Stakeholder Value Integration in Threshold Matrix for Road Transportation Flood Resilience in Tambaram, Chennai

Master Thesis

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Preface

This master's thesis represents the culmination of my studies in the Construction Management and Engineering master's program at TU Delft. My journey has been challenging yet rewarding, and one which has helped me to grow personally and professionally.

My interest in this research topic stemmed from a growing awareness of the urgent need for stakeholder value integration in transportation systems in disaster prone areas. Throughout this journey, I have been fortunate to engage with a variety of professionals, academics, and practitioners whose insights have greatly enriched my understanding of the subject.

I would like to express my deepest gratitude to my thesis committee, whose guidance, expertise, and encouragement have been invaluable in shaping this work. A heartfelt thanks to Dr. ir. J. (Johan) Ninan for his continuous supervision throughout the research. I am also deeply grateful to Dr. ir. M. (Maria) Nogal Macho and Dr. ir. M. (Ming) Yang for their valuable insights and feedback in every stage. My sincere thanks go to Postdoctoral Research Fellow Dr. E.L. (Erica) Arango Patiño and Z. (Zhaowen) Liu for their steadfast support and guidance from the very beginning.

I would like to thank all interview participants from for their cooperation and providing me with significant insights on the topic.

I would like to acknowledge the support of my family, whose unwavering encouragement has uplifted me in every step of my study in the Netherlands. Their belief in my abilities has kept me focused and determined throughout this process. Moreover, my most sincere thanks to my friends both in the Netherlands and India, who have been a constant source of support for my entire master's journey.

It is my hope that this thesis not only adds to the existing body of knowledge but also inspires further research and action in the field of resilience. As we collectively work towards a more stakeholder value integrated resilient future. I wish you a pleasant read!

- *Prethwin Rathnavelu,*
Delft, the Netherlands,
14th September, 2025.

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Executive Summary

Flooding is one of the most severe and recurring hazards affecting urban areas, particularly in rapidly growing coastal cities such as Chennai, India. The city's transportation systems, which function as lifelines for daily mobility and emergency response, are increasingly at risk from extreme rainfall and inundation events. Historical experiences, such as the 2015 Chennai floods, demonstrated the vulnerability of transport networks. Despite growing recognition of the need for resilient transport infrastructure, existing approaches to resilience assessment remain largely technocentric, focusing on engineering indicators while neglecting the values, needs, and expectations of the very stakeholders who depend on these systems.

This study aims to develop an approach for integrating stakeholder values into a threshold matrix for resilience assessment of urban road transportation systems. It focuses on capturing how road users define "minimum acceptable performance" under varying flood hazard intensities and translating these values into resilience assessment tools that are both technically robust and socially legitimate. The research is validated through a case study in Tambaram, Chennai, a flood prone locality that highlights the urgency of stakeholder centered resilience planning. Beyond constructing the threshold matrix, the study proposes an approach to guide the integration process, documents complexities encountered in stakeholder engagement, and outlines mitigation strategies to address these challenges. The resulting approach is designed to be replicable and adaptable across different hazard contexts, ensuring that resilience assessments align technical performance with stakeholder expectations. To achieve this objective, the following research question is formulated:

> ***"How can user values be captured to assess road transportation resilience to flooding considering different system functionalities and hazard intensities in the Tambaram, Chennai context?"***

Overview of research

To achieve the research aim, a mixed-methods approach was adopted, carefully designed to elicit both qualitative and quantitative insights from stakeholders.

The first phase of the research established the theoretical foundation. This review highlighted the emerging concept of dynamic thresholds (performance benchmarks that vary depending on hazard intensity) while also revealing that stakeholder input had rarely been incorporated into their formulation. This theoretical grounding was critical for defining and guiding the case study design.

The second phase of the research involved empirical data collection through semi-structured interviews with 15 local road users in Tambaram. Participants were asked both to articulate their reasoning about acceptable performance under flood conditions and to quantify minimum acceptable performance as percentages across three key system functionalities: safety, connectivity, and travel time reliability. Flood scenarios were categorized into four levels; normal, low (15 cm inundation), medium (25–30 cm), and high (>30 cm).

The qualitative data were analysed using the Gioia methodology, allowing first-order concepts to be distilled into second-order themes and overarching aggregate dimensions. These themes explained the logic behind user-defined thresholds, including tolerance for performance loss, performance expectations, system guarantees, user confidence, and the hierarchy of values across system functionalities.

The quantitative data were aggregated using a Weighted Average Aggregation (WAA). This produced a threshold matrix that captured the average stakeholder defined minimum acceptable performance levels for each functionality at each flood intensity. The integration of qualitative reasoning with quantitative thresholds ensured that the resulting matrix was not only numerically robust but also anchored with insights.

Finally, the study synthesized an approach to integrate stakeholder value in a threshold matrix for resilience assessment. This approach details the sequential steps of identifying the perspective, disaster phase, relevant stakeholders, relevant hazard intensity, system functionalities, eliciting stakeholder thresholds, aggregating values, and embedding them into resilience assessments. Importantly, it also documents the complexities faced during the research such as variability in user perceptions, challenges in communicating flood scenarios to participants, and difficulties in balancing qualitative richness with quantitative rigor and provided mitigation strategies and recommendations for future applications in other disaster contexts.

AN APPROACH TO INTEGRATE STAKEHOLDER VALUE IN A THRESHOLD MATRIX FOR RESILIENCE ASSESSMENT

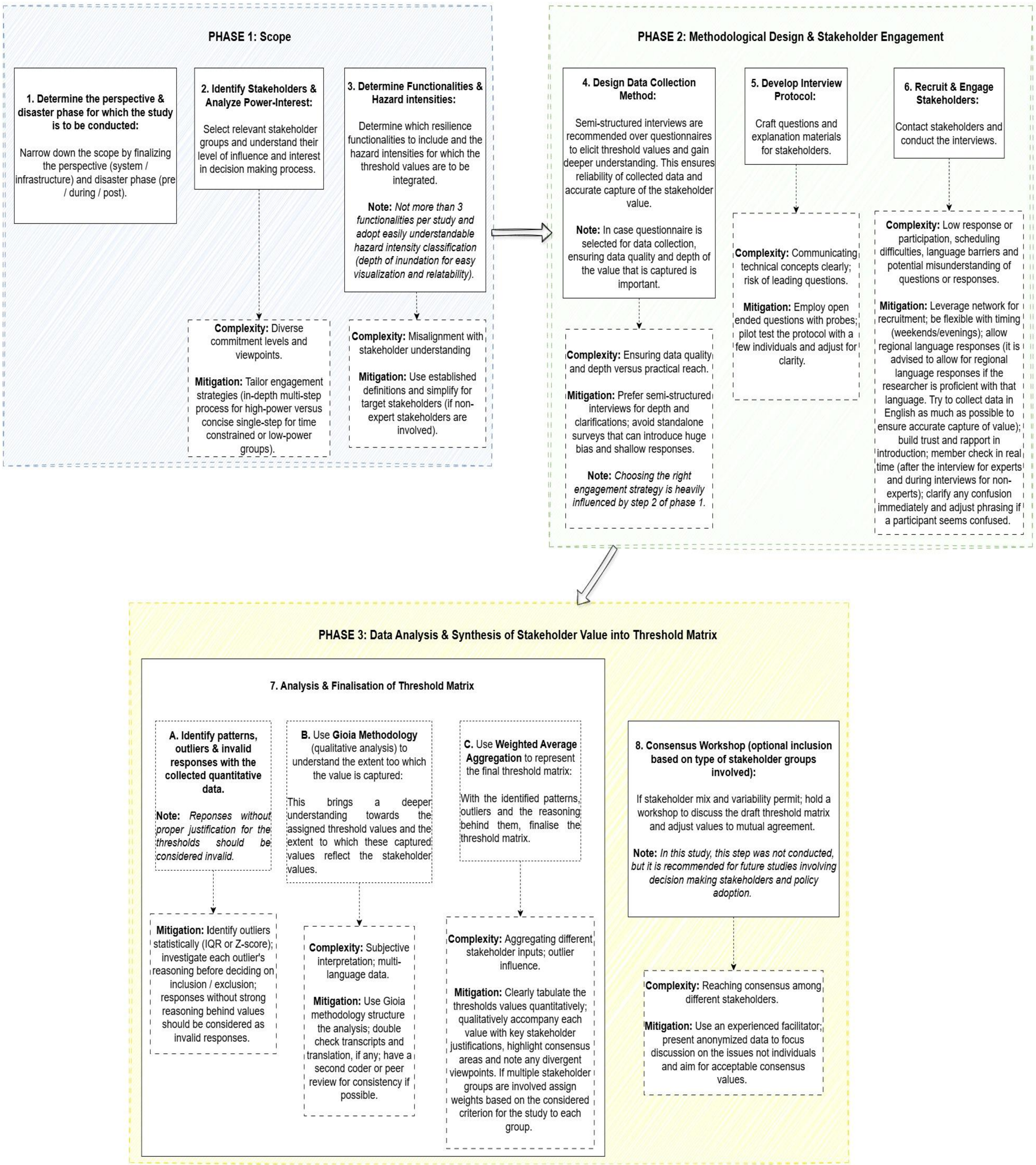

Figure A. *An approach to stakeholder value integration in a threshold matrix for resilience assessment*

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Introduction

1.1 Background

Urban areas in tropical and subtropical regions are increasingly vulnerable to hydro-climatic events such as floods, droughts, and cyclones, exacerbated by climate change. These events pose significant challenges to urban infrastructure, which is often characterized by complex interdependencies among systems like transport, energy, and water. A failure in one system can lead to cascading effects in others, amplifying the overall impact on the city's functionality and resilience.

Urban transportation networks are the lifelines of a city, and their resilience is vital for ensuring continuous connectivity during disasters. The concept of resilience has gained prominence as traditional risk management approaches proved insufficient against escalating climate hazards. In engineering terms, a resilient system is expected to suffer no catastrophic loss of functionality when shocked (robustness), have fallback options to maintain service (redundancy), adapt using available resources (resourcefulness), and restore normal operations swiftly (rapidity) (Coleman et al., 2024). Road transportation networks are recognized as critical infrastructure: any significant damage or downtime in the road system can cause cascading economic losses and impair essential services like disaster response and healthcare access. During flood events, road resilience translates to the network's ability to keep people and goods moving (at least at a minimal acceptable level) and to recover quickly after floodwaters recede. The importance of this cannot be overstated as disruptions to road transportation not only incur direct economic costs but also endanger lives by delaying emergency services and isolating communities. An analysis by the World Bank indicates that globally, direct damage to transport infrastructure from natural hazards already costs billions annually, a figure likely to rise as extreme weather events become more frequent. In Chennai's case, events like the 2020 Cyclone Nivar caused widespread inundation that halted public transport and underscored the need for robust flood ready transport systems (Using Mobility Data for Resilient Transport Planning and Investments, 2024). Thus, building resilience into urban road networks is now a core objective in both academic research and city planning practice.

