and / or technical search.
- Must be adequately staffed and resourced to allow maximum 12-hour operations on one site (site may change) for up to five days.
- Must be able to medically treat its own team members (including dogs if present) as well as victims encountered if allowed to do so by the government of the affected country.
- Must be capable of conducting USAR operations to ASR3 level and integrating into the standard INSARAG reporting mechanisms.

A suggested staffing level in the following table will enable a Light USAR Team to carry out 12-hour operations on one worksite. Refer to Annex C for further information.

USAR Component	Tasks	Suggested Staff Allocation	Suggested Number (17 to 20)
Management	Command	Team Leader	1
	Coordination / UCC / RDC / On-Site Operations Coordination Centre (OSOCC)	Deputy Team leader	1
	Planning / Information / Communications	Planning Officer	1
	Safety and Security	Safety Officer	1
Search & Rescue	Operations	Crew Leader	1
	Technical Search / Dog Search / Hazmat Assessment / Breaking and Breaching; cutting; shoring; technical rope; Lifting and moving	Search and Rescue team (including dogs if deployed)	8 (Plus dogs)
Medical	Medical Team Management: Coordination and administration of medical team. Integration with local health infrastructure Care of team (including canines) and victims encountered	Medical Doctor and/or	1
		Physician / Paramedic / Nurse	1
Logistics	BoO	Logistics Team Manager	1
	BoO	Logistician	1
	Water supply		
	Food supply		
	Transport capacity and fuel supply		

Table 3: Suggested staffing level for a Light USAR Team

Appendix I: Resources USAR teams

Medium USAR team

3.4.3 Medium USAR Teams

A Medium USAR Team comprises the five components required by the INSARAG Guidelines, i.e. Management, Logistics, Search, Rescue and Medical. Medium USAR Teams have the ability to conduct technical search and rescue operations in collapsed or failed structures of heavy wood and/or reinforced masonry construction, including structures reinforced with structural steel. They must also conduct rigging and lifting operations. Medium teams are expected to include RDC/UCC components, if applicable to national framework. The main differences between the two teams are as follows.

A Medium USAR Team:

- Is required to have the capacity to work only at a single worksite.
- Is required to have the capability of search dogs and/or technical search, and
- Must be adequately staffed to allow for 24-hour operations at one site (not necessarily at the same site; the sites may change) for up to seven days.
- Must be able to medically treat its team members (including search dogs if present) as well as victims encountered if allowed to do so by the government of the affected country.

A suggested staffing level in the following table will enable a USAR Team to carry out 24-hour operations on one worksite for up to seven days. Refer to Annex C for more information.

USAR Component	Tasks	Suggested Staff Allocation	Suggested Number (Total 42)
Management	Command	Team Leader	1
	Coordination	Deputy Team leader	1
	Planning/Follow Up	Planning Officer	1
	Liaison/Media/Reporting	Liaison Officer	1
	Assessment/Analysis	Structural Engineer	1
	Safety and Security	Safety Officer	1
	RDC/UCC	Coordination Officer	2 (If applicable to national framework)
Search	Technical Search	Technical Search Specialist	2
	Dog Search	Dog Handler	4
	Hazmat Assessment	Hazmat Specialist	2
Rescue	Breaking and Breaching; cutting; shoring; technical rope	Rescue Team Manager and Rescue Technicians	14 (2 teams: 1 Team Leader and 6 Rescuers each)
	Lifting and Moving	Heavy Rigging Specialist	2
Medical	Medical Team Management: Coordination and administration of medical team, Integration with local health infrastructure. Care of team (including canines) and victims encountered	Medical Doctor	1
		Physician, Paramedic, Nurse	3
Logistics	BoO	Logistics Team Manager	1
	Water supply	Transport Specialist	1
	Food supply	Logistician	1
	Transport capacity and fuel supply	Base Manager	2
	Communications	Communications Specialist	1

Table 4: Suggested staffing for a Medium USAR Team

Appendix I: Resources USAR teams

Heavy USAR team

3.4.4 Heavy USAR Teams

A Heavy USAR Team comprises the five components required by the INSARAG Guidelines, i.e.: Management, Logistics, Search, Rescue and Medical. Heavy USAR Teams have the operational capability for complex technical search and rescue operations in collapsed or failed structures that require the ability to cut, break and breach steel reinforced concrete structures, as well as delayer these structures using lifting and rigging techniques, setting up RDC/UCC component, if applicable to national framework.

A Heavy USAR Team:

- Is required to have the equipment and manpower to work at a Heavy technical capability at two separate worksites simultaneously. A separate worksite is defined as any area of work that requires a USAR Team to re-assign staff and equipment to a different location all of which will require separate logistical support.
- Is required to have both a search dog and technical search capability.
- Is required to have the technical capability to cut structural steel typically used for construction and reinforcement in multi-storey structures.
- Must be adequately staffed and logistically sufficient to allow for 24-hour operations at two independent sites (not necessarily at the same two sites; the sites may change) for up to ten consecutive days.
- Must be able to medically treat its team members (including search dogs as well as victims which the USAR Team is working to extricate prior to the medical handover. if allowed to do so by the government of the affected country.

A suggested staffing level in Table 5 will enable a USAR Team to carry out 24-hour operations on two worksites for up to ten days. Please refer to Annex C for more information and suggested equipment lists for Heavy USAR Team.

USAR Component	Tasks	Suggested Staff Allocation	Suggested Number (Total 63)
Management	Command	Team Leader	1
	Coordination	Deputy Team Leader	1
	Planning	Planning Officer	1
	Liaison/Follow Up	Liaison Officer	1
	Media/Reporting	Deputy Liaison Officer	1
	Assessment/Analysis	Structural Engineer	1
	Safety and Security	Safety Officer	1
	RDC/UCC	Coordination Officer	4 (If applicable to national framework)
Search	Technical Search	Technical Search Specialist	2
	Dog Search	Dog Handler	6
	Hazmat Assessment	Hazmat Specialist	2
Rescue	Breaking and Breaching: cutting; shoring; technical rope	Rescue Team Manager and Rescue Technicians	28 (4 teams Comprising 1 Team Leader and 6 Rescuers)
	Lifting and Moving	Heavy Rigging Specialist	2
Medical	Team Care (Personnel and Dogs) Patient Care	Medical Doctor	2
		Paramedic/Nurse	4
Logistics	BoO	Logistics Team Manager	1
	Water supply	Transport Specialist	1
	Food supply	Logistician	1
	Transport capacity and fuel supply	Base Manager	2
	Communications	Communications Specialist	1

Table 5: Suggested staffing for a Heavy USAR Team.

Appendix II: Rescue actions + codes

ACTION CODE	ACTION SUBCODE	ACTION DESCRIBTION	COMPETENCE		
STRUCTURAL RESCUE			STR RESCUE LVL 1	STR RESCUE LVL 2	STR RESCUE LVL 3
STR_	A	Size-up and Scene Safety	1	1,25	1,5
STR_	B	Casualty Assessment and Basic Medical Care	1	1,25	1,5
STR_	C	Shoring and Stabilization (Basic):	1	1,25	1,5
STR_	D	Safe Access and Egress:	1	1,25	1,5
STR_	E	Advanced Scene Assessment:	0	1	1,25
STR_	F	Advanced Medical Care and Triage:	0	1	1,25
STR_	G	Advanced Shoring Techniques:	0	1	1,25
STR_	H	Complex Casualty Extrication:	0	1	1,25
STR_	J	Command and Coordination:	0	0	1
STR_	K	Multiple Collapse Points:	0	0	1
STR_	L	Advanced Shoring and Heavy Machinery:	0	0	1
STR_	M	Urban Search and Rescue (USAR) Techniqes	0	0	1
TRENCH RESCUE			RESCUE LVL 1	RESCUE LVL 2	RESCUE LVL 3
TRE_	A	Scene Assessment and Safety	1	1,25	1,5
TRE_	B	Hazard Recognition:	1	1,25	1,5
TRE_	C	Casualty Assessment and Basic Care	1	1,25	1,5
TRE_	D	Trench Shoring and Stabilization (Basic):	1	1,25	1,5
TRE_	E	Advanced Hazard Recognition	0	1	1,25
TRE_	F	Advanced Shoring and Trench Box Systems	0	1	1,25
TRE_	G	Casualty Packaging and Extrication	0	1	1,25
TRE_	H	Equipment Operation	0	1	1,25
TRE_	J	Incident Command and Coordination	0	0	1
TRE_	K	Multiple Casualties and Complex Trench Configurations	0	0	1
TRE_	L	Technical Trench Rescue	0	0	1
TRE_	M	Integrate with Other Disciplines	0	0	1
TECHNICAL ROPE RESCUE			RESCUE LVL 1	RESCUE LVL 2	RESCUE LVL 3
TRO_	A	Knot Tying	1	1,25	1,5
TRO_	B	Anchor Systems	1	1,25	1,5
TRO_	C	Ascending and Descending	1	1,25	1,5

Appendix II: Rescue actions + codes

TRO_	D	Rigging and Mechanical Advantage	1	1,25	1,5
TRO_	E	Advanced Knot Tying	0	1	1,25
TRO_	F	Complex Rope Systems	0	1	1,25
TRO_	G	Difficult Access	0	1	1,25
TRO_	H	Confined Space Rope Rescue	0	1	1,25
TRO_	J	Dynamic Environments	0	0	1
TRO_	K	Rope-Based Confined Space Rescue	0	0	1
TRO_	L	Advanced Anchoring and Rigging	0	0	1

CONFINED SPACE RESCUE			**RESCUE LVL 1**	**RESCUE LVL 2**	**RESCUE LVL 3**
CSR_	A	Confined Space Hazard Assessment	1	1,25	1,5
CSR_	B	Safe Entry and Exit	1	1,25	1,5
CSR_	C	Retrieval Systems and Equipment	1	1,25	1,5
CSR_	D	Air Monitoring and Ventilation	1	1,25	1,5
CSR_	E	Advanced Confined Space Entry	0	1	1,25
CSR_	F	Specialized Confined Space Equipment	0	1	1,25
CSR_	G	Air Monitoring and Ventilation (Advanced)	0	1	1,25
CSR_	H	Advanced Patient Care	0	1	1,25
CSR_	J	Complex and Hazardous Incidents	0	0	1
CSR_	K	Leadership and Incident Command	0	0	1
CSR_	L	Integration with Other Disciplines	0	0	1

HAZMAT RESCUE			**RESCUE LVL 1**	**RESCUE LVL 2**	**RESCUE LVL 3**
HZM_	A	Hazard Identification	1	1,25	1,5
HZM_	B	Personal Protective Equipment (PPE):	1	1,25	1,5
HZM_	C	Decontamination Procedures	1	1,25	1,5
HZM_	D	Sampling and Analysis	1	1,25	1,5
HZM_	E	Advanced Hazard Recognition	0	1	1,25
HZM_	F	Advanced PPE	0	1	1,25
HZM_	G	Advanced Decontamination Techniques	0	1	1,25
HZM_	H	Detailed Hazardous Material Sampling and Analysis	0	1	1,25
HZM_	J	Large-Scale Incidents	0	0	1
HZM_	K	Incident Command and Coordination	0	0	1
HZM_	L	Environmental Protection	0	0	1
HZM_	M	Public Relations and Media Management	0	0	1

Appendix II: Rescue actions + codes

HEAVY RIGGING RESCUE			RESCUE LVL 1	RESCUE LVL 2	RESCUE LVL 3
RIG_	A	Equipment Familiarization	1	1,25	1,5
RIG_	B	Basic Rigging Techniques	1	1,25	1,5
RIG_	C	Safe Operation	1	1,25	1,5
RIG_	D	Safety Protocols	1	1,25	1,5
RIG_	E	Advanced Equipment Operation	0	1	1,25
RIG_	F	Complex Rigging Configurations	0	1	1,25
RIG_	G	Load Handling and Balance	0	1	1,25
RIG_	H	Safety Risk Management	0	1	1,25
RIG_	J	9.High-Risk Scenarios	0	0	1
RIG_	K	Coordination and Incident Command	0	0	1
RIG_	L	Integrate with Other Disciplines	0	0	1