A key emerging concept in resilience assessment is the notion of dynamic performance thresholds. Traditionally, infrastructure performance has been evaluated against fixed threshold levels, a road network might be deemed "failed" if capacity drops below a static benchmark. However, recent research argues that acceptable performance levels during extreme events are not fixed; instead, they can be context-dependent and vary with the severity of stress. Arango et al. (2023) introduced the dynamic threshold concept in resilience analysis of road networks, showing that the level of performance considered acceptable can shift between normal conditions and extreme hazard scenarios. In their study of wildfire impacts on traffic networks, they note that resilience assessment must account for “the acceptance of a specific loss of performance” under severe conditions, implemented by dynamic thresholds that reflect different requirements of the system under different hazard intensities. In simpler terms, rather than holding the network to the same performance standard in all situations, one recognizes that during a disaster stakeholders might temporarily tolerate a lower level of service. The dynamic threshold approach thus aligns resilience metrics with the reality of graduated service levels. It acknowledges that “failure” is not a binary state, but a spectrum governed by how much performance loss is bearable in a given scenario. This concept is highly relevant for flood prone transportation systems. By incorporating dynamic thresholds, planners and engineers can better characterize infrastructure performance across the full range of conditions, from normal operations to extreme disruptions. The emergence of this concept reflects a theoretical advance in resilience thinking it moves beyond static “fail/pass” criteria and instead uses performance targets that adjust to the context, providing a more nuanced picture of how infrastructure copes with stress. In the context of this thesis, dynamic thresholds offer a approach to evaluate Tambaram’s road network in a way that distinguishes what level of service is required during minor flooding versus catastrophic flooding. This is crucial for designing adaptive measures like uninterrupted service in routine floods, but plan for a managed degradation of service (yet avoiding total collapse) in extreme floods, aligned with what stakeholders deem acceptable.

Another critical dimension in contemporary resilience research is the integration of stakeholder values and perspectives into infrastructure planning. Urban resilience is not solely a technical issue of pavements, bridges, and drainage capacities; it is fundamentally about people, the users of infrastructure, the communities at risk, the institutions managing the systems. Resilience outcomes are inherently tied to value judgments: What level of performance is acceptable, and for whom? Traditionally, engineers and planners might set these performance benchmarks based on expert driven standards (e.g. design codes or economic optimization), often with an implicit assumption that if a road meets certain technical criteria, it is “resilient enough.” However, there is growing recognition that such a top down approach can overlook the priorities and experiences of the very stakeholders who rely on the infrastructure. For instance, residents and daily commuters may value certain aspects like personal safety or reliable access to healthcare and livelihoods far more than what generic level of service metrics capture. If their expectations are not met, the transport system is effectively failing its purpose even if technical metrics appear nominally satisfactory. Conversely, stakeholders might be willing to accept certain trade-offs (like longer travel times during big floods) as long as their highest priorities (no loss of life, access to essentials) are preserved. Incorporating these nuanced preferences into planning can lead to more socially legitimate and robust resilience strategies. Indeed, international frameworks such as the UN’s Sendai Framework for Disaster Risk Reduction advocate an “all of society” approach, calling for the engagement of multiple stakeholders from government and industry to communities and citizens in resilience decision making (Coleman et al., 2024). In practical terms, this means stakeholder engagement is not just a box ticking exercise, but central to defining what resilience means for a given community. Particularly in a place like Tambaram, differing stakeholder groups like local residents, commuters, municipal authorities, emergency services, business owners may have unique insights on vulnerabilities and what infrastructure functionality is most critical to protect. For example, during the 2021 Northeast monsoon floods, resident welfare associations in Tambaram proactively organized flood mitigation and relief efforts when official preparations fell short. Such experiences illustrate that engaging local stakeholders can surface priorities that might otherwise be underestimated in top down plans. Moreover, stakeholder involvement can enhance the legitimacy and effectiveness of resilience measures, when people see their values and inputs reflected in plans, they are more likely to trust and cooperate with the interventions.

Bringing together the above threads, this thesis is built on a confluence of theoretical insights and practical realities. Theoretically, it builds on resilience engineering scholarship and systems theory that view performance as a dynamic continuum rather than a binary state. The idea that system can operate at various degraded levels yet still fulfil its core function is rooted in the concept of degradation and adaptive capacity in systems, ideas long discussed in resilience literature, but now being formalized through tools like the dynamic threshold approach. Such approaches acknowledge that performance metrics (like an acceptable percentage of road capacity during floods) should not be arbitrarily set by experts alone but can be co-defined with stakeholders through empirical inquiry.

In summary, the background of this thesis is defined by its geographical focus on Tambaram, the conceptual focus on resilience (especially dynamic thresholds), and the normative focus on stakeholder value integration. This blend of context, concept, and community sets the stage for a research endeavour aimed at advancing practice in flood resilient transportation planning.

1.2 Problem Definition

Despite widespread acknowledgment that stakeholder engagement is essential to resilience planning, a persistent gap remains in how resilience is actually assessed. Prevailing approaches in road transport resilience privilege technical indicators while insufficiently incorporating the expectations and value trade-offs of those who depend on the system. The result is a one dimensional picture of resilience that can show how quickly traffic flow is restored or how many detour routes exist but reveals little about whether recovery meets people's needs under real flood constraints. Empirical critiques highlight that robust, user oriented methods for evaluating transport resilience are largely absent, and the omission extends beyond users to other actors like city authorities, emergency services, public transport operators, and local businesses whose priorities often diverge. Engineering success may be defined as rapid asset repair, while residents judge resilience by reliable access to hospitals and schools, and businesses by supply chain continuity; collapsing these lenses into a single "system performance" metric produces an oversimplified, technocentric view of a socio technical outcome experienced differently across groups.

The consequence in flood prone urban road systems assessments that ignore stakeholder perspectives risk recommendations misaligned with on the ground realities. A capacity based analysis might deem a corridor "resilient" post flood if it carries a specified volume, yet from the user standpoint that same outcome is unacceptable if it entails unsafe conditions. The 2015 Chennai floods exemplified this divergence: nominal "accessibility" on paper belied neighborhoods rendered functionally inaccessible by high water, demonstrating that technical connectivity does not equate to usable access.

Excluding stakeholder input also undervalues human safety, access to essentials, and community confidence. More broadly, sidelining stakeholder expectations undermines the legitimacy and effectiveness of resilience measures. The risks of assessment without multi-stakeholder input are therefore tangible: mis-prioritized investments, diminished public trust, slower recoveries, and avoidable losses. Flood impacts are also spatially heterogeneous and locally known; tolerance for disruption is ultimately a human judgment. Without clarity on which service levels people consider acceptable or critical under different flood severities, it is impossible to define transport resilience in a meaningful sense.

To address the identified deficit, it is essential to integrate stakeholder defined performance expectations into the resilience assessment. This research proposes an elicitation process to capture stakeholder values and apply data analysis techniques to understand the collected input. Building on this foundation, the study introduces an approach that incorporates stakeholder value into the evaluation of road system functionalities under varying levels of flood severity. This integrated methodology aims to enhance the accuracy and relevance of resilience assessments by aligning them with stakeholder value.

1.3 Research Gap

While the importance of transportation resilience is well recognized, how to assess and improve resilience, particularly with stakeholder input remaining as an evolving research area. Traditional engineering resilience metrics often focus on technical performance (e.g., time to recovery, capacity loss) without explicitly accounting for what different stakeholders value most in an extreme event scenario. Arango et al. (2023) proposed a novel approach to assess road network resilience under wildfire hazards, introducing the concept of dynamic performance thresholds for different network functions. In their study, road network resilience was evaluated across multiple "targets" (or system functionalities such as safety, connectivity, reliability, and efficiency) with performance thresholds that adjust based on wildfire intensity. This approach acknowledges that under extreme conditions, stakeholders might accept lower performance in certain functions (e.g., safety) while prioritizing others (e.g., connectivity, travel time, etc). **However, a key gap identified in that work is the lack of direct stakeholder input in setting these performance thresholds.** The authors note that incorporating **different stakeholders' perspectives** in defining the threshold matrix of acceptable performance is an important future research direction (Arango et al., 2023). In other words, questions remain about, *how stakeholders would define and prioritise various functionalities of the transport system under different hazard scenarios*. Do emergency responders, daily commuters, infrastructure planners, etc define the system functionalities, set contrasting performance thresholds and assign different importance to network safety versus travel time during floods? Addressing this gap is essential because resilience is ultimately a socio technical concept; system performance deemed "acceptable" during a disaster should reflect societal values and needs, not just engineering criteria.

1.3.1 Addressing the Research Gap

Existing literatures reveals a significant gap between the theoretical advancement of dynamic thresholds in resilience assessment and their practical implementation through stakeholder value integration. While Arango et al. (2023) pioneered the concept of dynamic performance thresholds for transportation resilience assessment, their work explicitly acknowledges the absence of direct stakeholder input in setting these performance thresholds. This gap represents a fundamental limitation in current resilience evaluation frameworks, where technical performance metrics fail to incorporate the values, expectations, and priorities of those who directly experience system disruptions.

Current flood resilience assessment methodologies predominantly rely on expert driven standards and static performance benchmarks, creating a disconnect between engineering criteria and community needs. The prevailing approaches in road transport resilience privilege technical indicators while insufficiently incorporating the expectations and value trade-offs of system users, emergency responders, and local authorities. This technocentric perspective risks producing resilience strategies that, while technically sound, may not align with stakeholder priorities or gain acceptance during actual flood events.

Furthermore, the integration of stakeholder perspectives into quantitative resilience metrics remains methodologically underdeveloped. Existing studies have explored stakeholder engagement in disaster management and infrastructure planning but has not developed a systematic way to translate stakeholder values into measurable performance thresholds for resilience assessment. The challenge lies in developing robust approach that can operationalize diverse stakeholder perspectives into coherent, actionable threshold matrices for resilience evaluation. This study proposes a systematic approach to integrate stakeholder value in a threshold matrix for resilience assessment using Tambaram, Chennai as a case study.

1.4 Research Objectives

This study addressed the need for stakeholder value integration in resilience assessment. This was achieved by developing an approach to integrate stakeholder value in a threshold matrix using Tambaram, Chennai as a case study. This study addresses this need through the following objectives:

- *To understand how stakeholders (road users) in Tambaram, Chennai quantifies minimum acceptable performance and prioritize the pre-defined road system functionalities under varying flood intensities.*
- To gain insights on non-technical perspectives and expectations; and provide suggestions on how to deal with these insights.
- **To provide guidelines on how to perform stakeholder value integration with complexities that can arise during the process and how to mitigate those complexities:** The approach to integrate stakeholder value in a threshold matrix for resilience assessment.

1.5 Research Question

This research is driven by a main question that encapsulates the core challenge and the need for integrating stakeholder value into a threshold matrix for road transportation flood resilience assessment. The main research question is as follows:

"How can user values be captured to assess road transportation resilience to flooding considering system functionalities and various hazard intensities in Tambaram, Chennai context?"