Appendix III: Vulnerability data from ESRM database

Typology	strsys	latres	codecomp	height	IMT	Median_DS1	Median_DS2	Median_DS3	Median_DS4	Beta
CR_LDUAL-DUH_H1	CR	LDUAL	CDH	1	PGA	1.38809268	2.21265511	2.73472712	3.12253315	0.35942546
CR_LDUAL-DUH_H10	CR	LDUAL	CDH	10	SA(0.6)	1.37682015	1.98571057	2.61946989	3.21685368	0.41725146
CR_LDUAL-DUH_H11	CR	LDUAL	CDH	11	SA(0.6)	1.62591987	2.15322787	2.70391022	3.21776813	0.40635785
CR_LDUAL-DUH_H12	CR	LDUAL	CDH	12	SA(0.6)	1.67185175	2.21987702	2.79326011	3.32913973	0.40969161
CR_LDUAL-DUH_H2	CR	LDUAL	CDH	2	PGA	0.72941914	1.40553493	1.85677236	2.20478306	0.39380268
CR_LDUAL-DUH_H3	CR	LDUAL	CDH	3	PGA	0.61926437	1.25730817	1.74679958	2.1482485	0.4661409
CR_LDUAL-DUH_H4	CR	LDUAL	CDH	4	PGA	0.59788544	1.20717975	1.71308675	2.14335487	0.52528014
CR_LDUAL-DUH_H5	CR	LDUAL	CDH	5	SA(0.3)	1.10109739	2.59082567	4.06216993	5.44062936	0.61678966
CR_LDUAL-DUH_H6	CR	LDUAL	CDH	6	SA(0.6)	0.60740188	1.41084914	2.27758335	3.13200206	0.58159485
CR_LDUAL-DUH_H7	CR	LDUAL	CDH	7	SA(0.6)	0.75763032	1.53974733	2.37023489	3.17886407	0.52219184
CR_LDUAL-DUH_H8	CR	LDUAL	CDH	8	SA(0.6)	0.93485112	1.6521514	2.39991855	3.11611047	0.46308704
CR_LDUAL-DUH_H9	CR	LDUAL	CDH	9	SA(0.6)	1.1396754	1.81174774	2.512237	3.17892716	0.43991555
CR_LDUAL-DUL_H1	CR	LDUAL	CDL	1	PGA	0.66281208	1.11001076	1.36799701	1.55448599	0.39054741
CR_LDUAL-DUL_H10	CR	LDUAL	CDL	10	SA(0.6)	0.78093722	1.1786614	1.58393907	1.96266678	0.44049646
CR_LDUAL-DUL_H11	CR	LDUAL	CDL	11	SA(0.6)	0.93467696	1.3102401	1.69609392	2.05567168	0.45523726
CR_LDUAL-DUL_H12	CR	LDUAL	CDL	12	SA(1.0)	0.48430637	0.70750487	0.94499856	1.17229937	0.42844235
CR_LDUAL-DUL_H2	CR	LDUAL	CDL	2	PGA	0.34658716	0.79058473	1.09052851	1.3258019	0.50631271
CR_LDUAL-DUL_H3	CR	LDUAL	CDL	3	PGA	0.30677817	0.76215503	1.11705274	1.41353139	0.5997889
CR_LDUAL-DUL_H4	CR	LDUAL	CDL	4	SA(0.6)	0.22121024	0.6578118	1.0817079	1.47731037	0.59496886
CR_LDUAL-DUL_H5	CR	LDUAL	CDL	5	SA(0.6)	0.26094639	0.67795359	1.08584411	1.46690826	0.51189435
CR_LDUAL-DUL_H6	CR	LDUAL	CDL	6	SA(0.6)	0.32376263	0.73703913	1.14290639	1.52160219	0.48470946
CR_LDUAL-DUL_H7	CR	LDUAL	CDL	7	SA(0.6)	0.40213822	0.82067649	1.24194683	1.63920645	0.46484214
CR_LDUAL-DUL_H8	CR	LDUAL	CDL	8	SA(0.6)	0.50280798	0.9245572	1.35060492	1.75160341	0.4496511
CR_LDUAL-DUL_H9	CR	LDUAL	CDL	9	SA(0.6)	0.63023964	1.03618395	1.44437366	1.82517785	0.43514831
CR_LDUAL-DUM_H1	CR	LDUAL	CDM	1	PGA	0.98442925	1.60895873	1.99050982	2.27098751	0.36497
CR_LDUAL-DUM_H10	CR	LDUAL	CDM	10	SA(0.6)	1.01682433	1.54252076	2.07791886	2.57830956	0.43438951
CR_LDUAL-DUM_H11	CR	LDUAL	CDM	11	SA(0.6)	1.22753539	1.71290207	2.21033603	2.67294201	0.42488635
CR_LDUAL-DUM_H12	CR	LDUAL	CDM	12	SA(0.6)	1.26696944	1.77056764	2.28736834	2.76844669	0.43118133
CR_LDUAL-DUM_H2	CR	LDUAL	CDM	2	PGA	0.51394895	1.07203945	1.4423817	1.7291218	0.44023593
CR_LDUAL-DUM_H3	CR	LDUAL	CDM	3	PGA	0.45736311	1.00476656	1.4196944	1.75985783	0.51480577
CR_LDUAL-DUM_H4	CR	LDUAL	CDM	4	PGA	0.43719795	1.005465	1.48780201	1.90520976	0.6394175
CR_LDUAL-DUM_H5	CR	LDUAL	CDM	5	SA(0.6)	0.36473846	0.99218451	1.63682773	2.25599729	0.59485919
CR_LDUAL-DUM_H6	CR	LDUAL	CDM	6	SA(0.6)	0.43883613	1.05672224	1.69249849	2.30240911	0.54043312
CR_LDUAL-DUM_H7	CR	LDUAL	CDM	7	SA(0.6)	0.54221742	1.14871153	1.77074191	2.36451642	0.50576475
CR_LDUAL-DUM_H8	CR	LDUAL	CDM	8	SA(0.6)	0.67905329	1.26159259	1.85267046	2.41071699	0.47155975
CR_LDUAL-DUM_H9	CR	LDUAL	CDM	9	SA(0.6)	0.83154404	1.39327407	1.96548156	2.50421227	0.45073915
CR_LFINF-CDH-15_H1	CR	LFINF	CDH	1	PGA	1.34680829	3.2217378	5.03544928	6.71618299	0.49375214
CR_LFINF-CDH-15_H2	CR	LFINF	CDH	2	SA(0.6)	0.59210308	1.43796316	2.32591833	3.18781789	0.61370123
CR_LFINF-CDH-15_H3	CR	LFINF	CDH	3	SA(0.6)	0.65821089	1.42966586	2.17471859	2.86242559	0.46474441
CR_LFINF-CDH-15_H4	CR	LFINF	CDH	4	SA(1.0)	0.38706179	0.97523293	1.60166383	2.21519658	0.49015574
CR_LFINF-CDH-15_H5	CR	LFINF	CDH	5	SA(1.0)	0.47055095	1.14292469	1.85407309	2.54737147	0.46159952
CR_LFINF-CDH-15_H6	CR	LFINF	CDH	6	SA(1.0)	0.53837917	1.25422198	1.99659422	2.71151522	0.42319935
CR_LFINF-CDL-15_H1	CR	LFINF	CDL	1	SA(0.6)	0.51947768	0.70086924	0.88800255	1.06189673	0.56454906
CR_LFINF-CDL-15_H2	CR	LFINF	CDL	2	SA(0.6)	0.39660848	0.54141475	0.68721576	0.82097464	0.41379736

Appendix III: Vulnerability data from ESRM database

CR_LFINF-CDL-15_H3	CR	LFINF	CDL	3	SA(1.0)	0.16418236	0.23383503	0.30613511	0.3740707	0.40988656
CR_LFINF-CDL-15_H4	CR	LFINF	CDL	4	SA(1.0)	0.16924512	0.22939689	0.29268963	0.35224907	0.40993695
CR_LFINF-CDL-15_H5	CR	LFINF	CDL	5	SA(1.0)	0.17517853	0.23103701	0.28935684	0.34373271	0.39861186
CR_LFINF-CDL-15_H6	CR	LFINF	CDL	6	SA(1.0)	0.18878409	0.2415533	0.29744571	0.34965922	0.44548406
CR_LFINF-CDM-15_H1	CR	LFINF	CDM	1	SA(0.3)	1.12506165	1.69229073	2.24942198	2.7583724	0.63222458
CR_LFINF-CDM-15_H2	CR	LFINF	CDM	2	SA(0.6)	0.42014199	0.58125038	0.74720084	0.90181375	0.42069872
CR_LFINF-CDM-15_H3	CR	LFINF	CDM	3	SA(0.6)	0.4592222	0.66397079	0.87429104	1.07098069	0.42489403
CR_LFINF-CDM-15_H4	CR	LFINF	CDM	4	SA(1.0)	0.26134858	0.3906079	0.5273662	0.65808699	0.41967817
CR_LFINF-CDM-15_H5	CR	LFINF	CDM	5	SA(1.0)	0.28745211	0.41657822	0.55234042	0.6811913	0.3773541
CR_LFINF-CDM-15_H6	CR	LFINF	CDM	6	SA(1.0)	0.32316605	0.45132957	0.58632739	0.71401021	0.36431376
CR_LFINF-CDN-0_H1	CR	LFINF	CDN	1	SA(0.6)	0.56961764	0.70494447	0.84660747	0.97697846	0.50901217
CR_LFINF-CDN-0_H2	CR	LFINF	CDN	2	SA(0.6)	0.41229744	0.54851563	0.68682818	0.81386192	0.43144377
CR_LFINF-CDN-0_H3	CR	LFINF	CDN	3	SA(1.0)	0.19492519	0.25620484	0.32053671	0.38066345	0.42398393
CR_LFINF-CDN-0_H4	CR	LFINF	CDN	4	SA(1.0)	0.22353833	0.28546178	0.35089799	0.41191173	0.50591477
CR_LFINF-CDN-0_H5	CR	LFINF	CDN	5	SA(1.0)	0.2237366	0.28814816	0.3558376	0.41888316	0.55895496
CR_LFINF-CDN-0_H6	CR	LFINF	CDN	6	SA(1.0)	0.25635352	0.33846864	0.42487937	0.50582752	0.5910687
CR_LFM-CDH-15_H1	CR	LFM	CDH	1	PGA	1.54312704	2.42031155	3.27876511	4.06396596	0.46912155
CR_LFM-CDH-15_H2	CR	LFM	CDH	2	SA(0.6)	0.96122561	1.57334649	2.18271148	2.74758167	0.44894368
CR_LFM-CDH-15_H3	CR	LFM	CDH	3	SA(1.0)	0.51216603	0.96431421	1.4422605	1.90522941	0.46701534
CR_LFM-CDH-15_H4	CR	LFM	CDH	4	SA(1.0)	0.6374993	1.14023608	1.65949453	2.15424882	0.4266883
CR_LFM-CDH-15_H5	CR	LFM	CDH	5	SA(1.0)	0.74047987	1.29195215	1.85867411	2.39632109	0.4376164
CR_LFM-CDH-15_H6	CR	LFM	CDH	6	SA(1.0)	0.85496127	1.49050382	2.15264998	2.78618259	0.46159551
CR_LFM-CDL-15_H1	CR	LFM	CDL	1	SA(0.6)	0.7216539	1.0415935	1.36573152	1.66622723	0.45219929
CR_LFM-CDL-15_H2	CR	LFM	CDL	2	SA(1.0)	0.20147605	0.29351406	0.38781546	0.47593249	0.43678142
CR_LFM-CDL-15_H3	CR	LFM	CDL	3	SA(1.0)	0.17549806	0.26583921	0.35846815	0.44539547	0.40730508
CR_LFM-CDL-15_H4	CR	LFM	CDL	4	SA(1.0)	0.19908275	0.26260851	0.32835651	0.38934127	0.39405251
CR_LFM-CDL-15_H5	CR	LFM	CDL	5	SA(1.0)	0.18532389	0.25250276	0.32278427	0.38874514	0.39940712
CR_LFM-CDL-15_H6	CR	LFM	CDL	6	SA(1.0)	0.23459499	0.29702483	0.36248794	0.42315305	0.45044708
CR_LFM-CDM-15_H1	CR	LFM	CDM	1	SA(0.6)	0.69996806	1.05567522	1.42381182	1.77114934	0.5156315
CR_LFM-CDM-15_H2	CR	LFM	CDM	2	SA(0.6)	0.54425892	0.79175815	1.04728443	1.28716421	0.43634645
CR_LFM-CDM-15_H3	CR	LFM	CDM	3	SA(1.0)	0.2608183	0.429001	0.60538523	0.77430845	0.4106654
CR_LFM-CDM-15_H4	CR	LFM	CDM	4	SA(1.0)	0.35207992	0.56202183	0.78091641	0.98935644	0.38655771
CR_LFM-CDM-15_H5	CR	LFM	CDM	5	SA(1.0)	0.40231198	0.60677642	0.8202106	1.02268449	0.38147101
CR_LFM-CDM-15_H6	CR	LFM	CDM	6	SA(1.0)	0.41552466	0.570682	0.73336949	0.88644813	0.38829324
CR_LFM-CDN-0_H1	CR	LFM	CDN	1	SA(0.6)	0.6754983	0.9634021	1.25629555	1.52817935	0.43886633
CR_LFM-CDN-0_H2	CR	LFM	CDN	2	SA(1.0)	0.24392109	0.34517444	0.44928191	0.54645987	0.40397988
CR_LFM-CDN-0_H3	CR	LFM	CDN	3	SA(1.0)	0.2486635	0.35980902	0.47455757	0.58221571	0.5220032
CR_LFM-CDN-0_H4	CR	LFM	CDN	4	SA(1.0)	0.30632114	0.43215776	0.56381607	0.68799042	0.58029242
CR_LFM-CDN-0_H5	CR	LFM	CDN	5	SA(1.0)	0.34334403	0.48329103	0.6286815	0.76516922	0.64962727
CR_LFM-CDN-0_H6	CR	LFM	CDN	6	SA(1.0)	0.4208928	0.60191106	0.79191189	0.9717736	0.69162792
CR_LWAL-DUH_H1	CR	LWAL	CDH	1	PGA	1.51589007	2.93001611	3.96875666	4.80197282	0.40872984
CR_LWAL-DUH_H10	CR	LWAL	CDH	10	SA(0.6)	1.52546371	2.08871741	2.68424701	3.24719416	0.41267679
CR_LWAL-DUH_H11	CR	LWAL	CDH	11	SA(0.6)	1.81416383	2.29660994	2.81078011	3.29146084	0.37808192
CR_LWAL-DUH_H12	CR	LWAL	CDH	12	SA(0.6)	2.11313991	2.49328606	2.90406277	3.28138299	0.36714041
CR_LWAL-DUH_H2	CR	LWAL	CDH	2	PGA	0.73792074	1.63936452	2.27676261	2.78485321	0.41869019
CR_LWAL-DUH_H3	CR	LWAL	CDH	3	PGA	0.70313422	1.46833411	2.08616698	2.60571916	0.42774296
CR_LWAL-DUH_H4	CR	LWAL	CDH	4	PGA	0.69268043	1.4064284	2.03518676	2.58613052	0.46693886
CR_LWAL-DUH_H5	CR	LWAL	CDH	5	SA(0.3)	1.30199286	2.80918754	4.30622955	5.70975983	0.5286346
CR_LWAL-DUH_H6	CR	LWAL	CDH	6	SA(0.3)	1.5002521	2.94234365	4.39572263	5.76533727	0.56881982
CR_LWAL-DUH_H7	CR	LWAL	CDH	7	SA(0.6)	0.85264469	1.66068722	2.54713005	3.42706722	0.54400889

Appendix III: Vulnerability data from ESRM database

CR_LWAL-DUH_H8	CR	LWAL	CDH	8	SA(0.6)	1.05701543	1.78873839	2.57289195	3.33553	0.48244689
CR_LWAL-DUH_H9	CR	LWAL	CDH	9	SA(0.6)	1.28257456	1.94578622	2.6524407	3.33192384	0.44080314
CR_LWAL-DUL_H1	CR	LWAL	CDL	1	PGA	0.60532232	1.24141974	1.59671773	1.85569957	0.41626644
CR_LWAL-DUL_H10	CR	LWAL	CDL	10	SA(0.6)	0.80174152	1.18445936	1.57355036	1.93590699	0.42045548
CR_LWAL-DUL_H11	CR	LWAL	CDL	11	SA(0.6)	0.96493883	1.32112931	1.68585	2.0239751	0.42492053
CR_LWAL-DUL_H12	CR	LWAL	CDL	12	SA(1.0)	0.5919523	0.78930102	1.00112218	1.20225071	0.42528562
CR_LWAL-DUL_H2	CR	LWAL	CDL	2	PGA	0.32699448	0.82003337	1.14262917	1.3942164	0.49276997
CR_LWAL-DUL_H3	CR	LWAL	CDL	3	PGA	0.36874918	0.82400713	1.17211216	1.45890372	0.56075111
CR_LWAL-DUL_H4	CR	LWAL	CDL	4	SA(0.3)	0.56603793	1.4943648	2.3521528	3.13035425	0.60519568
CR_LWAL-DUL_H5	CR	LWAL	CDL	5	SA(0.6)	0.28534119	0.73537505	1.18379856	1.60688114	0.5487291
CR_LWAL-DUL_H6	CR	LWAL	CDL	6	SA(0.6)	0.34418459	0.79168108	1.24522596	1.67613146	0.49863905
CR_LWAL-DUL_H7	CR	LWAL	CDL	7	SA(0.6)	0.42693697	0.85889792	1.29546893	1.70794834	0.45561985
CR_LWAL-DUL_H8	CR	LWAL	CDL	8	SA(0.6)	0.52895933	0.94561768	1.36661629	1.76239138	0.43194011
CR_LWAL-DUL_H9	CR	LWAL	CDL	9	SA(0.6)	0.65591142	1.05511469	1.45824276	1.83474312	0.42402327
CR_LWAL-DUM_H1	CR	LWAL	CDM	1	PGA	1.00783439	1.88932907	2.44777651	2.86921118	0.39057898
CR_LWAL-DUM_H10	CR	LWAL	CDM	10	SA(0.6)	1.14303157	1.66645064	2.20974889	2.72159037	0.39480679
CR_LWAL-DUM_H11	CR	LWAL	CDM	11	SA(0.6)	1.37132882	1.8481413	2.34840416	2.81791337	0.37706017
CR_LWAL-DUM_H12	CR	LWAL	CDM	12	SA(0.6)	1.60014089	1.99759172	2.41711505	2.80586465	0.37324818
CR_LWAL-DUM_H2	CR	LWAL	CDM	2	PGA	0.49835517	1.20018201	1.67146547	2.04157917	0.44161467
CR_LWAL-DUM_H3	CR	LWAL	CDM	3	PGA	0.51617301	1.1182883	1.58050241	1.96123416	0.473596
CR_LWAL-DUM_H4	CR	LWAL	CDM	4	PGA	0.51281879	1.11710863	1.64026137	2.09624343	0.56571238
CR_LWAL-DUM_H5	CR	LWAL	CDM	5	SA(0.3)	0.95875926	2.23256453	3.47168695	4.6225543	0.58813104
CR_LWAL-DUM_H6	CR	LWAL	CDM	6	SA(0.6)	0.49864979	1.19143085	1.94304598	2.68681619	0.56835593
CR_LWAL-DUM_H7	CR	LWAL	CDM	7	SA(0.6)	0.63197634	1.30622415	2.02244678	2.72028867	0.50550482
CR_LWAL-DUM_H8	CR	LWAL	CDM	8	SA(0.6)	0.78817222	1.40778378	2.05364751	2.67250444	0.4460039
CR_LWAL-DUM_H9	CR	LWAL	CDM	9	SA(0.6)	0.94720548	1.5263294	2.12977054	2.70453862	0.41868774
MCF_LWAL-DUH_H1	MR	LWAL	CDH	1	PGA	1.12993112	1.60326967	1.93474742	2.18766885	0.3463514
MCF_LWAL-DUH_H2	MR	LWAL	CDH	2	PGA	0.64681487	1.18097509	1.5856712	1.91323955	0.42958768
MCF_LWAL-DUH_H3	MR	LWAL	CDH	3	PGA	0.50873464	1.0244568	1.45096097	1.81294165	0.53075262
MCF_LWAL-DUH_H4	MR	LWAL	CDH	4	SA(0.6)	0.37266178	0.94513919	1.55137564	2.14319361	0.61455228
MCF_LWAL-DUH_H5	MR	LWAL	CDH	5	SA(0.6)	0.44279702	1.00403928	1.59211712	2.16158261	0.56434703
MCF_LWAL-DUH_H6	MR	LWAL	CDH	6	SA(0.6)	0.53852988	1.08567201	1.65700576	2.20750621	0.51207545
MCF_LWAL-DUL_H1	MR	LWAL	CDL	1	PGA	0.53283533	0.84035634	1.0441833	1.19808006	0.40303483
MCF_LWAL-DUL_H2	MR	LWAL	CDL	2	PGA	0.32968126	0.71947531	1.01573524	1.25881697	0.52863465
MCF_LWAL-DUL_H3	MR	LWAL	CDL	3	SA(0.3)	0.47780931	1.20648298	1.86305549	2.45039095	0.61044542
MCF_LWAL-DUL_H4	MR	LWAL	CDL	4	SA(0.6)	0.22052543	0.56626181	0.91211374	1.23910142	0.49637372
MCF_LWAL-DUL_H5	MR	LWAL	CDL	5	SA(0.6)	0.26607241	0.6020566	0.93749968	1.25334208	0.46268186
MCF_LWAL-DUL_H6	MR	LWAL	CDL	6	SA(0.6)	0.33581195	0.67201027	1.01249639	1.33452609	0.4541193
MCF_LWAL-DUM_H1	MR	LWAL	CDM	1	PGA	0.84464498	1.2585326	1.54317521	1.75995631	0.36343265
MCF_LWAL-DUM_H2	MR	LWAL	CDM	2	PGA	0.49801325	0.95020849	1.28629721	1.55694557	0.46969071
MCF_LWAL-DUM_H3	MR	LWAL	CDM	3	PGA	0.40688833	0.85644187	1.23282028	1.55496667	0.59084722
MCF_LWAL-DUM_H4	MR	LWAL	CDM	4	SA(0.6)	0.30499285	0.7849427	1.27563715	1.74524347	0.57933492
MCF_LWAL-DUM_H5	MR	LWAL	CDM	5	SA(0.6)	0.35814797	0.82651165	1.30650451	1.76548688	0.50703524
MCF_LWAL-DUM_H6	MR	LWAL	CDM	6	SA(0.6)	0.43024212	0.90209941	1.38951359	1.85663382	0.47104394
MR_LWAL-DUH_H1	MR	LWAL	CDH	1	PGA	0.60798948	1.07750383	1.38596517	1.62074245	0.38210621
MR_LWAL-DUH_H2	MR	LWAL	CDH	2	PGA	0.43457291	0.91409013	1.28814803	1.59791243	0.50088584
MR_LWAL-DUH_H3	MR	LWAL	CDH	3	SA(0.3)	0.64116636	1.65784307	2.61166028	3.48325186	0.61021616
MR_LWAL-DUH_H4	MR	LWAL	CDH	4	SA(0.6)	0.29922687	0.83335745	1.37881789	1.90118096	0.56835519
MR_LWAL-DUH_H5	MR	LWAL	CDH	5	SA(0.6)	0.36648232	0.90682828	1.46441619	2.00047068	0.51573437
MR_LWAL-DUL_H1	MR	LWAL	CDL	1	PGA	0.36641651	0.71626659	0.95370025	1.13821963	0.43904998

Appendix III: Vulnerability data from ESRM database

MR_LWAL-DUL_H2	MR	LWAL	CDL	2	PGA	0.28934212	0.64807905	0.93485188	1.17584539	0.5660498
MR_LWAL-DUL_H3	MR	LWAL	CDL	3	SA(0.6)	0.18679117	0.52855114	0.87289315	1.20032323	0.55298596
MR_LWAL-DUL_H4	MR	LWAL	CDL	4	SA(0.6)	0.21324242	0.55250524	0.89497894	1.22045931	0.48132587
MR_LWAL-DUL_H5	MR	LWAL	CDL	5	SA(0.6)	0.26500546	0.60356873	0.94556956	1.26979695	0.47135428
MR_LWAL-DUM_H1	MR	LWAL	CDM	1	PGA	0.51672966	0.92017045	1.19598669	1.40929723	0.41165221
MR_LWAL-DUM_H2	MR	LWAL	CDM	2	PGA	0.36610962	0.79156032	1.12701551	1.40661294	0.53048651
MR_LWAL-DUM_H3	MR	LWAL	CDM	3	SA(0.3)	0.54750265	1.45289623	2.29357096	3.05827689	0.60862181
MR_LWAL-DUM_H4	MR	LWAL	CDM	4	SA(0.6)	0.25645668	0.72007494	1.19647604	1.6543218	0.52648562
MR_LWAL-DUM_H5	MR	LWAL	CDM	5	SA(0.6)	0.31448021	0.78776497	1.27669479	1.74714391	0.47891797
MUR-CB99_LWAL-DNO_H1	MUR	LWAL	CDM	1	PGA	0.31725631	0.6149052	0.82521708	0.99120226	0.4539907
MUR-CB99_LWAL-DNO_H2	MUR	LWAL	CDM	2	SA(0.3)	0.40595732	0.99840526	1.52158368	1.98448849	0.60110274
MUR-CB99_LWAL-DNO_H3	MUR	LWAL	CDM	3	SA(0.6)	0.17364029	0.45513402	0.73472878	0.99816129	0.51529652
MUR-CB99_LWAL-DNO_H4	MUR	LWAL	CDM	4	SA(0.6)	0.20209795	0.49060752	0.7799992	1.05368211	0.46297946
MUR-CB99_LWAL-DNO_H5	MUR	LWAL	CDM	5	SA(0.6)	0.25262306	0.54809096	0.84797049	1.13267093	0.4576564
S_LFINF-DUH_H1	S	LFINF	CDH	1	PGA	0.86473057	1.86438383	2.64947678	3.30257138	0.52984193
S_LFINF-DUH_H10	S	LFINF	CDH	10	SA(0.6)	0.65469723	1.56125528	2.40393626	3.16835057	0.47639344
S_LFINF-DUH_H11	S	LFINF	CDH	11	SA(0.6)	0.68837396	1.63564057	2.51590292	3.31418746	0.49279021
S_LFINF-DUH_H12	S	LFINF	CDH	12	SA(0.6)	0.73393146	1.69869789	2.57981597	3.37096298	0.50425604
S_LFINF-DUH_H2	S	LFINF	CDH	2	PGA	0.58039106	1.27573101	1.82902219	2.29253285	0.55014901
S_LFINF-DUH_H3	S	LFINF	CDH	3	SA(0.3)	0.93258898	2.45723126	3.84429529	5.09282289	0.57004698
S_LFINF-DUH_H4	S	LFINF	CDH	4	SA(0.3)	0.97340358	2.43293797	3.75533814	4.94115786	0.60891395
S_LFINF-DUH_H5	S	LFINF	CDH	5	SA(0.6)	0.45155584	1.27217357	2.09640018	2.87876001	0.62419505
S_LFINF-DUH_H6	S	LFINF	CDH	6	SA(0.6)	0.52351728	1.34715237	2.13820614	2.86989867	0.56251537
S_LFINF-DUH_H7	S	LFINF	CDH	7	SA(0.6)	0.5752581	1.40519778	2.18371615	2.89385656	0.49865779
S_LFINF-DUH_H8	S	LFINF	CDH	8	SA(0.6)	0.6110684	1.48891447	2.31640297	3.07309241	0.47789675
S_LFINF-DUH_H9	S	LFINF	CDH	9	SA(0.6)	0.62701701	1.49710519	2.30439441	3.03602987	0.4557367
S_LFINF-DUM_H1	S	LFINF	CDM	1	PGA	0.63032578	1.11661007	1.48612211	1.78489408	0.56743646
S_LFINF-DUM_H10	S	LFINF	CDM	10	SA(0.6)	0.55678056	1.13420513	1.6795057	2.17540604	0.44374086
S_LFINF-DUM_H11	S	LFINF	CDM	11	SA(0.6)	0.5838578	1.20462553	1.79639794	2.33765027	0.46205409
S_LFINF-DUM_H12	S	LFINF	CDM	12	SA(0.6)	0.62808045	1.30422557	1.95185925	2.54592043	0.48120141
S_LFINF-DUM_H2	S	LFINF	CDM	2	PGA	0.4641428	0.88530571	1.22263503	1.50362701	0.5508705
S_LFINF-DUM_H3	S	LFINF	CDM	3	SA(0.3)	0.74541712	1.67529088	2.53866229	3.31972508	0.59066481
S_LFINF-DUM_H4	S	LFINF	CDM	4	SA(0.3)	0.78791731	1.67212009	2.47961715	3.20209341	0.57324836
S_LFINF-DUM_H5	S	LFINF	CDM	5	SA(0.6)	0.36750045	0.85029165	1.32961157	1.77977399	0.58486801
S_LFINF-DUM_H6	S	LFINF	CDM	6	SA(0.6)	0.41918443	0.9473011	1.47065899	1.96135262	0.55107391
S_LFINF-DUM_H7	S	LFINF	CDM	7	SA(0.6)	0.466025	1.01666534	1.55447849	2.05409052	0.49574537
S_LFINF-DUM_H8	S	LFINF	CDM	8	SA(0.6)	0.50012678	1.03241372	1.53890046	2.00168383	0.48051609
S_LFINF-DUM_H9	S	LFINF	CDM	9	SA(0.6)	0.52822767	1.06474886	1.56748322	2.02250849	0.4414232
S_LFM-DUH_H1	S	LFM	CDH	1	PGA	0.53275245	1.56652101	2.59721661	3.57238502	0.50890629
S_LFM-DUH_H10	S	LFM	CDH	10	SA(1.0)	0.46143773	1.24306833	2.06765163	2.87147694	0.48526466
S_LFM-DUH_H11	S	LFM	CDH	11	SA(1.0)	0.47900049	1.32234165	2.22793736	3.11997163	0.51514403
S_LFM-DUH_H12	S	LFM	CDH	12	SA(1.0)	0.49587913	1.3866042	2.35166961	3.30730077	0.56329612
S_LFM-DUH_H2	S	LFM	CDH	2	SA(0.3)	0.8996301	2.86335876	4.92688005	6.93728047	0.54697329
S_LFM-DUH_H3	S	LFM	CDH	3	SA(0.6)	0.49389025	1.4917837	2.5362231	3.55111383	0.42653451
S_LFM-DUH_H4	S	LFM	CDH	4	SA(0.6)	0.54854612	1.52698894	2.52266109	3.47431966	0.36699845
S_LFM-DUH_H5	S	LFM	CDH	5	SA(0.6)	0.61112288	1.61788293	2.62869974	3.58689895	0.4291762
S_LFM-DUH_H6	S	LFM	CDH	6	SA(1.0)	0.33694841	0.94283119	1.58472401	2.21222371	0.37565746
S_LFM-DUH_H7	S	LFM	CDH	7	SA(1.0)	0.37490131	1.0055325	1.66128402	2.29527562	0.3555854
S_LFM-DUH_H8	S	LFM	CDH	8	SA(1.0)	0.40515153	1.0900294	1.80839381	2.50636701	0.37369224
S_LFM-DUH_H9	S	LFM	CDH	9	SA(1.0)	0.43027693	1.14693791	1.89636201	2.62316876	0.44489331