To answer the main research question comprehensively, the study is guided by the following sub-research questions:

SQ-1: *"What are the system functionalities that define road transportation resilience during various flood severities?"*

SQ-2: *"To which extent the performance threshold captures the users value for the pre-defined system functionalities under different flood severities, and the reason behind the assigned thresholds?"*

SQ-3: *"How do the users prioritize these pre-defined functionalities under various flood intensities?"*

SQ-4: *"How can the captured stakeholder value be systematically integrated into a threshold matrix for resilience assessment?"*

Chapter 2

Theoretical Background

2.1 Resilience

Resilience has emerged as a critical concept in the face of growing threats from natural disasters and climate change. In general terms, Raicu et al. (2019), defines resilience as "*a system's ability to absorb disturbances and recover essential functions after disruption*". This capacity is crucial for reducing the impacts of shocks on society. A resilient system can withstand adverse events with minimal loss of service, protect lives, and reduce economic losses. Disruptions to essential services (water, energy, transportation, etc.) by extreme events have profound economic and social consequences, underscoring that resilience is vital to safeguard lives, livelihoods, and development gains (Bagnoli, 2024). In short, enhancing resilience helps ensure that critical systems continue to function (or quickly resume functioning) during crises, thereby mitigating cascading failures in modern society.

2.1.1 Resilience in the Context of Flooding

Among various natural hazards, floods stand out as particularly frequent and damaging events. Flooding has significantly increased in frequency and severity over recent decades (Guha-Sapir et al., 2011). It impacts human well-being and ecosystems and causes both direct and indirect losses. Direct losses include damage to buildings, infrastructure, and lives, while indirect losses manifest as disruptions to economic activities and essential services (e.g. transportation networks) (Tachaudomdach et al., 2021). In fact, floods are now recognized as the most common natural disaster worldwide, and their destructive potential is rising with climate change. When major floods occur, they can inundate vast areas for days, affecting communities and critical infrastructure on a large scale. The need for resilience in the context of flooding is therefore paramount. A resilient system can reduce the immediate damage floodwaters cause and speed up recovery, lessening long term socio-economic impacts. For instance, one study noted that even a 1 in 100 year flood could directly inundate ~14.7% of urban road networks globally yet cause nearly 45% of trips to fail due to network wide mobility disruptions (He et al., 2024). This dramatic multiplier effect where local inundation leads to citywide traffic failure illustrates why flood resilience measures (like flood proof design and emergency planning) are so important. By improving flood resilience, communities aim to ensure that critical functions (transportation, power, healthcare, etc.) continue to operate at an acceptable level during floods or can be restored quickly thereafter.

2.1.2 Criticality of Road Transportation Resilience during Floods

Road transportation networks are among the most critical infrastructures requiring resilience in flood prone areas. Transportation infrastructure is the backbone of economic activity and emergency response; during disasters, functioning road networks enable evacuation, delivery of relief, and maintenance of supply chains. However, floods can severely compromise road infrastructure performance. Low lying roads may be submerged, bridges can be damaged by high flows, and landslides or erosion can sever connections. Even relatively moderate flooding on key road segments may propagate disruptions across a whole urban area (He et al., 2024). Failed road links force detours or completely block access, isolating neighbourhoods and critical facilities. Studies have shown that road network density and redundancy (having multiple alternative routes) are key factors in limiting mobility loss during floods (He et al., 2024). Where networks lack alternate routes, even minor floods can trigger catastrophic connectivity losses, cutting off communities. In essence, road infrastructure that is not resilient to flooding can turn a hazardous event into a humanitarian crisis by hinder rescue and response and by stranding populations.

Conversely, resilient road networks through robust design, redundancy, effective drainage, and adaptive traffic management can sustain connectivity and safety even under extreme weather. Maintaining at least an "acceptable level of service" for travellers during flood conditions is a core aspect of resilience (Nipa & Kermanshachi, 2019). Additionally, road resilience means faster restoration of full functionality after floodwaters recede. Given that transportation systems are interdependent with other infrastructures (hospitals, emergency services, supply chains), their resilience during floods is especially critical for overall societal resilience (Tachaudomdach et al., 2021). Ensuring road networks in flood prone regions like Tambaram, Chennai remain operable and safe during flooding is therefore a high priority for both civil protection and economic stability.

2.2 Performance Thresholds in Context of Transportation Resilience

Transportation resilience broadly refers to the system's ability to maintain functional performance during disruptions and recover to normal operation in a timely manner (Arango et al., 2023). Modern definitions of resilience emphasize not only the capacity to absorb and withstand shocks, but also to adapt and recover while sustaining critical services (Arango et al., 2023). In practical terms, a resilient road network should continue maintaining essential functionality even under adverse events (e.g. floods), even though potentially at reduced levels. A key concept in quantifying such resilience is the idea of a performance threshold or minimum acceptable performance that must be upheld. Resilient systems are often characterized by having a predetermined acceptable minimum of functional performance that they should not fall below during crises (Leštáková et al., 2023). For instance, a water distribution network might be required to supply at least a basic volume of water per person per day during an emergency (Leštáková et al., 2023). Similarly, a road network could be expected to support a minimum percentage of trips or connectivity even in flooded conditions. This notion of a baseline performance threshold provides a standard for deciding when service degradation becomes unacceptable.

In the literature, several works have formalized the role of such thresholds in resilience metrics. Wen et al. (2019) note that "critical performance thresholds, below which performance is unacceptable" are commonly used to gauge infrastructure resilience. Many resilience models incorporate a binary evaluation: if system performance stays above the critical threshold (e.g. 80% functionality), the system is considered to have "met" the resilience requirement; dropping below that level signifies an intolerable loss of service (Wen et al., 2019). Indeed, some authors even define resilience itself in terms of maintaining performance above a minimum acceptable level or restoring performance to that level within a target timeframe (Wen et al., 2019). Table 1 summarizes several definitions of threshold values from recent studies, highlighting a common theme of minimum acceptable functionality.

Threshold Value Definition	Source
"Predetermined (required, acceptable) minimum of functional performance", baseline service level that resilient systems must maintain during a disruption.	Leštáková et al. (2023)
"Critical performance threshold, below which performance is unacceptable."	Wen et al. (2019)
"Admissible performance loss", level of performance degradation tolerated under specific conditions, beyond which interventions are triggered.	Arango et al. (2023)

Table 1. *Definitions of threshold value*

As shown in Table 1, the idea of an acceptable performance is universal. For transportation systems, such a threshold might be expressed as a level of service or functionality percentage that must be preserved during a flood. For example, transportation engineers may specify that at least 60% of road network connectivity should remain intact in a 1 in 100 year flood, below which the situation is deemed critical. By setting a concrete benchmark, stakeholders and planners have a reference point to decide when emergency measures or investments are needed (hence "triggers corrective action"). In essence, the threshold separates the realm of tolerable performance from unacceptable failure (Wen et al., 2019). If performance falls below this line, it signals that the system's resilience has been exceeded, and external intervention or rapid recovery is necessary.

However, a limitation in many traditional assessments is that the threshold is treated as a fixed, static value regardless of context (Arango et al., 2023). Often borrowed from risk assessment conventions, a single performance cutoff (e.g. 70% network functionality) is used uniformly for all scenarios. This one size fits all threshold approach yields a binary view of resilience. The system is either “acceptable” (above threshold) or “unacceptable” (below threshold) with no nuance in between. While straightforward, static thresholds ignore the fact that what is acceptable can depend on the severity of the event and stakeholder expectations. A fixed benchmark may be overly lenient under mild disruptions or overly strict under extreme conditions. For instance, expecting 90% mobility during a catastrophic flood may be unrealistic (and unnecessarily costly to design for), whereas accepting only 50% mobility during a minor flood could unduly underestimate achievable performance. In recognition of this issue, recent research has started to explore dynamic thresholds that adjust to circumstances (Arango et al., 2023). The next section delves into the concept of dynamic threshold values and why it offers a more flexible and value informed way to assess transportation resilience.

2.2.1 Dynamic Threshold Value in Resilience

A dynamic threshold value is an adaptive performance benchmark that varies with the context such as the hazard intensity or scenario rather than remaining fixed. In this thesis, dynamic threshold is defined as the as the minimum acceptable performance percentage of the functionality under a given set of conditions (hazard severity), informed by stakeholder values, below which performance is deemed unacceptable. This concept builds on the static threshold idea but introduces context specific acceptability criteria (Arango et al., 2023). Instead of one universal cut off, there may be multiple threshold levels corresponding to different disaster intensities or operational states. Dynamic thresholds thus reflect the intuitive notion that the harsher the crisis, the more we may temporarily tolerate reduced service, whereas in routine or minor events we expect near normal performance.

Arango et al. (2023) provide one of the clearest articulations of the dynamic threshold approach in a transportation context. Their study, focusing on road networks under wildfire hazards, argues that “the system cannot be asked to perform equally for all types of hazard intensities for economic reasons. Hence, there is a need to consider dynamic thresholds.”. In other words, a resilient design should differentiate between normal conditions and extreme events in terms of performance targets. Arango et al. (2023), introduce dynamic thresholds that “reflect the different requirements of the system under different conditions, including normal and extreme” scenarios. These thresholds represent the acceptable loss of performance at each level of hazard effectively formalizing how much service degradation stakeholders are willing to accept as, say, floods go from minor to moderate to severe. Crucially, these thresholds are not arbitrary: they are meant to be grounded in stakeholder expectations and priorities. The more critical a particular functionality (target) is to stakeholders, the higher (stricter) its minimum performance threshold will be, even under stress (Arango et al., 2023).

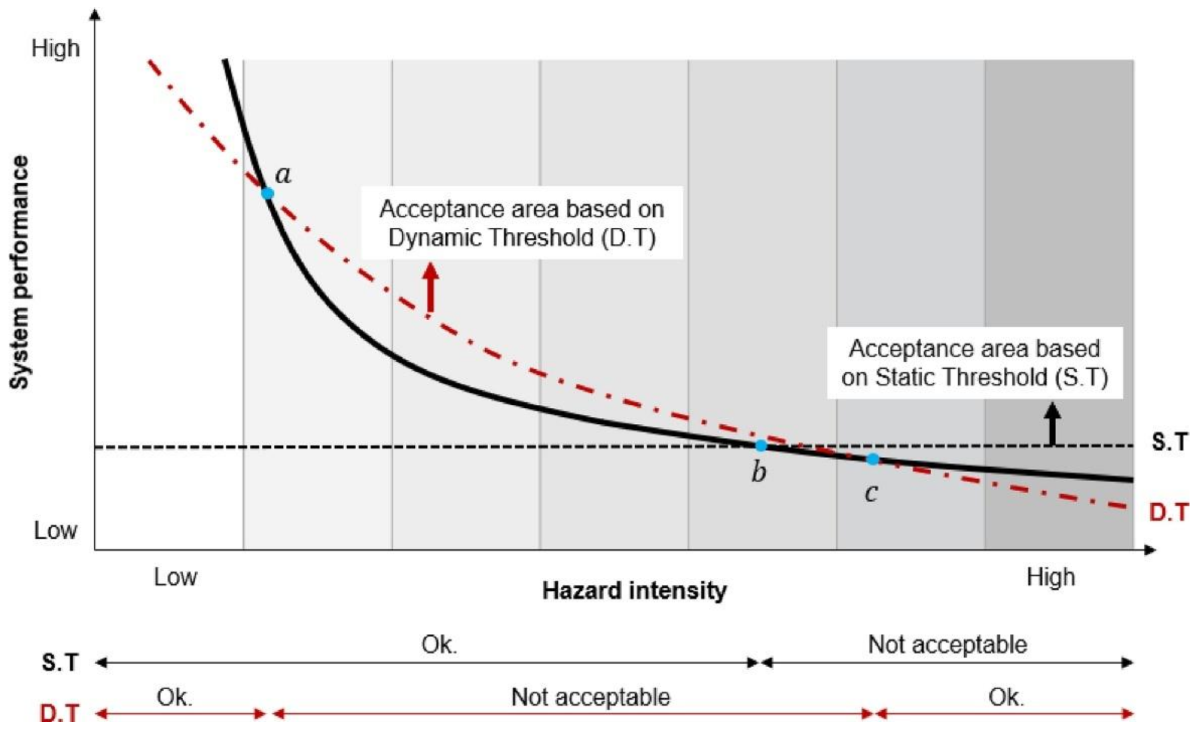

Figure 1. *Comparison between static and dynamic thresholds, S.T., and D.T., respectively, for resilience assessment (Arango et al., 2023).*

Figure 1 illustrates the contrast between a static and dynamic threshold on a hypothetical performance curve. A static threshold is a horizontal line, performance above the line is deemed acceptable, below the line unacceptable, regardless of the event's magnitude. This dichotomy splits outcomes into a simple pass/fail resilience evaluation. In contrast, a dynamic threshold (the dashed curve) rises or falls with hazard intensity. At lower intensities, the acceptable performance level is high (close to normal operations), but as the hazard worsens, the acceptable level may dip, acknowledging that some loss of service is inevitable and tolerable. Eventually, at the highest intensities, the dynamic threshold might even flatten or rise, indicating that beyond a certain point, performance must again be kept above some absolute lifesaving minimum (for example, maintaining basic emergency access). This gradation creates three performance zones instead of two:

(1) Fully acceptable performance (system meets targets for given intensity),

(2) A middle range where performance is degraded yet not disastrous relative to intensity (below ideal but not triggering failure, as long as above the dynamic threshold), and

(3) Unacceptable performance (system fails to meet even the reduced expectations for that intensity).

By dividing performance into these nuanced categories, dynamic thresholds enable a more fine grained resilience assessment. Non-compliance with a threshold at a given intensity does not necessarily imply total system failure it simply flags that performance is worse than stakeholders deem acceptable for that scenario. This perspective aligns with resilience being about degrees of functionality rather than a binary functional versus failed state.

From existing literature, it becomes evident that dynamic or context dependent performance targets are gaining traction as a solution to shortcomings of static metrics. Poulin and Kane (2021), in a comprehensive review of 274 publications on resilience "curves", recommend "broader adoption of adaptive performance targets" that can vary with conditions. They observe that resilience evaluations often implicitly assume fixed benchmarks, which can oversimplify stakeholder needs. Instead, incorporating thresholds that shift with time or severity can better capture stakeholder valuations of performance at different stages of a disruption. Another study on critical infrastructure resilience criteria by Petersen et al. (2020) implicitly uses a dynamic threshold idea by measuring the public's tolerance for service loss under various outage durations. The public's tolerance levels essentially form a variable threshold e.g. citizens might accept only a short power outage on a normal day, but during a major crisis their tolerance (threshold for acceptable outage length) increases. Petersen et al. (2020) found that these tolerance thresholds were higher for severe scenarios than operators might expect, underscoring the importance of empirically determining acceptable performance levels from stakeholders.

In the specific arena of transportation network resilience, Arango et al. (2023) demonstrate how to implement dynamic thresholds via a threshold index. They identified key resilience functions (or "targets") for road networks safety, connectivity, reliability, efficiency and solicited what level of performance should be maintained for each function under both normal wildfire conditions and extreme wildfire events. For example, stakeholders could insist on full connectivity (100% of origin-destination pairs connected) during ordinary disruptions but accept perhaps 70% connectivity during an extreme event. In their case, that meant setting a connectivity threshold of 1.0 for mild conditions versus 0.7 for extreme wildfire, i.e. at least 70% of the network's connectivity should remain intact in the worst case. Such thresholds are expressed on a normalized 0 –1 scale (0% to 100% of ideal performance) for each functionality. A threshold of 1 means no performance loss tolerated (the function must be fully preserved), whereas a threshold of 0 means total loss is accepted (that function can fail without immediate system failure). In practice, a threshold of 0.6 for travel reliability signifies that 60% of trips should remain on-time/reliable even during the disruptive event. By assigning such values for each system functionality at each hazard intensity, one obtains a matrix of acceptable performance levels. This is effectively a "dynamic threshold index" that can be used as a reference to evaluate actual system performance during simulations or real events.

The dynamic threshold concept is particularly suited to this thesis because it marries technical performance metrics with stakeholder value judgments. Traditional static thresholds might be set by engineers or regulations (e.g. design standards requiring X% capacity), but a dynamic threshold approach invites stakeholders the users and operators of the system to define what performance is "good enough" under varying conditions. This is precisely the gap identified in the research problem: resilience should be measured not just in absolute terms, but in terms of what matters most to people relying on the system during floods. By adopting the definition of dynamic threshold value as "the minimum percentage of functionality that must be maintained before performance is unacceptable," and allowing that percentage to change with flood severity, the assessment will directly reflect community and stakeholder priorities. Compared to other possible definitions (see Table 1), this dynamic interpretation is most appropriate here because urban flooding presents a spectrum of severities and trade-offs. A definition that allows thresholds to flex (rather than a rigid pass/fail criterion) is better able to capture whether stakeholders deem that acceptable for an event or a failure. Therefore, a dynamic threshold value approach provides the theoretical backbone for integrating human values into resilience metrics, ensuring that the resulting evaluation is not only technically sound but also socially relevant.

Thus, various definitions of threshold values in resilience literature highlight a minimum acceptable performance level, though terminology varies (critical threshold, baseline functionality, etc). This study adopts a threshold definition as "***the minimum percentage of functionality that must be maintained before system performance is considered unacceptable or triggers corrective action***," aligning with the above concepts.

2.3 Stakeholder Value Integration

Stakeholder value integration at its core, represents the systematic process of identifying, quantifying, and incorporating the diverse values, priorities, and perspectives of multiple stakeholders into resilience assessment and planning frameworks (Babar et al., 2015). This integration goes beyond simple stakeholder consultation to encompass the fundamental restructuring of assessment methodologies to reflect the multifaceted nature of value creation and risk perception across different stakeholder groups.

The theoretical foundation for stakeholder value integration draws heavily from value based requirements engineering, where stakeholders are recognized as, key players in the requirements engineering process (Babar et al., 2015). In the context of resilience assessment, this translates to understanding that different stakeholders may prioritize different aspects of system performance, risk tolerance, and recovery objectives. For instance, emergency responders may prioritize rapid system recovery and alternative route availability, while commercial transporters may focus on predictable service levels and minimal economic disruption.

The concept extends beyond traditional stakeholder engagement by emphasizing the quantification and systematic integration of stakeholder values into technical assessment frameworks. This approach recognizes that the quality of value based idea is realized through the careful consideration of stakeholder requirements (Babar et al., 2015). In transportation resilience contexts, this means that effective resilience assessment must capture not only technical system performance metrics but also the diverse ways that different stakeholders experience and value are affected by system disruptions and recovery processes.

2.3.1 Multi-Dimensional Stakeholder Engagement Frameworks

Contemporary approaches to stakeholder value integration in resilience assessment emphasize the development of collaborative research frameworks that facilitate iterative interactions among diverse researchers and stakeholders around the topic of enhanced climate resilience (Singletary et al., 2022). These frameworks recognize that stakeholder engagement must be designed as an ongoing, iterative process rather than a one time consultation exercise. The implementation of such frameworks requires careful attention to the design of engagement experiences that can effectively facilitate knowledge co-production (Singletary et al., 2022), between technical experts and diverse stakeholder communities.

The multi-dimensional nature of stakeholder value integration becomes particularly evident when considering the diverse perspectives that different stakeholder groups bring to resilience assessment. Transportation system performance indicators are inherently subjective, as every stakeholder in the transport system has a set of indicators that he will find most important (ITF et al., 2024). This recognition necessitates the development of assessment frameworks that can accommodate and systematically integrate these diverse indicator preferences and value systems.

Effective stakeholder value integration frameworks address several key dimensions simultaneously. First, they account for the temporal dimension of stakeholder values, recognizing that priorities may shift across different phases of disaster management, from pre-disaster mitigation (Stage I), post-disaster emergency response (Stage II) and long-term recovery (Stage III) (Zhang et al., 2018). Second, they must accommodate the spatial dimension of stakeholder concerns, acknowledging that local communities, regional authorities, and national agencies may have different spatial scales of concern and responsibility. Third, they must address the functional dimension, recognizing that different stakeholder groups may have fundamentally different relationships with and dependencies on transportation systems.

This multi-dimensional understanding of stakeholder value integration directly informs the design and methodological foundation of this thesis. By focusing on the functional perspective specifically, how system functionalities are valued differently by stakeholders. Unlike traditional models that apply uniform performance criteria across systems, this study captures the dynamic, context specific perspectives of diverse stakeholder groups involved in road transportation management. These perspectives are essential in an urban environment where timely response and continued mobility are critical. By integrating stakeholder value across different flood hazard intensities into a threshold index, the thesis operationalizes the functional dimension of stakeholder engagement in a way that reflects both the complexity and specificity of real world decision making in urban resilience planning.

2.3.2 Resilience Specific Value Integration Approaches

The application of stakeholder value integration to resilience assessment requires a nuanced understanding of resilience itself, which is defined as "the capacity of a system to persist, adapt, or transform in the face of change" (Buyl et al., 2022). This definition encompasses three distinct but interrelated capabilities that stakeholders may value differently: persistence (maintaining functionality during disruption), adaptation (adjusting operations to accommodate changing conditions), and transformation (fundamental system redesign in response to new challenges). Different stakeholder groups may prioritize these capabilities differently based on their specific roles, responsibilities, and dependencies within the transportation system.

The integration of stakeholder values into resilience assessment must account for the fact that resilience itself is a multifaceted concept with different dimensions that stakeholders may prioritize differently. Some stakeholders may prioritize robustness - "the extent to which disruption reduces the functioning of the system", while others may focus more heavily on recovery capacity "the time needed to return to business as usual" (ITF et al., 2024). This distinction is crucial for developing threshold index that can accommodate diverse stakeholder preferences while maintaining analytical rigor.

2.3.3 Defining Stakeholder Value Integration

In the context of infrastructure and disaster resilience, stakeholder value integration is the process of identifying stakeholder value systems (the things stakeholders consider important) and incorporating these values into decision making and analysis tools for resilience. In essence, stakeholder value integration ensures that resilience assessments are not solely technical evaluations of infrastructure performance, but also reflections of what stakeholders deem most vital for the system's functionality and post-disaster recovery.