Appendix III: Vulnerability data from ESRM database

S_LFM-DUM_H1	S	LFM	CDM	1	PGA	0.43654283	1.08092626	1.70653801	2.28791653	0.51387982
S_LFM-DUM_H10	S	LFM	CDM	10	SA(1.0)	0.38157171	0.88116904	1.39913886	1.89778364	0.49096378
S_LFM-DUM_H11	S	LFM	CDM	11	SA(1.0)	0.39792641	0.92247124	1.46818549	1.99464566	0.5199251
S_LFM-DUM_H12	S	LFM	CDM	12	SA(1.0)	0.41951952	0.98229977	1.57206864	2.1435741	0.56903881
S_LFM-DUM_H2	S	LFM	CDM	2	SA(0.3)	0.73460683	1.97750696	3.25612528	4.4849574	0.54841515
S_LFM-DUM_H3	S	LFM	CDM	3	SA(0.6)	0.41325325	1.09221024	1.80348613	2.49392502	0.4232072
S_LFM-DUM_H4	S	LFM	CDM	4	SA(0.6)	0.45552624	1.0954917	1.73994461	2.35062295	0.37700051
S_LFM-DUM_H5	S	LFM	CDM	5	SA(1.0)	0.23732787	0.60513274	0.9995332	1.38740453	0.43321107
S_LFM-DUM_H6	S	LFM	CDM	6	SA(1.0)	0.27741026	0.66151657	1.06028343	1.44472362	0.37739087
S_LFM-DUM_H7	S	LFM	CDM	7	SA(1.0)	0.31032611	0.72034825	1.14225552	1.54669132	0.35803343
S_LFM-DUM_H8	S	LFM	CDM	8	SA(1.0)	0.32698925	0.74457865	1.171059	1.57793023	0.39364981
S_LFM-DUM_H9	S	LFM	CDM	9	SA(1.0)	0.35239478	0.80619071	1.27280598	1.71976911	0.45028314
S_LWAL-DUH_H1	S	LWAL	CDH	1	PGA	0.60005347	1.9742102	3.25714523	4.43349944	0.51900007
S_LWAL-DUH_H10	S	LWAL	CDH	10	SA(0.6)	0.46784937	1.52869063	2.5966536	3.61383165	0.39186405
S_LWAL-DUH_H11	S	LWAL	CDH	11	SA(0.6)	0.50032712	1.58169101	2.65171412	3.66126904	0.42212959
S_LWAL-DUH_H12	S	LWAL	CDH	12	SA(0.6)	0.51175059	1.62400045	2.7227269	3.75851665	0.43987371
S_LWAL-DUH_H2	S	LWAL	CDH	2	PGA	0.40574492	1.39360563	2.31111732	3.15102859	0.50923022
S_LWAL-DUH_H3	S	LWAL	CDH	3	SA(0.3)	0.66624694	2.50888673	4.39930998	6.22029242	0.48681174
S_LWAL-DUH_H4	S	LWAL	CDH	4	SA(0.3)	0.67513832	2.47344779	4.3121358	6.07976315	0.51747497
S_LWAL-DUH_H5	S	LWAL	CDH	5	SA(0.6)	0.3191613	1.27147822	2.32904991	3.39170153	0.5509468
S_LWAL-DUH_H6	S	LWAL	CDH	6	SA(0.6)	0.35584345	1.32739313	2.36988008	3.39802189	0.49324186
S_LWAL-DUH_H7	S	LWAL	CDH	7	SA(0.6)	0.40251291	1.39691633	2.43130329	3.43427554	0.43769692
S_LWAL-DUH_H8	S	LWAL	CDH	8	SA(0.6)	0.4221743	1.41677313	2.4305939	3.40283826	0.38166545
S_LWAL-DUH_H9	S	LWAL	CDH	9	SA(0.6)	0.44413913	1.47204965	2.51883592	3.52205748	0.36502912
S_LWAL-DUM_H1	S	LWAL	CDM	1	PGA	0.47416023	1.30121259	2.04606883	2.71402357	0.54693112
S_LWAL-DUM_H10	S	LWAL	CDM	10	SA(0.6)	0.37738638	0.98196585	1.5864512	2.15796773	0.40542368
S_LWAL-DUM_H11	S	LWAL	CDM	11	SA(0.6)	0.40170257	1.02711895	1.64438015	2.22363794	0.43810212
S_LWAL-DUM_H12	S	LWAL	CDM	12	SA(1.0)	0.18913433	0.54303305	0.92435602	1.30082239	0.44184553
S_LWAL-DUM_H2	S	LWAL	CDM	2	PGA	0.31980875	0.86122993	1.34674581	1.78095893	0.52880336
S_LWAL-DUM_H3	S	LWAL	CDM	3	SA(0.3)	0.53214122	1.51889879	2.5000534	3.42655247	0.51110651
S_LWAL-DUM_H4	S	LWAL	CDM	4	SA(0.3)	0.53381269	1.47788665	2.41433442	3.29697739	0.56526966
S_LWAL-DUM_H5	S	LWAL	CDM	5	SA(0.6)	0.24702462	0.74805375	1.28443081	1.81223093	0.54032442
S_LWAL-DUM_H6	S	LWAL	CDM	6	SA(0.6)	0.28393338	0.83812577	1.42768671	2.00565712	0.48736924
S_LWAL-DUM_H7	S	LWAL	CDM	7	SA(0.6)	0.31623451	0.8656636	1.43344159	1.98062348	0.41889223
S_LWAL-DUM_H8	S	LWAL	CDM	8	SA(0.6)	0.33752268	0.89660475	1.46348577	2.00381073	0.38816489
S_LWAL-DUM_H9	S	LWAL	CDM	9	SA(0.6)	0.35556189	0.93486474	1.51887783	2.07366279	0.38291225
W_LFM-DUH_H1	W	LFM	CDH	1	PGA	0.88761719	1.31555049	1.7557891	2.16895023	0.45013125
W_LFM-DUH_H2	W	LFM	CDH	2	SA(0.3)	1.68426537	2.70102354	3.7613553	4.77149973	0.33462118
W_LFM-DUH_H3	W	LFM	CDH	3	SA(0.3)	2.1742008	3.56224443	5.09832628	6.62094717	0.54077997
W_LFM-DUH_H4	W	LFM	CDH	4	SA(0.6)	1.45440632	2.28649436	3.23345058	4.1867832	0.51499158
W_LFM-DUH_H5	W	LFM	CDH	5	SA(0.6)	1.74318997	2.39687549	3.11067151	3.79924545	0.40481685
W_LFM-DUH_H6	W	LFM	CDH	6	SA(0.6)	2.08907354	2.59108166	3.13454478	3.6437546	0.32320293
W_LFM-DUL_H1	W	LFM	CDL	1	PGA	0.39376236	0.68498788	0.96659233	1.22414563	0.50438169
W_LFM-DUL_H2	W	LFM	CDL	2	SA(0.3)	0.75799387	1.49519655	2.2397958	2.94257153	0.43824928
W_LFM-DUL_H3	W	LFM	CDL	3	SA(0.6)	0.40601851	0.82359707	1.28263544	1.7393414	0.5639595
W_LFM-DUL_H4	W	LFM	CDL	4	SA(0.6)	0.54330398	0.9650794	1.41870165	1.86192655	0.47463046
W_LFM-DUL_H5	W	LFM	CDL	5	SA(0.6)	0.71517246	1.10907642	1.52426364	1.92147605	0.38923262
W_LFM-DUL_H6	W	LFM	CDL	6	SA(0.6)	0.89335129	1.23737433	1.59884133	1.9398239	0.33137234
W_LFM-DUM_H1	W	LFM	CDM	1	PGA	0.63528675	1.00617341	1.38157512	1.73232666	0.49902364
W_LFM-DUM_H2	W	LFM	CDM	2	SA(0.3)	1.23457826	2.15917649	3.12115789	4.04088755	0.35964403

Appendix III: Vulnerability data from ESRM database

W_LFM-DUM_H3	W	LFM	CDM	3	SA(0.3)	1.52666907	2.65716911	3.87879933	5.07494717	0.54777282
W_LFM-DUM_H4	W	LFM	CDM	4	SA(0.6)	0.97222738	1.65130727	2.41746175	3.18827585	0.49805846
W_LFM-DUM_H5	W	LFM	CDM	5	SA(0.6)	1.20561026	1.76994312	2.37705979	2.9625237	0.40052795
W_LFM-DUM_H6	W	LFM	CDM	6	SA(0.6)	1.51330662	2.01300379	2.54884888	3.05713667	0.32359974

Appendix IV:

Table 5. Calculated weights for main criteria (A) and sub-criteria (B).

A		B		Consistency ratio (CR)
Indicators for search and rescue operation:	Weight, CR = 0.097		Weight	CR = 0.085
The destruction level of buildings	0.25	Completely collapsed: 81%–100%	0.34	
		Very high destruction: 61%–80%	0.29	
		High destruction: 41%–60%	0.22	
		Moderate destruction: 21%–40%	0.07	
		Slight destruction: 3%–20%	0.05	
		Without destruction: 0%–2%	0.03	
The risk level in the damaged areas	0.15	Not acceptable > 70%	0.19	CR = 0.045
		Acceptable: 0%–70%	0.81	
Population density	0.13	Very high: 81%–100%	0.50	CR = 0.037
		High: 61%–80%	0.25	
		Moderate: 41%–60%	0.12	
		Low: 21%–40%	0.07	
		Very low: 0%–20%	0.04	
The number of injured people (density map)	0.14	Very high: 81%–100%	0.49	CR = 0.053
		High: 61%–80%	0.27	
		Moderate: 41%–60%	0.12	
		Low: 21%–40%	0.07	
		Very low: 0%–20%	0.05	
The occupancy level of buildings (density map)	0.07	Very high: 81%–100%	0.48	CR = 0.094
		High: 61%–80%	0.27	
		Moderate: 41%–60%	0.13	
		Low: 21%–40%	0.07	
		Very low: 0%–20%	0.05	

(continued)

Appendix IV:

Table 5. Calculated weights for main criteria (A) and sub-criteria (B).

A		B		Consistency ratio (CR)
Indicators for search and rescue operation:	Weight, CR = 0.097		Weight	CR = 0.085
The destruction level of buildings	0.25	Completely collapsed: 81%–100%	0.34	
		Very high destruction: 61%–80%	0.29	
		High destruction: 41%–60%	0.22	
		Moderate destruction: 21%–40%	0.07	
		Slight destruction: 3%–20%	0.05	
		Without destruction: 0%–2%	0.03	
The risk level in the damaged areas	0.15	Not acceptable > 70%	0.19	CR = 0.045
		Acceptable: 0%–70%	0.81	
Population density	0.13	Very high: 81%–100%	0.50	CR = 0.037
		High: 61%–80%	0.25	
		Moderate: 41%–60%	0.12	
		Low: 21%–40%	0.07	
		Very low: 0%–20%	0.04	
The number of injured people (density map)	0.14	Very high: 81%–100%	0.49	CR = 0.053
		High: 61%–80%	0.27	
		Moderate: 41%–60%	0.12	
		Low: 21%–40%	0.07	
		Very low: 0%–20%	0.05	
The occupancy level of buildings (density map)	0.07	Very high: 81%–100%	0.48	CR = 0.094
		High: 61%–80%	0.27	
		Moderate: 41%–60%	0.13	
		Low: 21%–40%	0.07	
		Very low: 0%–20%	0.05	

(continued)

Appendix IV:

Table 5. (*Continued*).

A		B		Consistency ratio (CR)
The severity level of injuries (density map)	0.16	Very high: 81%–100%	0.51	CR = 0.080
		High: 61%–80%	0.29	
		Moderate: 41 %–60%	0.10	
		Low: 21%–40%	0.06	
		Very low: 0%–20%	0.04	
The number of trapped people (density map)	0.15	Very high: 81%–100%	0.49	CR = 0.039
		High: 61%–80%	0.25	
		Moderate: 41%–60%	0.14	
		Low: 21%–40%	0.07	
		Very low: 0%–20%	0.05	

Appendix IV: Action overview damage state 1

Rescue Action- Rescue Team Correlation

Rescue Team type

Building Class	material_1_code	material_2_code	lat_load_code	height_code	Damage State	Structural Rescue												Trench Rescue												Technical Rope Rescue											Confined Space Rescue											Heavy Rigging Rescue										
						A	B	C	D	E	F	G	H	J	K	L	M	A	B	C	D	E	F	G	H	J	K	L	M	A	B	C	D	E	F	G	H	J	K	L	A	B	C	D	E	F	G	H	J	K	L	A	B	C	D	E	F	G	H	J	K	L
concrete frame, infill panels	CR	CR	LFINF	HBET:1-3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Concrete Frame, structural infill	CR	CR	LDUAL	HBET:1-3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Concrete Walls	CR	CR	LWAL	HBET:1-3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Unreinforced Masonry, Rubble Stone	MUR	STRUB	LWAL	HBET:1-3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Unreinforced Masonry, Clay Brick	MUR	CL	LWAL	HBET:1-3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Unreinforced Masonry, Hollow Concrete Blocks	MUR	CBH	LWAL	HBET:1-3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Unreinforced Masonry, Adobe	MUR	ADO	LWAL	HBET:1-3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Timber	W	W	LWAL	HBET:1-3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Steel	S	S	LFM	HBET:1-3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Construction site	CS	CS	LFM	HBET:1-3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix IV: Action overview damage state 2

Rescue Action- Rescue Team Correlation

						Rescue Team type																							
						Structural Rescue												Trench Rescue											
Building Class	material_1_code	material_2_code	lat_load_code	height_code	Damage State	A	B	C	D	E	F	G	H	J	K	L	M	A	B	C	D	E	F	G	H	J	K	L	M
concrete frame, infill panels	CR	CR	LFINF	HBET:1-3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	2	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Concrete Frame, structural infill	CR	CR	LDUAL	HBET:1-3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	2	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Concrete Walls	CR	CR	LWAL	HBET:1-3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	2	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Unreinforced Masonry, Rubble Stone	MUR	STRUB	LWAL	HBET:1-3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	2	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	2	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Unreinforced Masonry, Clay Brick	MUR	CL	LWAL	HBET:1-3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	2	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	2	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Unreinforced Masonry, Hollow Concrete Blocks	MUR	CBH	LWAL	HBET:1-3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	2	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	2	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Unreinforced Masonry, Adobe	MUR	ADO	LWAL	HBET:1-3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	2	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	2	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Timber	W	W	LWAL	HBET:1-3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Steel	S	S	LFM	HBET:1-3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Construction site	CS	CS	LFM	HBET:1-3	2	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0
				HBET:4-6	2	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0
				HBET:7-	2	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0

						Technical Rope Rescue											Confined Space Rescue											Heavy Rigging Rescue										
Building Class	material_1_code	material_2_code	lat_load_code	height_code	Damage State	A	B	C	D	E	F	G	H	J	K	L	A	B	C	D	E	F	G	H	J	K	L	A	B	C	D	E	F	G	H	J	K	L
concrete frame, infill panels	CR	CR	LFINF	HBET:1-3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Concrete Frame, structural infill	CR	CR	LDUAL	HBET:1-3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Concrete Walls	CR	CR	LWAL	HBET:1-3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Unreinforced Masonry, Rubble Stone	MUR	STRUB	LWAL	HBET:1-3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Unreinforced Masonry, Clay Brick	MUR	CL	LWAL	HBET:1-3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Unreinforced Masonry, Hollow Concrete Blocks	MUR	CBH	LWAL	HBET:1-3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Unreinforced Masonry, Adobe	MUR	ADO	LWAL	HBET:1-3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Timber	W	W	LWAL	HBET:1-3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Steel	S	S	LFM	HBET:1-3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Construction site	CS	CS	LFM	HBET:1-3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix IV: Action overview damage state 3