Recent literature provides converging definitions that highlight the essence of this concept. Table 2 presents a comparative summary of definitions and descriptions of stakeholder value integration. These definitions underscore a common theme: resilience planning and evaluation must align with stakeholder priorities to be truly effective and inclusive.

Source	Definition / Description of Stakeholder Value Integration
Pathak (2020) - Disaster resilience context	*Stakeholder values* are defined as *"the things that are of importance, merit, and utilities to the stakeholders".* Integrating these values into resilience planning is crucial yet often overlooked. Stakeholders hold numerous values with varying importance (a value system) and recognizing these in decision-making helps address shared responsibilities in emergency management.
Ren et al. (2024) – Resilience planning context	Resilience planning *"necessitates the integration of diverse stakeholder values, the things and interests that hold significance and importance [to them] to formulate strategies that are effective and inclusive."* Different sectors (public, private, non-profit) have unique value systems; integrating them is vital to avoid conflicts and achieve consensus in resilience strategies (i.e., a human-centered, inclusive approach).
Gosain (2023) – Infrastructure resilience evaluation	A *human-centered resilience evaluation* framework that incorporates stakeholder value systems and dynamics into the assessment. The approach addresses the gap of traditional models by providing a method to measure what stakeholders value, thereby reducing debates over the costs and effectiveness of resilience initiatives. In practice, this means quantifying and embedding stakeholder priorities into the resilience metrics (e.g., for buildings or networks) to ensure the maximum value is delivered to stakeholders through resilience efforts.

Table 2: *Comparative definitions of stakeholder value integration*

As shown in Table 2, these sources collectively paint stakeholder value integration as a dynamic, multi-sector process of aligning resilience goals with stakeholder priorities. All definitions stress that stakeholders, whether public agencies, private entities, or community groups, have their own value systems (ranked preferences for outcomes or functions) that must be understood and merged into resilience planning. Notably, Ren *et al.* (2024) focus on the need to unify diverse values for consensus building, while Gosain (2023) focuses on embedding values into evaluation models for tangible metrics. Pathak (2020) emphasizes identification of values and acknowledges their dynamic nature across disaster phases. Despite nuanced differences, each perspective underscores that resilience is context dependent, hinging on "resilience of what, to what, for whom" (Linkov et al., 2016), than a one size fits all approach.

Among these definitions, the human centered integration described by Gosain (2023) is the most suitable definition for this research. The reason is that this research aims to directly infuse stakeholder values into a threshold index. Gosain's description explicitly highlights incorporating stakeholder value systems into resilience evaluation, aligning perfectly with this research of developing a stakeholder value integrated threshold index. While Ren et al. provide a valuable lens on achieving consensus among divergent stakeholders, and Pathak illuminates the identification of values, Gosain's definition best captures the methodological integration aspect crucial to this study. It justifies treating stakeholder input not as external to analysis, but as integral data that shapes the metrics and thresholds of resilience. Accordingly, this thesis adopts the view that, stakeholder value integration is the infusion of stakeholder defined priorities and preferences into the core of resilience assessment metrics and decision criteria, ensuring the process and outcomes remain aligned with what stakeholders consider most important.

2.3.4 Stakeholder Value Integration in Threshold Matrix

The development of threshold index for resilience assessment represents a sophisticated approach to stakeholder value integration that can systematically incorporate diverse stakeholder priorities while maintaining analytical tractability. The matrix provides a structured way for translating stakeholder values into quantitative thresholds that can guide resilience assessment and investment decision making. The integration of stakeholder values into threshold index requires careful attention to both the identification of relevant functionalities and the establishment of stakeholder informed performance thresholds for each functionality.

Functionalities in transportation flooding contexts typically encompass several key areas that different stakeholders may value differently. Technical resilience focuses on the physical capacity of infrastructure systems to withstand and recover from flooding impacts, including factors such as structural integrity, drainage capacity, and material durability. Operational resilience addresses the capacity of transportation systems to maintain service delivery during and after flooding events, including route availability, service frequency, and alternative transportation options. Economic resilience encompasses the capacity of transportation systems to minimize economic disruption and support rapid economic recovery following flooding events. Social resilience addresses the capacity of transportation systems to maintain equitable access to essential services and employment opportunities during and after flooding events, with particular attention to vulnerable populations who may have limited transportation alternatives. Environmental resilience considers the capacity of transportation systems to minimize environmental impacts during flooding events and support broader ecosystem recovery processes. Institutional resilience addresses the capacity of governance and management systems to coordinate effective response and recovery processes across multiple stakeholder groups and jurisdictions.

The integration of stakeholder values into threshold index for these system functionalities enhances systematic approaches to stakeholder engagement that can identify both preferences of different functionalities and specific performance expectations within each functionality.

2.4 System Functionality in Road Transportation

To ground the evaluation of "system functionalities" for resilient road transportation, it is necessary to understand the broad dimensions of resilience identified in transportation infrastructure literature. Resilience is multifaceted, and numerous studies have attempted to break it down into constituent dimensions or attributes (often termed **resilience dimensions** or components). A comprehensive review by Nipa and Kermanshachi (2019) identified, eighteen key dimensions of resilience for critical transportation infrastructures. These dimensions encapsulate the various ways a transport system can resist, absorb, and recover from disruptions. Table 3 below lists all 18 resilience dimensions from that study, along with definitions. The dimensions range from structural qualities (like robustness and redundancy) to operational and organizational qualities (like mobility, adaptability, and collaboration). Each definition in the table below highlights how the dimension contributes to a transportation system's resilience.

#	Dimensions	Explanation
1	Robustness	It is the characteristics of the system to be strong enough to absorb the disturbance when exposed to disastrous events (Wan et al., 2018). Hence, a strong and healthy system will have higher robustness.
2	Redundancy	It allows system to have multiple back-up components with same functionality so that in case emergencies the system can continue its service using back-up components when its existing components was disturbed (Liao et al., 2018).
3	Resourcefulness	Frenkleton et al. (2012) took three variables related to resources while evaluating resiliency of transportation network. They are good and material access, resources available (Kermanshachi and Rouhanizadeh, 2018), and fuel and energy. Whereas, Wan et al. (2018) defined it simply as the availability of material and human resources to achieve recovery after a disaster.
4	Rapidity	It is the speed of the system to be recovered to the functionality after a disaster considering all potential barriers to timely post-disaster recovery (Sun et al., 2018; Rouhanizadeh et al., 2019).
5	Efficiency	It is the characteristic of the system that optimizes input-output ration of energy of a system (Murray-Tuite, 2006).
6	Diversity	This characteristic of a system allows the system to have back-up components with different kinds of functionality (Liao et al., 2018). This serves the purpose that the system will be able to withstand multiple types of disasters and threats.
7	Autonomous components	A transportation system to be resilient must have ability to independently function without any control from outside (Liao et al., 2018).
8	Collaboration	This characteristic enables a system to have the ability to share information and resources among stakeholder or components (Murray-Tuite, 2006; Rouhanizadeh and Kermanshachi, 2019).
9	Mobility	This characteristic indicates that the transportation system will be able to provide an acceptable level of service for travelers to move from one place to another (Liao et al., 2018).

10	Safety	A transportation system, to be resilient must be safe enough for the users so that users do not get exposed to the hazards (Liao et al., 2018). In this regard, safety educational sessions are needed to be held for the public (Safapour and Kermanshachi, 2020). Murray-Tuite (2006) listed two variables, count of traffic incidents for a specific section of road and number of vehicles traveling through disaster-prone area, to measure safety.
11	Strength	It is the inherent power of the system to resist outside attack (Liao et al., 2018).
12	Vulnerability	It refers to physical weakness of the transportation system to a disruptive event. It has a negative impact on the speed of the loss of performance during a disaster (Wan et al., 2018).
13	Adaptability	It is the ability of the transportation system to adopt lessons from the current disaster which will help the system to be resilient against future disaster (Panteli and Mancarella, 2017).
14	Flexibility	This dimension measures the ability of the transportation system to adapt itself with the impact of disaster through emergency plan. Though Faturechi and Miller-Hooks (2014) considered flexibility same as adaptability, this study found distinguishing definitions of these two terms in the literature and believed that they should be considered separately.
15	Survivability	It is the ability of the transportation system to endure the initial impact of the disaster to continue the service (Baroud et al., 2014).
16	Preparedness	It is the ability to have certain measures which will help the system in dealing with the disaster (Jin et al., 2014). For example, incorporating an emergency rescue plan with the construction plan of the roads and bridge will make the system more prepared to deal with the disaster.
17	Reliability	It indicates the probability of continuing normal operation all the times (Wan et al., 2018).
18	Responsiveness	It is the ability of the transportation system to recognize the changes that occurred due to a disastrous event (Ivanov et al. 2014).

Figure 2. *Resilience Dimensions for Transportation Infrastructure and Their Definitions*

As shown in Figure 2, transportation infrastructure resilience encompasses a broad spectrum of qualities. Some dimensions are physical/structural (e.g., *robustness, strength, redundancy*), ensuring the system and infrastructure can handle disruptions without failing. Others are functional/operational (e.g., *mobility, reliability, rapidity*), focusing on maintaining service levels and quick recovery. There are also organizational or adaptive dimensions (like *resourcefulness, collaboration, adaptability, preparedness*) that highlight the role of human management and learning in resilience. Notably, many of these dimensions are interrelated. For example, greater redundancy (alternative routes) usually improves mobility during disruptions and contributes to reliability, while preparedness (planning) can improve safety and rapidity of recovery.

2.4.1 Adaptation of System Functionalities for Flood Resilience in Road Transportation

While all the above dimensions are relevant in a broad sense, not all will be explicitly used as "functionalities" in this study. The choice of functionalities to operationalize depends on the context (urban flooding) and the aspects of performance that are more critical for the resilience of the system. In this case, the road network in Tambaram, Chennai is the system. Based on the literature and the specific needs of road transportation in Tambaram, this research will focus on a tailored subset of functionalities that define the resilience of the system:

- **Safety** in the context of flood resilience refers to the transportation system's capacity to remain safe for users during and after a disaster. This includes preventing accidents on flooded roads, ensuring secure conditions for travel, and enabling safe evacuation or emergency access. A resilient road network should not only remain open but do so without endangering its users. Flood conditions often increase crash risks (e.g. vehicles skidding in water, people driving into inundated areas) and pose hazards like road collapse or strong currents. Therefore, safety is an indispensable functionality: a transport system that functions during floods but results in injuries or fatalities would be a failure in resilience terms.

  Academic research increasingly treats safety resilience as a measurable aspect of transport systems. For example, Tang *et al.* (2022) developed a method to assess the safety resilience of urban road traffic during extreme rain (waterlogging) by examining changes in system performance before and after the flood. This approach recognizes that maintaining a high level of service is not enough, the system must also operate safely under disaster conditions. Safety oriented resilience can include features like "safe to fail" infrastructure design (where any failures cause minimal harm) and traffic management strategies (e.g. timely road closures or warnings) to avoid accidents during floods. As noted in one study, transport resilience is essentially a guarantee for the safety and good operation of a city during disasters, meaning a resilient transport system keeps people out of harm's way while maintaining functionality (Tang *et al.,* 2022).

  The emphasis on safety aligns strongly with the priorities of government officials and emergency responders, Key stakeholders in this study. Their first concern in any disaster is protecting lives and public safety. A flood-resilient road system in Tambaram must allow emergency services to reach people swiftly and without undue risk, and it must minimize situations where citizens are trapped in hazardous conditions. Indeed, a safe network supports efficient rescue and relief: if ambulances and relief convoys can move without facing washed out roads or accidents, response times improve. Literature on resilience planning echoes this, noting that transportation resilience ensures the safety and operation of the system in response to disasters (Tang *et al.,* 2022).

Therefore, **"Safety"** as a functionality means that during floods the road network remains secure for travel, thereby preventing secondary disasters (like traffic accidents or unsafe evacuations) and upholding the fundamental duty of care the transport system owes its users.

- **Reliability** in this context denotes the consistency and dependability of the road transportation system's performance during flooding. A reliable transport system maintains predictable travel times and overall service quality even under stress. In resilience terms, reliability can be thought of as the network's inherent robustness and its ability to function without frequent breakdowns or excessive variability when facing a flood. This functionality is important because during disasters, travel time can severely hamper emergency response and public confidence. If roads that are expected to hold up remain within acceptable travel time bounds, we consider the system performance reliable.

  Transportation experts have increasingly integrated reliability metrics into resilience assessment. For example, Dong *et al.* (2022) incorporate a "link reliability" concept using thresholds of road link performance (speed/travel time) to evaluate network resilience during floods. By doing so, they capture how consistently the network can meet travel demand in a disrupted scenario. Their case study of Hurricane Harvey in Houston showed that reliability-based metrics effectively tracked the network performance variation during flooding. In simpler terms, a resilient network should not suffer erratic or catastrophic performance drops; it should remain as stable and predictable as possible throughout the event. Another way to view reliability is the probability that the system or a given link "survives" the flood without failing. In infrastructure engineering, reliability is about preventing initial failures (Kim et al., 2025). For instance, ensuring that key bridges and road segments are unlikely to be washed out or closed. A highly reliable road network has strong robustness (can take a hit without failing) and often is designed with safety factors and protection measures that keep it operational.

  From a stakeholder perspective, reliability is paramount for planning and response. Government transport planners set resilience goals that explicitly mention reliability. Minnesota's Department of Transportation (2017), defined its resilience objective as *"reducing vulnerability and ensuring redundancy and reliability to meet essential travel needs"*. This highlights that reliability, alongside redundancy, is seen as crucial to guaranteeing essential mobility (for work, emergency, etc.) during extreme events. Emergency responders require reliable routes, they must trust that certain roads will be passable when needed, and travel times will be consistent enough to plan evacuation or medical logistics. An unreliable system (where roads unpredictably fail or congestion skyrockets) can undermine response efforts and public safety. On the other hand, a reliable road network would mean, for instance, that even in heavy rain, critical corridors can be counted on to remain open, and travel time variability is minimized by proactive measures (like real time traffic management and flood monitoring). Such steadiness greatly aids coordination among responders and maintains public trust that mobility needs will be met.

Thus, **“Travel time Reliability”** as a functionality ensures that the transport system’s performance under flood is as close as possible to normal conditions with respect to travel time. It complements redundancy: while redundancy provides alternative options, reliability ensures that both primary and backup options are likely to function as intended without much travel time delay.

- **Connectivity:** Connectivity is chosen as a functionality because it directly contributes to connectivity under duress. In the flood context, redundancy refers to having multiple routes or backup options if a particular road segment is inundated. In practice it covers keeping critical routes open or finding alternative paths providing connectivity between important locations (hospitals, shelters, residential areas). This aligns with stakeholders’ interest in maintaining access for emergency response and essential travel. The questionnaire will, for example, gauge how stakeholders value having alternate roads as compared to other features. Redundancy is highly relevant to Tambaram, where flood-prone choke points can paralyze traffic if no alternate routes exist.

  Connectivity refers to the presence of alternate routes and interconnections in the road network that allow traffic to reroute when some links are disrupted by flooding. It is a measure of how well the system can continue to connect origins and destinations despite partial failures. A highly redundant road network has multiple paths between key locations, so that even if one corridor is flooded, others can take over the traffic flow. This functionality is crucial in flood resilience: it directly addresses the risk of certain areas becoming isolated or inaccessible when specific roads are underwater.

  Connectivity is widely recognized as a cornerstone of resilient system. As a Transportation Research Board study succinctly states, *“Road network redundancy contributes to reducing [disruption] consequences by providing viable alternative routes.” (Allen et al., 2024)*. By having backup links, the system ensures that communities are not cut off a factor especially important for isolated communities and emergency routes (Allen et al., 2024). Recent research quantifies the benefit: adding secondary roads to increase redundancy can decrease the expected increase in travel times during disruptions by over 90% on average (Allen et al., 2024). In other words, a web of well-connected streets can absorb the shock of a flood by rerouting traffic and drastically reducing delays and isolation. Kasmalkar *et al.* (2020) found in a flood study of the San Francisco Bay Area that areas with dense road networks (high connectivity) were more resilient to flood-related travel time delays, because alternate roads had enough capacity to handle detoured traffic. This empirical insight reinforces that connectivity is vital for keeping the city moving in a flood.

For stakeholders like government officials, redundancy is a strategic asset. It provides flexibility in crisis management: officials can implement diversions and use alternate corridors for relief logistics or evacuation. Emergency responders likewise rely on multiple access routes; a blocked road should not mean a blocked rescue. Indeed, research on lifeline networks often defines reliance on redundancy as a means to avert progressive failures across the system (Kim et al., 2025).

By selecting **"Connectivity"** as a key functionality, this study focuses on the network level resilience ensuring the transport system has the necessary "web" of connections so that no area becomes unreachable and critical services can reroute as needed during floods.

With the system functionalities finalized for the threshold index, the next step involves classifying hazard intensity to support its construction. The following section provides a concise overview of the flood intensity classification.

2.5 Flood Intensity Classification

In performance-based flood resilience frameworks, categorizing flood hazard intensity into discrete bands (e.g., low, medium, high) is essential for mapping and quantifying acceptable system performance thresholds. The selection of low flood: **15 cm**, medium flood: **25–30 cm**, and high flood: **> 30 cm** as inundation depth reflects a balance between stakeholder experience, operational meaningfulness, and empirical evidence on damage and response. Table 3 represent the classification of flood intensity based on depth of inundation.

Depth band	Resources
Low (15 cm)	Baseline threshold; widely used as minimum hazard level globally (Fox et al., 2024). Represents minor impacts easily recognized by stakeholders.
Medium (25–30 cm)	Aligns with onset of moderate damage/functionality loss (commonly 0.25–0.5 m damage bands). Accessible for stakeholder reasoning and aligns with depth damage evidence (Romali et al., 2025; Maranzoni et al., 2022).
High (>30 cm)	Crossing into severe impairment of safety/connectivity. Recognizes significant disruption prior to more extreme flooding.

Table 3. *Flood Intensity Classification*

Flood depth values as low as 15 cm (0.15 m) are not trivial. Global risk assessments have commonly used 15 cm as a baseline inundation threshold with substantial implications. For instance, studies estimate that approximately 2 billion people are exposed to fluvial floods at depths ≥ 10 cm, underscoring its relevance as a baseline flood hazard category with real impact on populations (Fox et al., 2024). This makes it a practical starting point for low intensity hazard classification, water depths that may still impair base level services, pedestrian mobility, or minor vehicle operation, yet are commonly recognizable by the public and stakeholders (Fox et al., 2024).

While exact literature on 25–30 cm thresholds is less abundant, many depth damage studies and building vulnerability models use damage and impact bands (e.g., 0.25–0.5 m) reflecting moderate damage onset. System functions, especially in transport networks often degrade significantly as water depth crosses 25 cm: doors become harder to open, electrical or mechanical equipment may be affected, and slower vehicle operation becomes typical. Thus, the choice of 25–30 cm corresponds to the boundary where moderate functional degradation starts to materialize (Romali et al., 2025; Maranzoni et al., 2022).

Flood depths exceeding 30 cm (0.30 m) have clear, adverse operational implications—road networks become obstructed, pedestrian and vehicular safety dramatically decrease, and many essential services (e.g., pumping stations, ground floor utilities) risk complete failure. Many global guidance frameworks start marking 0.5 m as a damaging threshold for buildings or serious safety concerns. Setting the high flood category at > 30 cm thus captures a regime of severe impact while remaining sensitive to functional degradation.

2.5.1 Why Depth of Inundation is suitable for this study

Flood depth is among the most direct hydrological variables tied to damage and functional loss. System functionality including safety, connectivity, and reliability typically degrades as water depth increases. Depth damage functions central to flood risk modeling, as used in NFIP claims studies, emphasize depth as the strongest predictor of damage even if its predictive form varies locally (Romali et al., 2025).

In addition, this study emphasizes stakeholder input via semi-structured interviews and mixed-methods threshold elicitation. Therefore, depth is intuitive, participants can readily imagine or have experienced water levels of 15 cm, 25 cm, or 30 cm and can articulate what system performance means under such conditions. This interpretability ensures that the quantitative matrix genuinely reflects system’s perspective from the users.

2.6 Weighted Average Aggregation (WAA)

Weighted average aggregation is a mathematical technique for combining multiple inputs (e.g. criteria scores, stakeholder opinions) into a single representative value by assigning a weight to each input proportional to its importance and then summing the weighted inputs (Ruangpan et al., 2020). This approach is essentially the linear additive model in multi-criteria decision analysis (MCDA), also known as simple additive weighting (Ruangpan et al., 2020). When all weights are equal, the method reduces to a simple arithmetic mean. In the context of this thesis, weighted average aggregation is used to synthesize stakeholders' numeric inputs (threshold percentages for each functionality under each flood severity) into a aggregated value for analysis. Each stakeholder's input contributes to the final threshold, with the "weight" reflecting the relative influence or count of that input. For this study, all stakeholders are treated equally (equal weights), meaning the aggregate is essentially the mean of the provided percentages. This aligns with the principle of giving each participant an equal voice in defining performance thresholds.

Weighted averages are widely favored in decision making and resilience assessment for their simplicity, transparency, and intuitiveness (Ruangpan et al., 2020). First, the method makes combining different inputs straightforward and easily explainable every stakeholder's opinion or every criterion's value is explicitly represented by a weight, enabling transparency of how the final number is obtained. This transparency is valuable in participatory processes and stakeholder-driven studies, since participants and decision-makers can understand how the final results were derived. Marttunen et al. (2015) and Guarini et al. (2018) note that simple weighted summation provides a high degree of clarity in evaluation processes, making it "very suitable to be used in participatory processes".

Secondly, weighted averaging treats inputs impartially when equal weights are used, no single stakeholder's response is prioritized over another's, which aligns with normative ideals of fairness in stakeholder engagement. This was important for this study: every interviewed road user's perspective is equally valid, so the aggregation reflects a collective threshold rather than an expert driven one. As a result, the threshold index derived is grounded in an equitable combination of perspectives.