Rescue Action- Rescue Team Correlation

Building Class	material_1_code	material_2_code	lat_load_code	height_code	Damage State	Rescue Team type																							
						Structural Rescue												Trench Rescue											
						A	B	C	D	E	F	G	H	J	K	L	M	A	B	C	D	E	F	G	H	J	K	L	M
concrete frame, infill panels	CR	CR	LFINF	HBET:1-3	3	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	3	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	3	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Concrete Frame, structural infill	CR	CR	LDUAL	HBET:1-3	3	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	3	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	3	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Concrete Walls	CR	CR	LWAL	HBET:1-3	3	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	3	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	3	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Unreinforced Masonry, Rubble Stone	MUR	STRUB	LWAL	HBET:1-3	3	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	3	0	1	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	3	0	0	0	0	0	1	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Unreinforced Masonry, Clay Brick	MUR	CL	LWAL	HBET:1-3	3	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	3	0	1	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	3	0	0	0	0	0	1	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Unreinforced Masonry, Hollow Concrete Blocks	MUR	CBH	LWAL	HBET:1-3	3	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	3	0	1	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	3	0	0	0	0	0	1	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Unreinforced Masonry, Adobe	MUR	ADO	LWAL	HBET:1-3	3	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	3	0	1	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	3	0	0	0	0	0	1	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Timber	W	W	LWAL	HBET:1-3	3	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	3	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	3	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Steel	S	S	LFM	HBET:1-3	3	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	3	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	3	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Construction site	CS	CS	LFM	HBET:1-3	3	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0
				HBET:4-6	3	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0
				HBET:7-	3	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0

Building Class	material_1_code	material_2_code	lat_load_code	height_code	Damage State	Rescue Team type																																
						Technical Rope Rescue											Confined Space Rescue											Heavy Rigging Rescue										
						A	B	C	D	E	F	G	H	J	K	L	A	B	C	D	E	F	G	H	J	K	L	A	B	C	D	E	F	G	H	J	K	L
concrete frame, infill panels	CR	CR	LFINF	HBET:1-3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	3	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	3	1	1	1	1	0	0	0	0	0	0	0	1	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Concrete Frame, structural infill	CR	CR	LDUAL	HBET:1-3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	3	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	3	1	1	1	1	0	0	0	0	0	0	0	1	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Concrete Walls	CR	CR	LWAL	HBET:1-3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	3	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	3	1	1	1	1	0	0	0	0	0	0	0	1	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Unreinforced Masonry, Rubble Stone	MUR	STRUB	LWAL	HBET:1-3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	3	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	3	1	1	1	1	0	0	0	0	0	0	0	1	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Unreinforced Masonry, Clay Brick	MUR	CL	LWAL	HBET:1-3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	3	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	3	1	1	1	1	0	0	0	0	0	0	0	1	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Unreinforced Masonry, Hollow Concrete Blocks	MUR	CBH	LWAL	HBET:1-3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	3	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	3	1	1	1	1	0	0	0	0	0	0	0	1	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Unreinforced Masonry, Adobe	MUR	ADO	LWAL	HBET:1-3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	3	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	3	1	1	1	1	0	0	0	0	0	0	0	1	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Timber	W	W	LWAL	HBET:1-3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	3	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	3	1	1	1	1	0	0	0	0	0	0	0	1	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Steel	S	S	LFM	HBET:1-3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	3	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	3	1	1	1	1	0	0	0	0	0	0	0	1	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Construction site	CS	CS	LFM	HBET:1-3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix IV: Action overview damage state 4

Rescue Action- Rescue Team Correlation

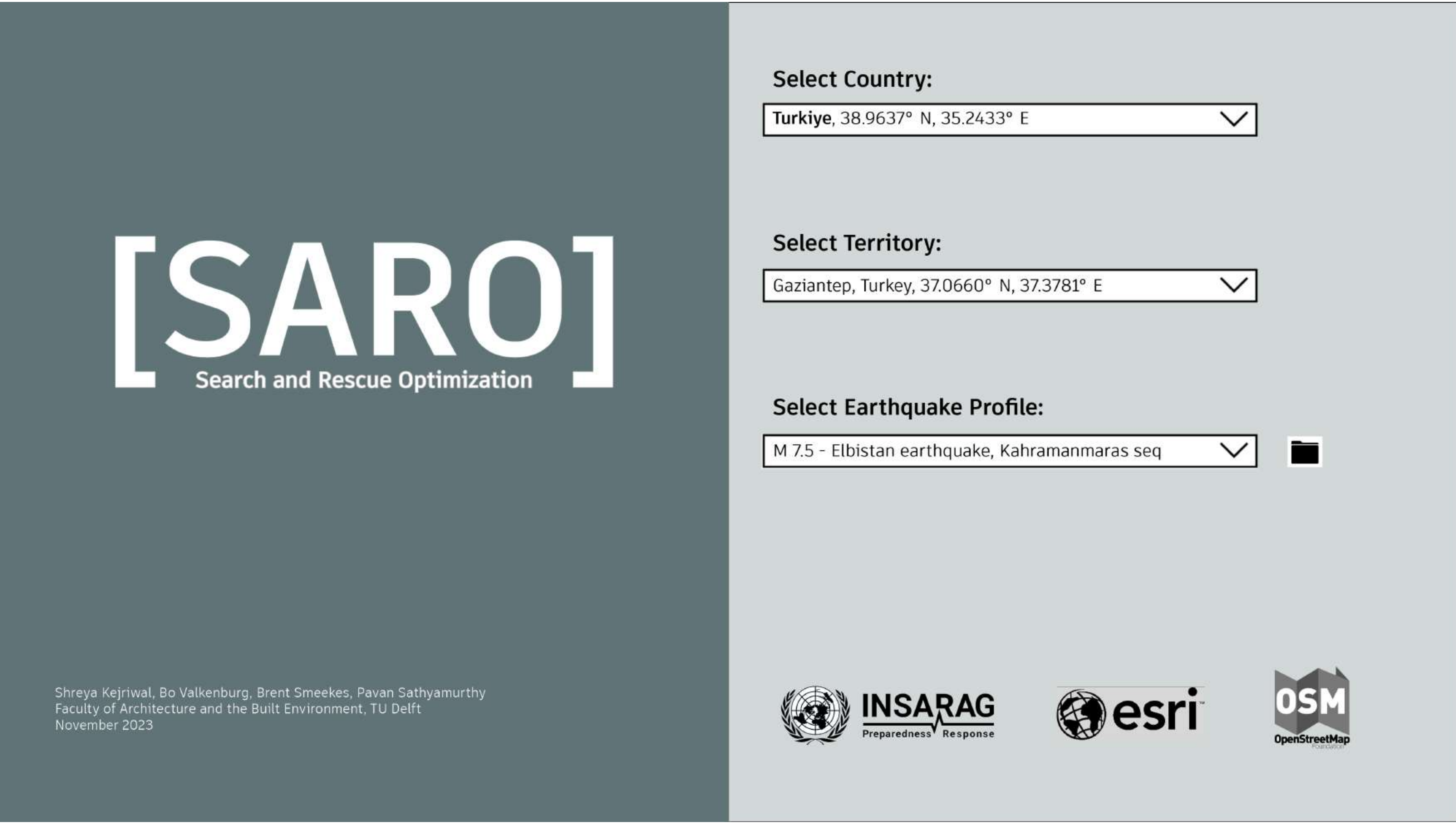
Building Class	material_1_code	material_2_code	lat_load_code	height_code	Damage State	Rescue Team type																																																					
						Structural Rescue												Trench Rescue												Technical Rope Rescue											Confined Space Rescue											Heavy Rigging Rescue										
						A	B	C	D	E	F	G	H	J	K	L	M	A	B	C	D	E	F	G	H	J	K	L	M	A	B	C	D	E	F	G	H	J	K	L	A	B	C	D	E	F	G	H	J	K	L	A	B	C	D	E	F	G	H	J	K	L
concrete frame, infill panels	CR	CR	LFINF	HBET:1-3	4	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0
				HBET:4-6	4	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	1	1	1	1	0	0	0	0	0	0	0
				HBET:7-	4	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	0	1	1	1	0	0	0	0	1	1	1	1	0	0	0
Concrete Frame, structural infill	CR	CR	LDUAL	HBET:1-3	4	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0
				HBET:4-6	4	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	1	1	1	1	0	0	0	0	0	0	0
				HBET:7-	4	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	0	1	1	1	0	0	0	0	1	1	1	1	0	0	0
Concrete Walls	CR	CR	LWAL	HBET:1-3	4	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0
				HBET:4-6	4	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	1	1	1	1	0	0	0	0	0	0	0
				HBET:7-	4	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	0	1	1	1	0	0	0	0	1	1	1	1	0	0	0
Unreinforced Masonry, Rubble Stone	MUR	STRUB	LWAL	HBET:1-3	4	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0
				HBET:4-6	4	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0
				HBET:7-	4	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	0	1	1	1	0	0	0	0	0	0	0	0	1	1	1
Unreinforced Masonry, Clay Brick	MUR	CL	LWAL	HBET:1-3	4	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0
				HBET:4-6	4	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0
				HBET:7-	4	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Unreinforced Masonry, Hollow Concrete Blocks	MUR	CBH	LWAL	HBET:1-3	4	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0
				HBET:4-6	4	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0
				HBET:7-	4	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Unreinforced Masonry, Adobe	MUR	ADO	LWAL	HBET:1-3	4	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0
				HBET:4-6	4	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0
				HBET:7-	4	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Timber	W	W	LWAL	HBET:1-3	4	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0
				HBET:4-6	4	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	1	1	1	1	0	0	0	0	0	0	0
				HBET:7-	4	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	0	1	1	1	0	0	0	0	1	1	1	1	0	0	0
Steel	S	S	LFM	HBET:1-3	4	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0
				HBET:4-6	4	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	1	1	1	1	0	0	0	0	0	0	0
				HBET:7-	4	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	0	1	1	1	0	0	0	0	1	1	1	1	0	0	0
Construction site	CS	CS	LFM	HBET:1-3	4	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	4	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	4	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix IV: Action overview damage state 5

Rescue Action- Rescue Team Correlation

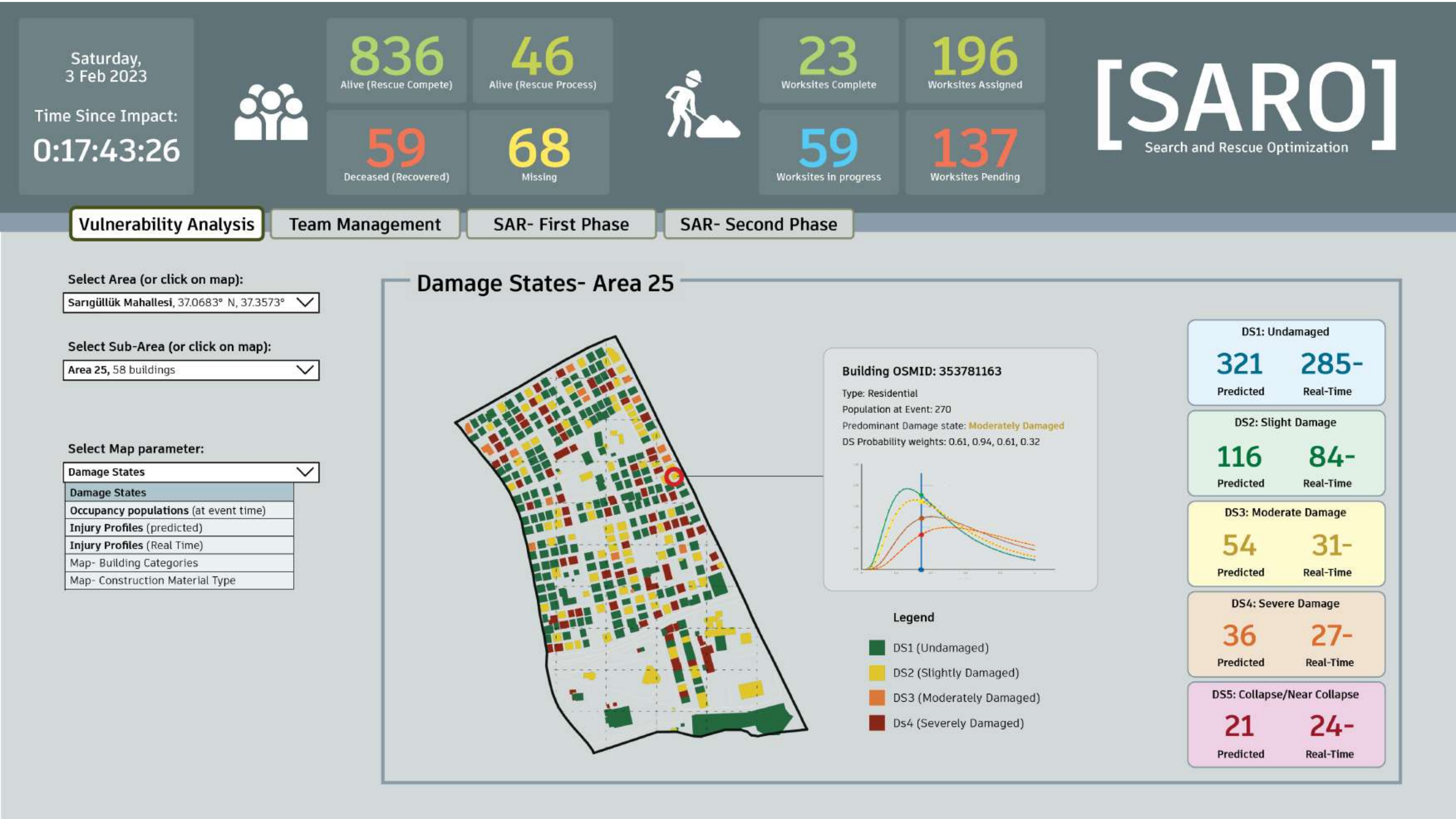
						Rescue Team type: Structural Rescue												Trench Rescue												Technical Rope Rescue											Confined Space Rescue											Heavy Rigging Rescue										
Building Class	material_1_code	material_2_code	lat_load_code	height_code	Damage State	A	B	C	D	E	F	G	H	J	K	L	M	A	B	C	D	E	F	G	H	J	K	L	M	A	B	C	D	E	F	G	H	J	K	L	A	B	C	D	E	F	G	H	J	K	L	A	B	C	D	E	F	G	H	J	K	L
concrete frame, infill panels	CR	CR	LFINF	HBET:1-3	5	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	1	1	1	1	0	0	0	0	0	0	0
				HBET:4-6	5	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	1
				HBET:7-	5	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	0	1	1	1	0	0	0	0	0	0	0	0	1	1	1
Concrete Frame, structural infill	CR	CR	LDUAL	HBET:1-3	5	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	1	1	1	1	0	0	0	0	0	0	0
				HBET:4-6	5	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	1
				HBET:7-	5	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	0	1	1	1	0	0	0	0	0	0	0	0	1	1	1
Concrete Walls	CR	CR	LWAL	HBET:1-3	5	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	1	1	1	1	0	0	0	0	0	0	0
				HBET:4-6	5	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	1
				HBET:7-	5	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	0	1	1	1	0	0	0	0	0	0	0	0	1	1	1
Unreinforced Masonry, Rubble Stone	MUR	STRUB	LWAL	HBET:1-3	5	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0
				HBET:4-6	5	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	1
				HBET:7-	5	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	0	1	1	1	0	0	0	0	0	0	0	0	1	1	1
Unreinforced Masonry, Clay Brick	MUR	CL	LWAL	HBET:1-3	5	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0
				HBET:4-6	5	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	1
				HBET:7-	5	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	0	1	1	1	0	0	0	0	0	0	0	0	1	1	1
Unreinforced Masonry, Hollow Concrete Blocks	MUR	CBH	LWAL	HBET:1-3	5	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0
				HBET:4-6	5	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	1
				HBET:7-	5	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	0	1	1	1	0	0	0	0	0	0	0	0	1	1	1
Unreinforced Masonry, Adobe	MUR	ADO	LWAL	HBET:1-3	5	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0
				HBET:4-6	5	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	1
				HBET:7-	5	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	0	1	1	1	0	0	0	0	0	0	0	0	1	1	1
Timber	W	W	LWAL	HBET:1-3	5	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	1	1	1	1	0	0	0	0	0	0	0
				HBET:4-6	5	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	1
				HBET:7-	5	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	0	1	1	1	0	0	0	0	0	0	0	0	1	1	1
Steel	S	S	LFM	HBET:1-3	5	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	1	1	1	1	0	0	0	0	0	0	0
				HBET:4-6	5	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	1
				HBET:7-	5	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	0	1	1	1	0	0	0	0	0	0	0	0	1	1	1
Construction site	CS	CS	LFM	HBET:1-3	5	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:4-6	5	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				HBET:7-	5	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix V: UI Design