Moreover, the method aligns with the mixed methods approach by providing a straightforward quantitative outcome (the threshold values) that can be easily paired with qualitative insights. Because the results are simple percentages (e.g. "on average, stakeholders in Tambaram require ~50% of normal road safety to still be ensured under a high severity flood"), they can be readily interpreted and discussed alongside interview quotes and themes. This is harder to achieve with opaque mathematical models. Additionally, using a weighted average avoids imposing any external value judgments beyond what stakeholders provided. This simplicity also aids in validating and checking the results.

In essence, the weighted average served as a “group aggregation” mechanism, wherein the average acts as a central tendency of the community’s minimum acceptance, while still allowing to note variability around that average. This combination of methodological rigor and practical clarity is a prime reason Weighted average Aggregation was chosen as the core quantitative technique for developing the Threshold Index in this thesis.

2.6.1 Comparison with Other Decision-Making Methods

While a simple weighted average was deemed most suitable for our purposes, it is important to justify this choice by comparing it to other available methods for incorporating stakeholder values into resilience assessments. Many decision-making and multi-criteria analysis (MCA) methods exist, each with its own strengths, assumptions, and fit to context. In this section, two prominent alternatives are discussed and why the weighted average (as implemented in this study) is a better fit for this research design.

2.6.1.1 Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) is one of the most widely used decision-support methods, especially in fields like flood risk management and infrastructure resilience. AHP works by structuring a decision problem into a hierarchy (e.g. goal → criteria → sub-criteria) and then deriving priority weights through pairwise comparisons of elements at each level. Decision makers (or stakeholders/experts) compare two criteria at a time, expressing which is more important and by how much, and through an eigenvector calculation AHP yields a set of weights for all criteria that best reflects those comparisons. This structured approach is valued for converting qualitative judgments into quantitative weights in a consistent way (Won et al., 2024). Indeed, a review by De Brito and Evers (2016) found that AHP was the “most common MCA method used in flood risk management” due to its flexibility and ease of application. Numerous resilience studies have adopted AHP to integrate stakeholder or expert preferences. For example, Moghadas et al. (2019) applied AHP to determine the relative importance of six urban flood resilience dimensions and their indicators in Tehran. By interviewing experts and performing AHP, they obtained weights for criteria like social, economic, infrastructural resilience, which were then used to construct a composite resilience index for different city districts. The appeal of AHP in such cases is that it provides a systematic framework to capture subjective priorities. AHP also includes a built-in consistency check; it calculates a consistency ratio to ensure that the pairwise comparisons made by participants are logically consistent (e.g., if A is preferred to B and B to C, then A should be preferred to C). This adds a level of rigor to the elicitation of stakeholder preferences.

Despite its strengths, AHP has notable limitations that affect its suitability for this study. One issue is scalability. AHP requires pairwise comparisons to weight criteria, which becomes tedious as number of criteria grows. In this study, stakeholders would potentially need to compare each system functionality against each other (safety vs. connectivity, safety vs. reliability, etc.) for each flood scenario, which could be overwhelming and impractical in an interview setting. Even with a moderate number of criteria, the cognitive load on participants to perform numerous comparisons reliably is high. Also, semi structured interviews were designed to be respondent friendly and mostly qualitative. So, inserting a full AHP questionnaire would disrupt the conversational flow and possibly deter participants with its repetitive nature. Instead, stakeholders were directly asked for threshold percentages in an intuitive way ("what % of normal service would you consider acceptable for X in a flood?") rather than indirectly via pairwise comparison questions. Another limitation is that AHP yields relative weights, not absolute performance values. AHP by itself would only tell us, for instance, that stakeholders prioritize "Safety" twice as much as "connectivity" (hypothetically), but it would not directly give the acceptable performance level for the functionalities. In other words, AHP is excellent for priority weighting but not for threshold setting. If this research aim were to produce a single composite resilience score for the road network, then AHP might be used to weight each dimension and then compute a weighted sum. However, this research aims to establish specific threshold values per system functionality, reflecting stakeholder expectations on each.

Thus, incorporating AHP would add complexity without clear value for this specific goal. In fact, Kim et al. (2024) note that while AHP is convenient for criteria importance, it often "faces limitations when dealing with interdependence among factors, necessitating an additional step to generate a composite index using the calculated weights". This threshold index is designed in a way that it keeps each functionality separate during the data collection.

2.6.1.2 Fuzzy Logic and Other Multi-Criteria Methods

Beyond AHP, a variety of other decision-making methods could potentially be applied to integrate stakeholder values in resilience assessments. Two categories worth comparison are fuzzy logic-based aggregation and other multi-criteria decision-making (MCDM) techniques like TOPSIS or Delphi based aggregation/consensus. This sub section briefly examines these and explain why a basic weighted average was still preferable for this thesis.

Fuzzy Aggregation Methods: One advanced extension of the weighted average is the use of fuzzy logic to handle uncertainty or vagueness in stakeholder inputs. In many real world cases, stakeholders might not have precise numeric answers about their preferences; instead, they might express things in linguistic terms (e.g. "safety should be almost fully ensured" or "mobility can drop a bit"). Fuzzy logic provides a mathematical way to convert such linguistic or uncertain inputs into fuzzy sets and then aggregate them. A technique known as Ordered Weighted Averaging (OWA), introduced by Yager (1988), allows a range of aggregation behaviors between pure “AND” (minimum) and “OR” (maximum) by applying ordered weights to sorted inputs. A recent study by Tavakoli et al. (2025) applied a fuzzy ordered weighted averaging (FOWA) method in flood risk management. Their integrated approach combined AHP (to get factor weights) with FOWA to incorporate expert uncertainty in evaluating flood risk scenarios. The authors highlight that “the fuzzy ordered weighted averaging method addresses data imprecision and subjective variability, which are often limitations in conventional approaches”. In other words, fuzzy OWA can produce aggregated /consensus outcomes that consider not just the central values stakeholders give, but also the range of opinions and the confidence in those opinions. For example, if some stakeholders are very uncertain or divided, a fuzzy aggregation could reflect that by not averaging in a straight line but perhaps giving more weight to cautious estimates under certain “pessimistic” scenarios.

Fuzzy methods have been used in other domains for stakeholder integration as well. For instance, in construction project management, Chong et al. (2024) utilized fuzzy stakeholder salience scores and then defuzzified them with a weighted average to get clear rankings of stakeholder importance. Likewise, in climate adaptation planning, fuzzy Delphi techniques (iterative expert surveys with fuzzy scoring) are sometimes employed to achieve aggregated /consensus on uncertain parameters. These methods are powerful when dealing with ambiguity, offering a nuanced output that a single crisp average might miss.

However, for his research, the added complexity of fuzzy logic was not justified. To obtain percentage thresholds from stakeholders by clarifying their responses during interviews (e.g. asking follow-up questions like “could you put a number to what ‘significantly reduced’ means in percent?”). As a result, the data is already in a quantified form. The variation and any uncertainty in these responses can be observed in the spread of answers, which we handle by analyzing variability qualitatively (flagging outliers, discussing divergence) rather than by computing a fuzzy interval. In a larger sample or a survey where respondents simply tick qualitative boxes, a fuzzy approach might be more needed. But in this case, the semi-structured interviews allowed recording numbers, effectively reducing ambiguity at the data collection stage. Thus, a straightforward average on those numbers is sufficient and easier to communicate.

Other MCDM Techniques (e.g., TOPSIS, VIKOR, Delphi): Aside from AHP and fuzzy logic, various other multi-criteria decision-making techniques exist such as TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), VIKOR, ELECTRE, and so on, as well as consensus building processes like the Delphi method. Some of these have been applied in resilience measurement studies. For example, TOPSIS was used by Abdallah et al. (2022) to rank emergency flood management options, using stakeholder-weighted criteria to identify the solution closest to an “ideal” resilience scenario. Moghadas et al. (2019), mentioned earlier, actually combined AHP with TOPSIS: AHP produced weights for resilience indicators, and then TOPSIS was employed to score and rank Tehran’s districts by resilience.

These approaches are very useful when the goal is to choose among or rank alternatives (e.g., which district is most resilient, which intervention is best) based on multiple weighted criteria. However, for this research ranking alternatives is not the aim instead capturing minimum acceptable performance percentages (threshold percentage). Thus, applying a full TOPSIS or similar method would be conceptually misaligned with the objectives.

Also, traditional MCDM tools add unnecessary layers in this setup. The Delphi method is another avenue one might consider for reaching consensus on resilience thresholds. Delphi involves multiple rounds of surveys where experts (or stakeholders) anonymously rate or estimate something, see the group feedback, and revise their answers in subsequent rounds, converging toward consensus. Delphi has been used to develop indicators and thresholds in disaster management by leveraging expert agreement over iterations. Mini-Delphi approach theoretically can be used with the participants of this study. For example, doing a second round where the initial average thresholds will be presented and allow stakeholders to adjust their views. However, Delphi is time intensive and typically relies on expert panels rather than users. Participants for this study were everyday road users; expecting them to participate in iterative rounds was not practical. Given the limited timeframe, a one round direct query with a simple average aggregation was the most efficient path. This still captures the essence of the average without the attrition and effort of multiple Delphi rounds.

Table 4 below synthesizes the comparison of the three approaches discussed: simple weighted average, AHP, and a fuzzy/advanced method in terms of their effectiveness and use in integrating stakeholder values.