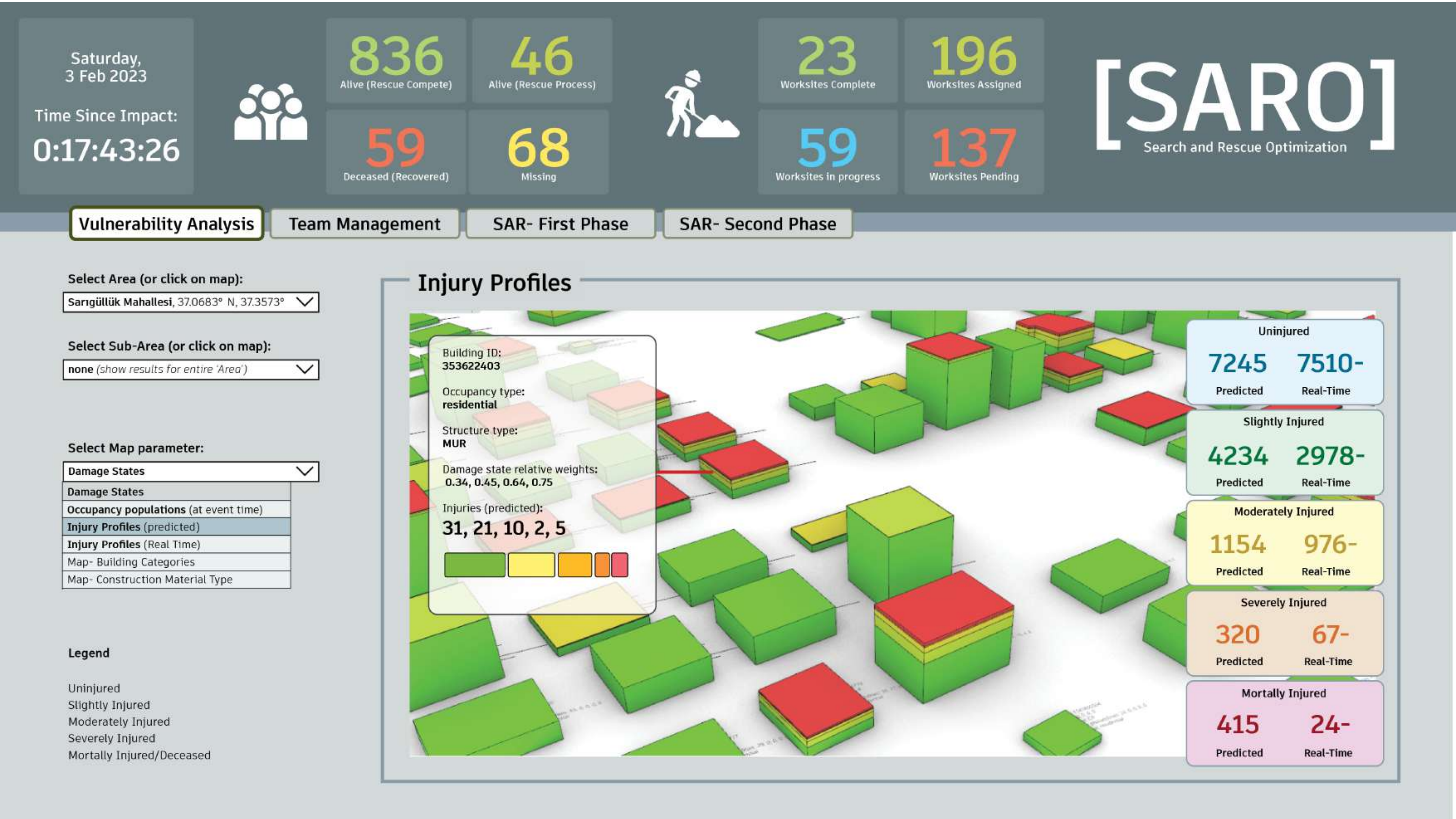


Appendix V: UI Design

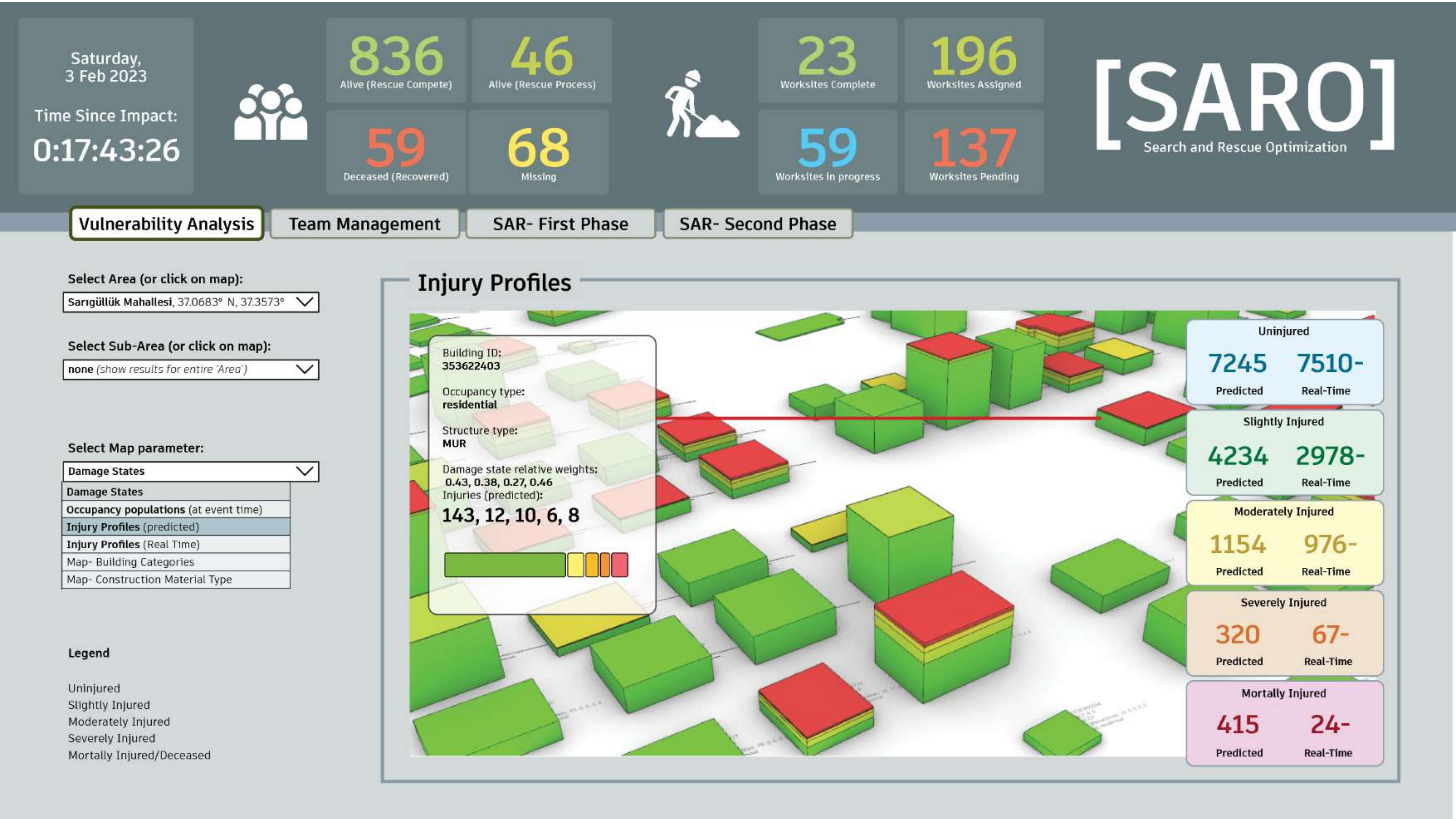
Appendix V: UI Design



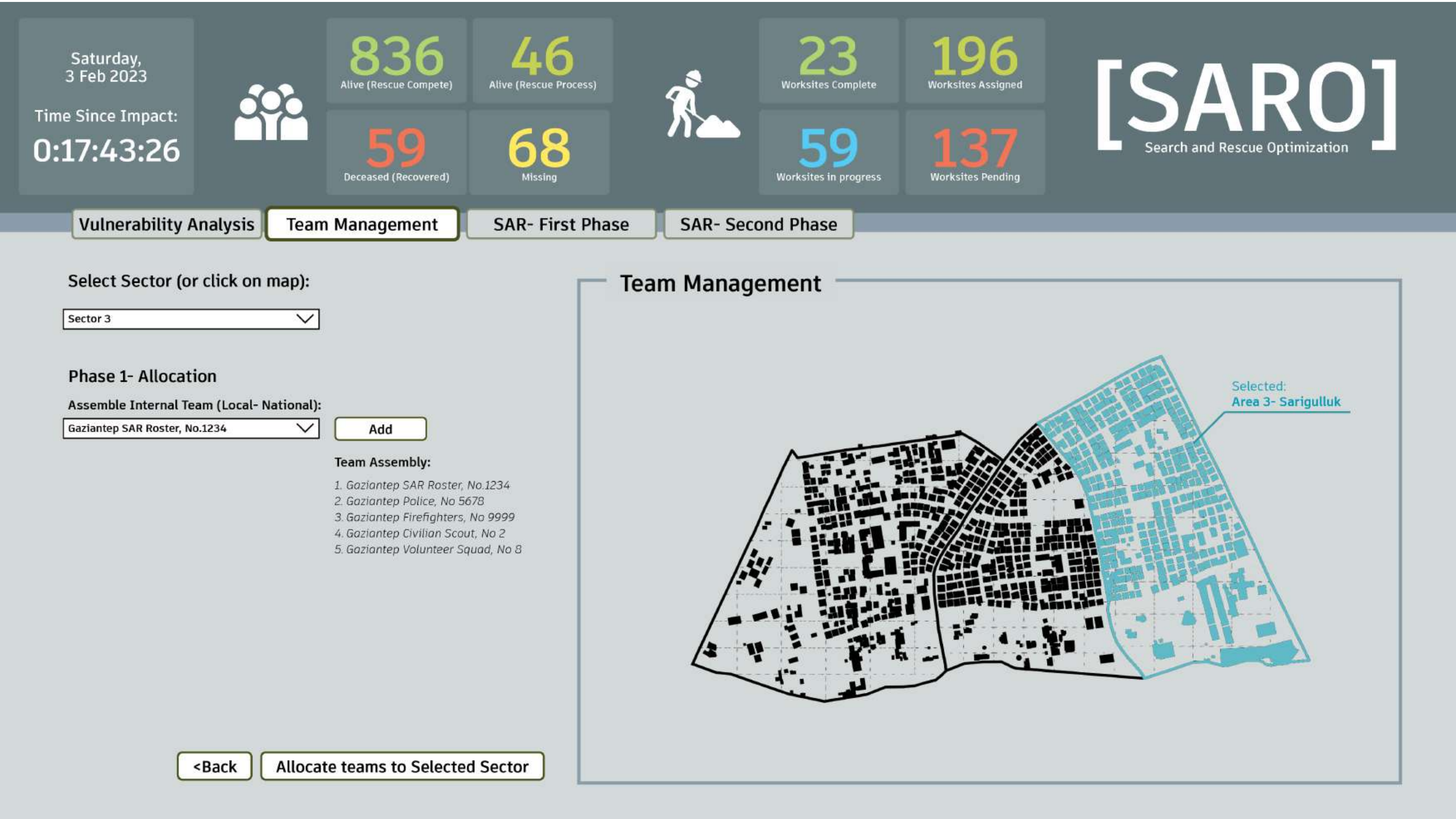
Appendix V: UI Design



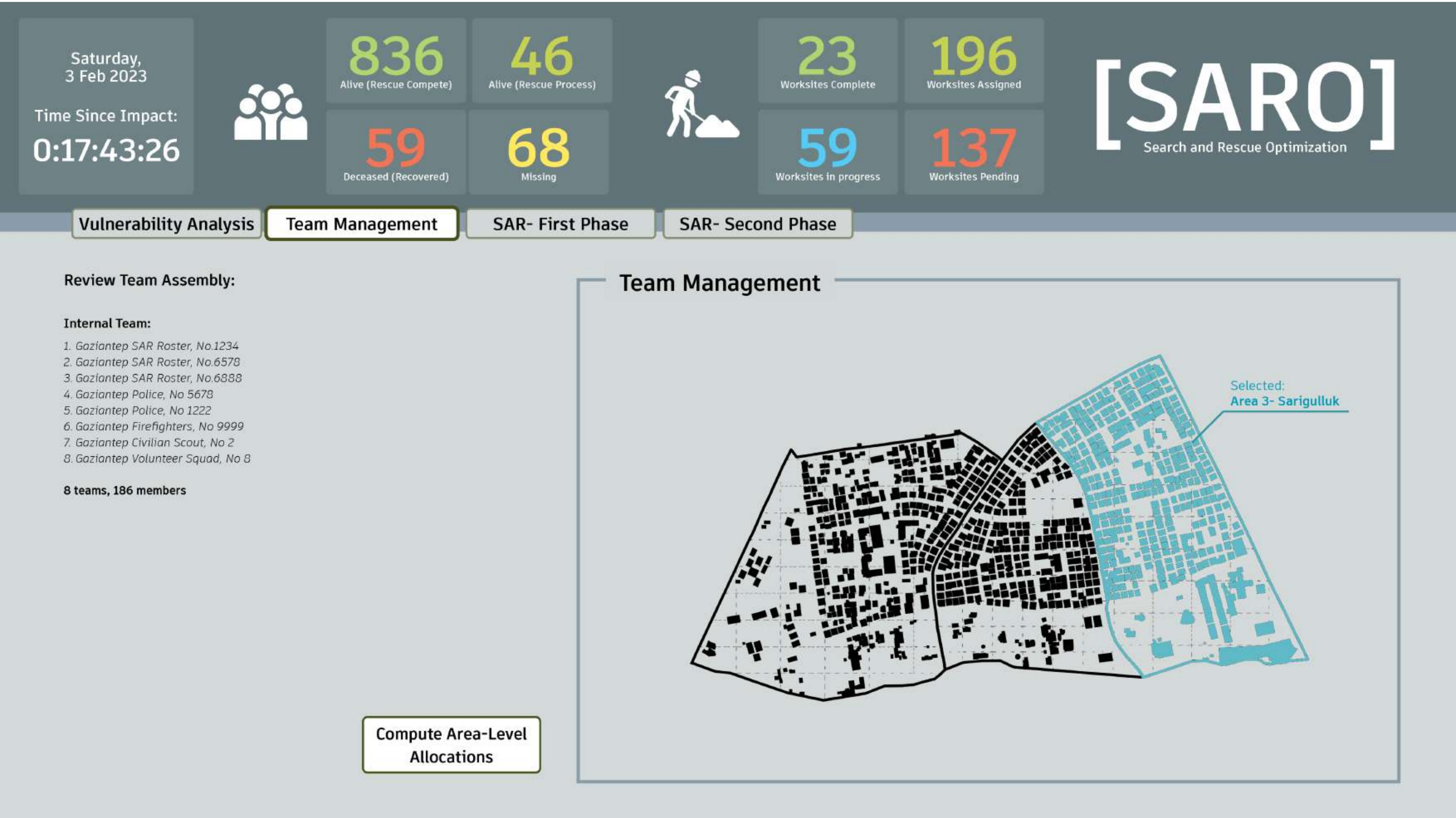
Appendix V: UI Design



Appendix V: UI Design



Appendix V: UI Design



Appendix V: UI Design

Saturday,
3 Feb 2023

Time Since Impact:
0:17:43:26

836 Alive (Rescue Compete)

46 Alive (Rescue Process)

59 Deceased (Recovered)

68 Missing

23 Worksites Complete

196 Worksites Assigned

59 Worksites in progress

137 Worksites Pending

[SARO]
Search and Rescue Optimization

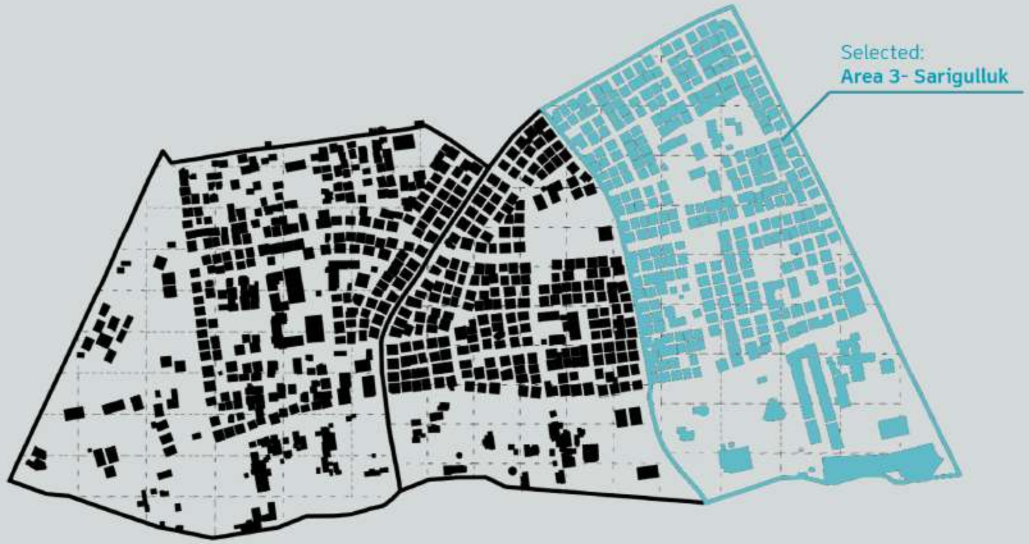
Vulnerability Analysis | Team Management | SAR- First Phase | SAR- Second Phase

Allocation- Internal Team:

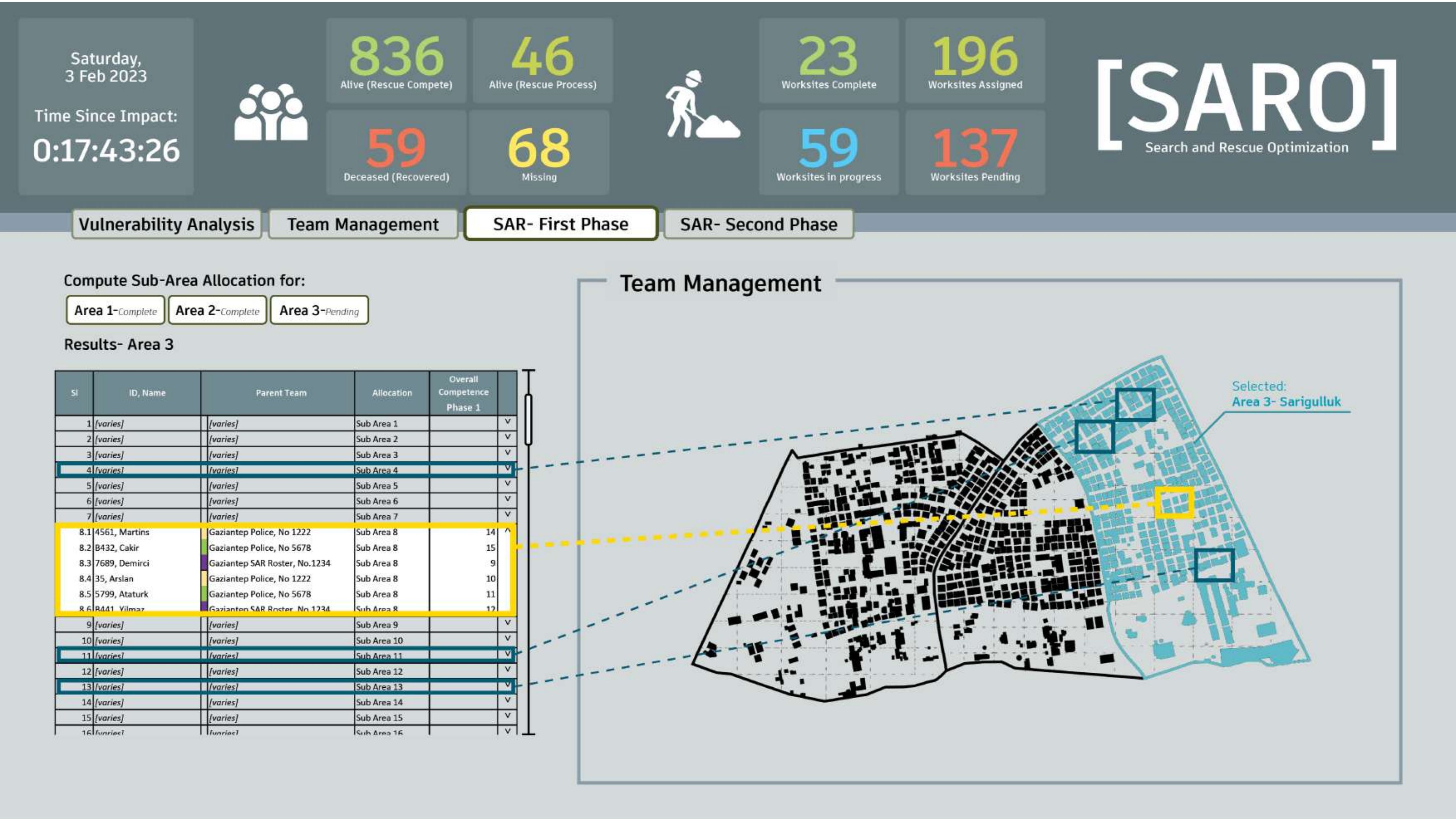
SI	Team	Area	ETA
1	Gaziantep SAR Roster, No.1234	Area 3	0
2	Gaziantep SAR Roster, No.6578	Area 2	
3	Gaziantep SAR Roster, No.6888	Area 1	
4	Gaziantep Police, No 5678	Area 3	0
5	Gaziantep Police, No 1222	Area 3	
6	Gaziantep Firefighters, No 9999	Area 1	0
7	Gaziantep Civilian Scout, No 2	Area 2	0
8	Gaziantep Volunteer Squad, No 8	Area 2	0

<Back | Reassign Teams | Accept

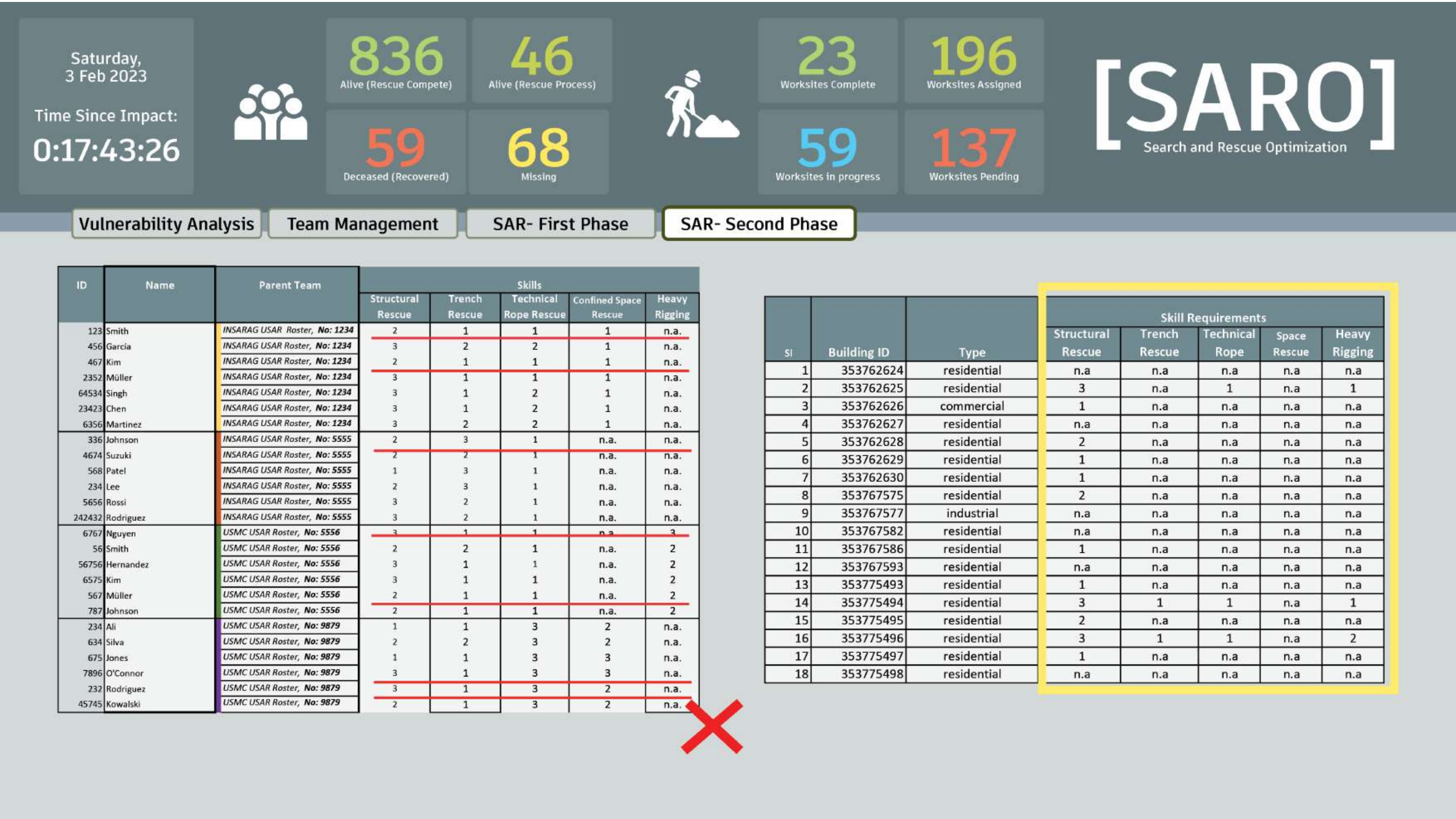
Team Management



Appendix V: UI Design



Appendix V: UI Design



ID	Name	Parent Team	Skills				
			Structural Rescue	Trench Rescue	Technical Rope Rescue	Confined Space Rescue	Heavy Rigging
123	Smith	INSARAG USAR Roster, **No: 1234**	2	1	1	1	n.a.
456	Garcia	INSARAG USAR Roster, **No: 1234**	3	2	2	1	n.a.
467	Kim	INSARAG USAR Roster, **No: 1234**	2	1	1	1	n.a.
2352	Müller	INSARAG USAR Roster, **No: 1234**	3	1	1	1	n.a.
64534	Singh	INSARAG USAR Roster, **No: 1234**	3	1	2	1	n.a.
23423	Chen	INSARAG USAR Roster, **No: 1234**	3	1	2	1	n.a.
6356	Martinez	INSARAG USAR Roster, **No: 1234**	3	2	2	1	n.a.
336	Johnson	INSARAG USAR Roster, **No: 5555**	2	3	1	n.a.	n.a.
4674	Suzuki	INSARAG USAR Roster, **No: 5555**	2	2	1	n.a.	n.a.
568	Patel	INSARAG USAR Roster, **No: 5555**	1	3	1	n.a.	n.a.
234	Lee	INSARAG USAR Roster, **No: 5555**	2	3	1	n.a.	n.a.
5656	Rossi	INSARAG USAR Roster, **No: 5555**	3	2	1	n.a.	n.a.
242432	Rodriguez	INSARAG USAR Roster, **No: 5555**	3	2	1	n.a.	n.a.
6767	Nguyen	USMC USAR Roster, **No: 5556**	3	1	1	n.a.	3
56	Smith	USMC USAR Roster, **No: 5556**	2	2	1	n.a.	2
56756	Hernandez	USMC USAR Roster, **No: 5556**	3	1	1	n.a.	2
6575	Kim	USMC USAR Roster, **No: 5556**	3	1	1	n.a.	2
567	Müller	USMC USAR Roster, **No: 5556**	2	1	1	n.a.	2
787	Johnson	USMC USAR Roster, **No: 5556**	2	1	1	n.a.	2
234	Ali	USMC USAR Roster, **No: 9879**	1	1	3	2	n.a.
634	Silva	USMC USAR Roster, **No: 9879**	2	2	3	2	n.a.
675	Jones	USMC USAR Roster, **No: 9879**	1	1	3	3	n.a.
7896	O'Connor	USMC USAR Roster, **No: 9879**	3	1	3	3	n.a.
232	Rodriguez	USMC USAR Roster, **No: 9879**	3	1	3	2	n.a.
45745	Kowalski	USMC USAR Roster, **No: 9879**	2	1	3	2	n.a.

Sl	Building ID	Type	Skill Requirements				
			Structural Rescue	Trench Rescue	Technical Rope	Space Rescue	Heavy Rigging
1	353762624	residential	n.a	n.a	n.a	n.a	n.a
2	353762625	residential	3	n.a	1	n.a	1
3	353762626	commercial	1	n.a	n.a	n.a	n.a
4	353762627	residential	n.a	n.a	n.a	n.a	n.a
5	353762628	residential	2	n.a	n.a	n.a	n.a
6	353762629	residential	1	n.a	n.a	n.a	n.a
7	353762630	residential	1	n.a	n.a	n.a	n.a
8	353767575	residential	2	n.a	n.a	n.a	n.a
9	353767577	industrial	n.a	n.a	n.a	n.a	n.a
10	353767582	residential	n.a	n.a	n.a	n.a	n.a
11	353767586	residential	1	n.a	n.a	n.a	n.a
12	353767593	residential	n.a	n.a	n.a	n.a	n.a
13	353775493	residential	1	n.a	n.a	n.a	n.a
14	353775494	residential	3	1	1	n.a	1
15	353775495	residential	2	n.a	n.a	n.a	n.a
16	353775496	residential	3	1	1	n.a	2
17	353775497	residential	1	n.a	n.a	n.a	n.a
18	353775498	residential	n.a	n.a	n.a	n.a	n.a

Appendix V: UI Design

Saturday,
3 Feb 2023

Time Since Impact:
0:17:43:26

836 Alive (Rescue Compete)	46 Alive (Rescue Process)
59 Deceased (Recovered)	68 Missing

23 Worksites Complete	196 Worksites Assigned
59 Worksites in progress	137 Worksites Pending

[SARO]
Search and Rescue Optimization

Vulnerability Analysis | Team Management | SAR- First Phase | **SAR- Second Phase**

ID	Name	Parent Team	Skills				
			Structural Rescue	Trench Rescue	Technical Rope Rescue	Confined Space Rescue	Heavy Rigging
123	Smith	*INSARAG USAR Roster,* ***No: 1234***	2	1	1	1	n.a.
456	Garcia	*INSARAG USAR Roster,* ***No: 1234***	3	2	2	1	n.a.
467	Kim	*INSARAG USAR Roster,* ***No: 1234***	2	1	1	1	n.a.
2352	Müller	*INSARAG USAR Roster,* ***No: 1234***	3	1	1	1	n.a.
64534	Singh	*INSARAG USAR Roster,* ***No: 1234***	3	1	2	1	n.a.
23423	Chen	*INSARAG USAR Roster,* ***No: 1234***	3	1	2	1	n.a.
6356	Martinez	*INSARAG USAR Roster,* ***No: 1234***	3	2	2	1	n.a.
336	Johnson	*INSARAG USAR Roster,* ***No: 5555***	2	3	1	n.a.	n.a.
4674	Suzuki	*INSARAG USAR Roster,* ***No: 5555***	2	2	1	n.a.	n.a.
568	Patel	*INSARAG USAR Roster,* ***No: 5555***	1	3	1	n.a.	n.a.
234	Lee	*INSARAG USAR Roster,* ***No: 5555***	2	3	1	n.a.	n.a.
5656	Rossi	*INSARAG USAR Roster,* ***No: 5555***	3	2	1	n.a.	n.a.
242432	Rodriguez	*INSARAG USAR Roster,* ***No: 5555***	3	2	1	n.a.	n.a.
6767	Nguyen	*USMC USAR Roster,* ***No: 5556***	3	1	1	n.a.	3
56	Smith	*USMC USAR Roster,* ***No: 5556***	2	2	1	n.a.	2
56756	Hernandez	*USMC USAR Roster,* ***No: 5556***	3	1	1	n.a.	2
6575	Kim	*USMC USAR Roster,* ***No: 5556***	3	1	1	n.a.	2
567	Müller	*USMC USAR Roster,* ***No: 5556***	2	1	1	n.a.	2
787	Johnson	*USMC USAR Roster,* ***No: 5556***	2	1	1	n.a.	2
234	Ali	*USMC USAR Roster,* ***No: 9879***	1	1	3	2	n.a.
634	Silva	*USMC USAR Roster,* ***No: 9879***	2	2	3	2	n.a.
675	Jones	*USMC USAR Roster,* ***No: 9879***	1	1	3	3	n.a.
7896	O'Connor	*USMC USAR Roster,* ***No: 9879***	3	1	3	3	n.a.
232	Rodriguez	*USMC USAR Roster,* ***No: 9879***	3	1	3	2	n.a.
45745	Kowalski	*USMC USAR Roster,* ***No: 9879***	2	1	3	2	n.a.

Sl	Building ID	Type	Skill Requirements				
			Structural Rescue	Trench Rescue	Technical Rope	Space Rescue	Heavy Rigging
1	353762624	residential	n.a	n.a	n.a	n.a	n.a
2	353762625	residential	3	n.a	1	n.a	1
3	353762626	commercial	1	n.a	n.a	n.a	n.a
4	353762627	residential	n.a	n.a	n.a	n.a	n.a
5	353762628	residential	2	n.a	n.a	n.a	n.a
6	353762629	residential	1	n.a	n.a	n.a	n.a
7	353762630	residential	1	n.a	n.a	n.a	n.a
8	353767575	residential	2	n.a	n.a	n.a	n.a
9	353767577	industrial	n.a	n.a	n.a	n.a	n.a
10	353767582	residential	n.a	n.a	n.a	n.a	n.a
11	353767586	residential	1	n.a	n.a	n.a	n.a
12	353767593	residential	n.a	n.a	n.a	n.a	n.a
13	353775493	residential	1	n.a	n.a	n.a	n.a
14	353775494	residential	3	1	1	n.a	1
15	353775495	residential	2	n.a	n.a	n.a	n.a
16	353775496	residential	3	1	1	n.a	2
17	353775497	residential	1	n.a	n.a	n.a	n.a
18	353775498	residential	n.a	n.a	n.a	n.a	n.a

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Saturday,
3 Feb 2023

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836 Alive (Rescue Compete)

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23 Worksites Complete

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[SARO]
Search and Rescue Optimization

Vulnerability Analysis | Team Management | SAR- First Phase | SAR- Second Phase

ID	Name	Parent Team	Skills				
			Structural Rescue	Trench Rescue	Technical Rope Rescue	Confined Space Rescue	Heavy Rigging
123	Smith	INSARAG USAR Roster, No: 1234	2	1	1	1	n.a.
456	Garcia	INSARAG USAR Roster, No: 1234	3	2	2	1	n.a.
467	Kim	INSARAG USAR Roster, No: 1234	2	1	1	1	n.a.
2352	Müller	INSARAG USAR Roster, No: 1234	3	1	1	1	n.a.
64534	Singh	INSARAG USAR Roster, No: 1234	3	1	2	1	n.a.
23423	Chen	INSARAG USAR Roster, No: 1234	3	1	2	1	n.a.
6356	Martinez	INSARAG USAR Roster, No: 1234	3	2	2	1	n.a.
336	Johnson	INSARAG USAR Roster, No: 5555	2	3	1	n.a.	n.a.
4674	Suzuki	INSARAG USAR Roster, No: 5555	2	2	1	n.a.	n.a.
568	Patel	INSARAG USAR Roster, No: 5555	1	3	1	n.a.	n.a.
234	Lee	INSARAG USAR Roster, No: 5555	2	3	1	n.a.	n.a.
5656	Rossi	INSARAG USAR Roster, No: 5555	3	2	1	n.a.	n.a.
242432	Rodriguez	INSARAG USAR Roster, No: 5555	3	2	1	n.a.	n.a.
6767	Nguyen	USMC USAR Roster, No: 5556	3	1	1	n.a.	3
56	Smith	USMC USAR Roster, No: 5556	2	2	1	n.a.	2
56756	Hernandez	USMC USAR Roster, No: 5556	3	1	1	n.a.	2
6575	Kim	USMC USAR Roster, No: 5556	3	1	1	n.a.	2
567	Müller	USMC USAR Roster, No: 5556	2	1	1	n.a.	2
787	Johnson	USMC USAR Roster, No: 5556	2	1	1	n.a.	2
234	Ali	USMC USAR Roster, No: 9879	1	1	3	2	n.a.
634	Silva	USMC USAR Roster, No: 9879	2	2	3	2	n.a.
675	Jones	USMC USAR Roster, No: 9879	1	1	3	3	n.a.
7896	O'Connor	USMC USAR Roster, No: 9879	3	1	3	3	n.a.
232	Rodriguez	USMC USAR Roster, No: 9879	3	1	3	2	n.a.
45745	Kowalski	USMC USAR Roster, No: 9879	2	1	3	2	n.a.

Sl	Building ID	Type	Skill Requirements				
			Structural Rescue	Trench Rescue	Technical Rope	Space Rescue	Heavy Rigging
1	353762624	residential	n.a	n.a	n.a	n.a	n.a
2	353762625	residential	3	n.a	1	n.a	1
3	353762626	commercial	1	n.a	n.a	n.a	n.a
4	353762627	residential	n.a	n.a	n.a	n.a	n.a
5	353762628	residential	2	n.a	n.a	n.a	n.a
6	353762629	residential	1	n.a	n.a	n.a	n.a
7	353762630	residential	1	n.a	n.a	n.a	n.a
8	353767575	residential	2	n.a	n.a	n.a	n.a
9	353767577	industrial	n.a	n.a	n.a	n.a	n.a
10	353767582	residential	n.a	n.a	n.a	n.a	n.a
11	353767586	residential	1	n.a	n.a	n.a	n.a
12	353767593	residential	n.a	n.a	n.a	n.a	n.a
13	353775493	residential	1	n.a	n.a	n.a	n.a
14	353775494	residential	3	1	1	n.a	1
15	353775495	residential	2	n.a	n.a	n.a	n.a
16	353775496	residential	3	1	1	n.a	2
17	353775497	residential	1	n.a	n.a	n.a	n.a
18	353775498	residential	n.a	n.a	n.a	n.a	n.a

Appendix V: UI Design

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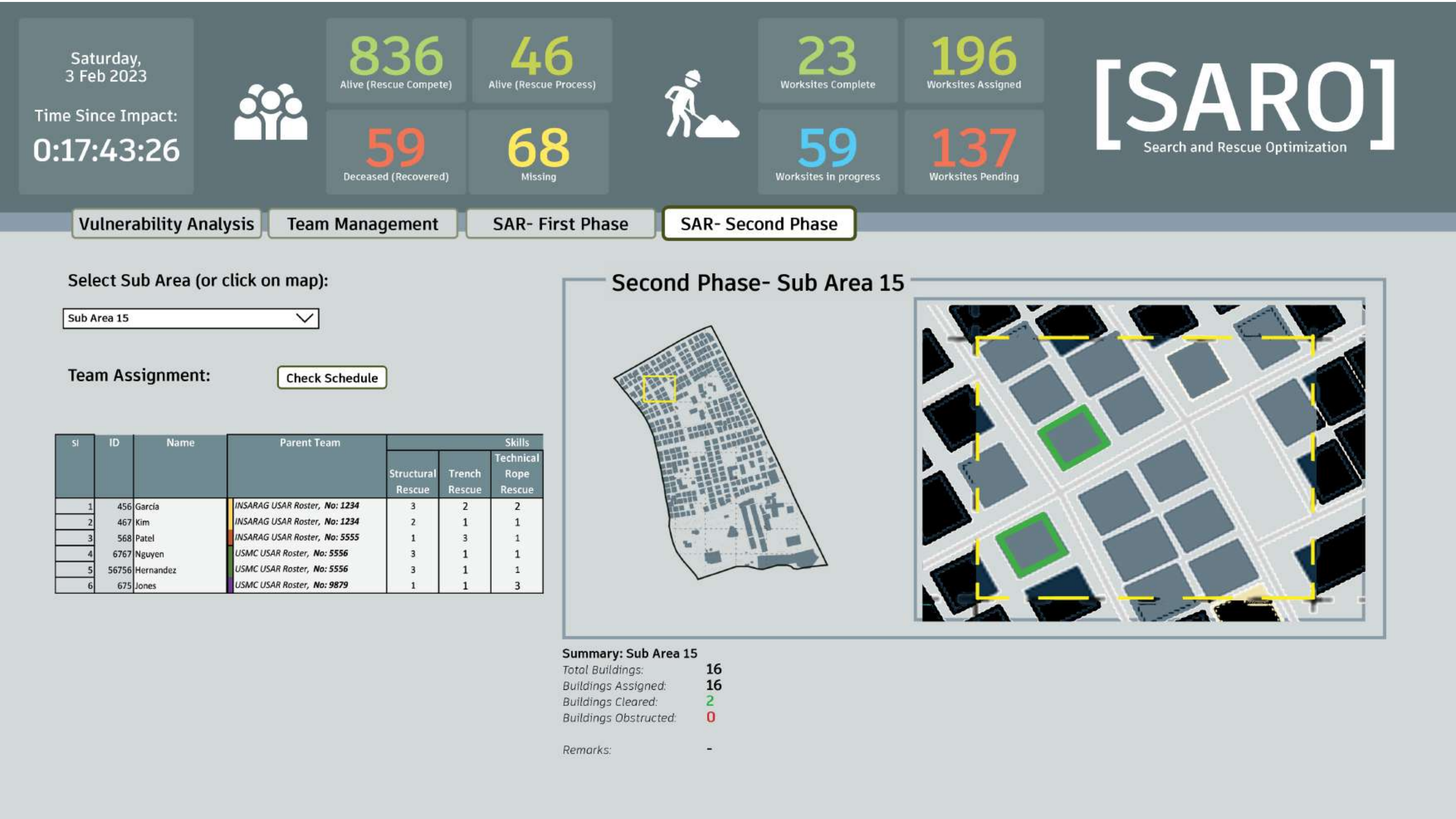

Sl	ID	Name	Parent Team	Skills		
				Structural Rescue	Trench Rescue	Technical Rope Rescue
1	456	Garcia	INSARAG USAR Roster, **No: 1234**	3	2	2
2	467	Kim	INSARAG USAR Roster, **No: 1234**	2	1	1
3	568	Patel	INSARAG USAR Roster, **No: 5555**	1	3	1
4	6767	Nguyen	USMC USAR Roster, **No: 5556**	3	1	1
5	56756	Hernandez	USMC USAR Roster, **No: 5556**	3	1	1
6	675	Jones	USMC USAR Roster, **No: 9879**	1	1	3

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