Method	Description & Use	Pros	Cons	Application
Weighted Average Aggregation (WAA)	Simple linear combination of inputs with assigned weights. Used to aggregate criteria scores or stakeholder opinions into one value. In this case, stakeholders' acceptable performance percentages are averaged (equal weights) to reflect group aggregation.	– Transparent & easy to interpret. – Impartial if weights equal (each voice equal). – Suitable for participatory settings (stakeholders can follow the logic). – Requires minimal data processing (direct use of inputs).	– Does not inherently capture uncertainty or differing confidence levels (treats inputs as precise values). – Minority extreme views can be masked by the average (outliers get diluted). – Assumes criteria or inputs are commensurable (often requires normalization if scales differ).	Stakeholder mapping: Zhu et al. (2024) combined fuzzy stakeholder scores via weighted average to identify priorities
Analytical Hierarchy Process (AHP)	Hierarchical decision method involving pairwise comparisons to derive weights for criteria. Common in risk management to integrate expert preferences into a weighting scheme for multi-criteria evaluation. Could be used to weight system functionalities.	– Structured elicitation of preferences (pairwise comparison simplifies complex judgments). – Ensures consistency (calculates consistency ratio) in stakeholder judgments. – Widely validated in literature for incorporating	– Scalability issues: impractical with many criteria or participants due to explosion of comparisons. – Only yields relative importance weights; needs to be combined with actual performance scores to make decisions.	– Urban flood resilience index: Moghadas et al. (2019) used AHP to weight indicators, combined with TOPSIS for ranking districts. – Stakeholder preference in NBS: Loc et al. (2017) and Alves et al. (2018) used AHP to get stakeholder weights on criteria (social, enviro,

		stakeholder/ expert input in decisions	– Participants may find pairwise comparisons repetitive or confusing, potentially affecting reliability.	economic) in flood solution appraisal. – General flood planning: Many studies reviewed by De Brito & Evers (2016) cite AHP as the go-to method for criteria weighting in flood risk MCA.
Fuzzy & Advanced MCDA (Fuzzy Ordered Weighted Averaging, TOPSIS, Delphi)	Extensions or alternatives to linear weighting that can handle uncertainty or provide rank order decisions. Fuzzy OWA introduces a range of weights reflecting optimism/ pessimism in aggregation. TOPSIS identifies best option by distance to ideal solution. Delphi uses iterative consensusbuilding among experts.	– Accounts for uncertainty: Fuzzy sets capture ambiguity in human inputs, potentially yielding more robust consensus. – Scenario analysis: OWA can produce optimistic vs pessimistic aggregate scenarios by adjusting weighting strategy. – Alternative ranking: Methods like TOPSIS/ELECTRE can give a full ranking of options, useful for decision making (not just a single value). – Delphi: rich qualitative insight alongside quantitative	– Complexity: requires expertise to set up (membership functions, rule sets) and interpret by stakeholders (reducing transparency). – Data demands: often need larger sample or more data points to justify fuzzy distributions or multiple rounds of Delphi. – Not directly needed if goal is not option selection: e.g., TOPSIS gives relative rankings but we needed absolute threshold values, which is a different task.	– Resilient flood management: Tavakoli et al. (2025) integrated AHP with FuzzyOWA to improve handling of data imprecision in flood risk mapping. – Stakeholder consensus with uncertainty: Fuzzy Delphi used in climate adaptation to settle on priority actions under uncertainty (e.g., Kwon et al., 2017 in coastal planning – hypothetical example for illustration). – Disaster indicator prioritization: Kim et al. (2024) propose a Q-methodology (inverted factor analysis) as an alternative, ultimately suggesting a

		ratings; reduces extreme divergence through iteration.		weighted-average approach for combining local importance of indicators (showing innovative use of averaging after qualitative sorting). – Expert consensus: Delphi method applied in developing community resilience indicators (e.g., Cutter et al., 2013 used Delphi to refine a set of recovery indicators illustrative reference), though seldom used for setting numeric performance thresholds due to time required.

Table 4. *Comparison of weighted average aggregation with AHP and fuzzy/advanced methods for integrating stakeholder values*

As shown in the table, each method has distinct merits. AHP offers a rigorous weighting mechanism that is well proven for incorporating stakeholder judgments, but it introduces process complexity that can be at odds with an exploratory, interview-based study. Fuzzy methods and other sophisticated MCDA tools can handle nuanced uncertainties and provide additional analytical depth (like scenario exploration with optimistic vs pessimistic aggregates), yet they come at the cost of technical overhead and potential opacity in results communication. The weighted average, in contrast, strikes a balance by being simple yet effective, yielding easily interpretable outputs that directly reflect the collected data.

Chapter 3

Methodology

3.1 Introduction

This chapter details the research design, data collection, and analysis methods used to address the study's objectives. A mixed method approach was adopted, combining qualitative insights from semi structured stakeholder interviews with a quantitative aggregation of responses into a threshold matrix. The methodology is structured in several sections. First, the overall research design and approach is explained, including the rationale for integrating qualitative and quantitative methods. Next, the geographical scope of the study context and participant sampling strategy are described, followed by a detailed account of the semi-structured interview procedure and protocol. The chapter then outlines the analytical techniques: qualitative analysis of interview data (following the Gioia methodology for rigor) and quantitative calculation of the threshold matrix using a weighted average. Finally, ethical considerations and quality measures (such as validity and reliability strategies) are discussed.

3.2 Research Design and Approach

This research focuses on the Tambaram area in Chennai, using semi-structured interviews as the primary data collection method. The nature of the inquiry is exploratory and inductive, aiming to understand users' perspectives on acceptable road system performance under flood conditions. Given the exploratory goals and the emphasis on contextual stakeholder input, a qualitative methodology is central to capture nuanced views and values. Semi structured interviews are well suited for this purpose, as they allow respondents to openly express their viewpoints in a flexible conversation format while still covering predetermined questions (Ruslin et al., 2022). Unlike fully structured interviews or surveys, the semi structured format provides both comparability across interviews and adaptability in probing relevant issues raised by participants (Ruslin et al., 2022). This flexibility is important to delve deeper into the reasons behind users' threshold choices and to clarify concepts during the conversation.

While primarily qualitative, the study incorporates a quantitative component in the form of the threshold matrix. Participants provided numeric estimates (percentage thresholds) for acceptable performance levels of the road network. These numerical inputs are aggregated to produce a quantitative threshold matrix representing collective user defined acceptable performance under various flood scenarios. Thus, the research design can be considered a convergent mixed methods design, where qualitative and quantitative data are collected from the same interviews and then integrated. The qualitative data (participants' explanations, opinions, and contextual insights) provide depth and understanding, while the quantitative data (percentage thresholds) provide a structured outcome. This integration aligns with a pragmatic research paradigm valuing both subjective insights and objective measures appropriate for resilience assessment that needs to bridge technical metrics with stakeholder perspectives.

The choice of this design is driven by the identified research gap that current flood resilience assessments lack stakeholder defined performance thresholds. Traditional engineering resilience models often apply uniform technical standards without accounting for user perceptions. By directly eliciting thresholds from road users, the study ensures the assessment criteria reflect user values and priorities. The combination of qualitative and quantitative methods is intended to produce a result (the threshold matrix) that is both grounded in stakeholder input and operationally useful for decision making. The qualitative insights help explain why stakeholders consider certain levels acceptable, adding context to the raw numbers. This strengthens the study's interpretive rigor and helps in translating the findings into practical recommendations.

The research is confined to Tambaram, Chennai, an urban region frequently affected by flooding, which disrupts its road transportation network. The findings are intended primarily to benefit Tambaram. Thus, emphasizing internal validity and contextual relevance over broad generalizability. However, the methodology integrating stakeholder values into resilience thresholds is designed to be a transferable process for other flood prone urban areas. This aligns with the aim of developing a practical yet context sensitive method for resilience planning.

In summary, the research design is characterized by an interpretive, qualitative core (to capture users' perspectives) augmented with a simple quantitative synthesis (to under and justify the threshold values through their rationale). The subsequent sections detail how this design was implemented.

3.3 Participant Selection and Sampling Strategy

The study targeted daily users of the road network in Tambaram as the key stakeholders. This included ordinary citizens such as commuters, residents, and local drivers who regularly travel within Tambaram, especially in and around the Tambaram railway station area. These individuals are likely to experience the impacts of road flooding firsthand and can provide information based on perceived risks on what performance levels (in terms of safety, connectivity, and travel time reliability) are acceptable during flood events. By focusing on daily road users (rather than, say, policymakers or engineers), the study embraces a bottom up perspective on resilience and to gain insights on unique/peculiar perspectives that occurs from looking at the system from a non-technical view point.

All participants were adults (over 18), capable of giving informed consent. A purposive sampling strategy was employed, deliberately selecting participants who fit specific criteria aligned with the research objectives. In qualitative research, a relatively small, purposively selected sample is appropriate to gain depth of understanding (Campbell et al., 2020). The aim here was not statistical representativeness but to ensure that those interviewed could offer rich, relevant information about the expected road network's performance under flood conditions. Purposive sampling allows to include participants who are most likely to yield insightful data (Campbell et al., 2020). In this study, the key criteria were:

1. the participant is a regular user of Tambaram's roads, and

2. the participant resides in one of the five zones of Tambaram.

The latter criterion was important to capture spatial variation in experiences. Tambaram is administratively divided into five zones, and flooding impacts (and possibly expectations of road performance) might differ across these zones. Therefore, the sample was stratified by zone to ensure coverage of all areas of Tambaram.

A total of 15 participants were interviewed. The distribution was 2 to 4 participants per zone, resulting in fairly balanced representation from each of the five zones (Zone 1 through Zone 5). This stratified purposive approach (covering all zones) was chosen so that the final threshold matrix/index would integrate perspectives from across the entire area rather than being dominated by one locality (Campbell et al., 2020). In qualitative inquiry, 15 interviews are within a common range for achieving data saturation, where additional interviews are unlikely to yield fundamentally new insights (Guest et al., 2006). Guest et al. (2006) observed that saturation of themes often occurs within the first dozen interviews in a relatively homogeneous population. Given that road users in a single town share many common experiences (though with individual differences), 15 was deemed sufficient to capture the major trends and variations in stakeholder responses.

It is worth noting that the goal of the sample was not to generalize to all Tambaram residents with statistical confidence, but to understand a range of perspectives and ensure inclusivity of different neighbourhoods. This kind of purposeful variation sampling enhances the study's rigor by making sure that potentially different viewpoints (due to different flood exposures in each zone) are all reflected in the data (Campbell et al., 2020). In other words, if certain zones experience worse flooding or have different road conditions, the study wanted those voices included. This strategy improves the credibility and transferability of findings: credibility because it increases the chance that all relevant viewpoints were heard, and transferability because readers can see how thresholds might vary with context (so they can judge applicability to other settings).

Participants were recruited through professional and personal networks in Tambaram. This involved reaching out to contacts who either themselves fit the criteria or could refer the researcher to others (snowball technique). Specifically, colleagues from a prior internship, friends' parents, and acquaintances of family in Tambaram were contacted as initial leads. Importantly, recruitment followed a voluntary opt-in process. Initial contact was made only to inform individuals about the study and ask if they would be interested in learning more. If they expressed interest, they were then sent the formal invitation and Informed Consent Form (ICF). The study took care to avoid any form of coercion or undue influence. No financial incentives were offered, to avoid biasing participation; interviewees participated pro bono, motivated by interest in the topic or altruism towards improving local flood resilience.

The resulting sample (15 interviewees across five zones) is summarized as follows: Zone I – 3 participants, Zone II – 3 participants, Zone III – 3 participants, Zone IV – 3 participants, Zone V – 3 participants. Within these, there was a mix of genders, ages, and occupations (for instance, participants included working professionals who commute daily and who travel locally, and small business owners). This diversity adds breadth to the perspectives, though the study did not explicitly stratify by demographics beyond location. All participants reported using private cars as a mode of transport, which is relevant since the threshold values elicited were specifically framed for private car travel (this was a deliberate focus to keep responses comparable, as different modes of transportation change the perspective or the acceptable performance might vary).

3.4 Data Collection Procedure

All data were collected through semi-structured interviews conducted online. Given that participants were located in Tambaram, Chennai, India, the interviews were carried out via video conferencing. An online mode was selected for practicality and safety (especially considering any travel restrictions or convenience for participants). The consent was received from the participants prior to the interview or at the beginning of the interview (see Appendix B for the Informed Consent Form) and a brief explanation of the study's purpose and what the interview would involve. Participants were asked to read the informed consent form carefully and were encouraged to ask any questions about it before proceeding.

In line with ethical protocols, informed consent was obtained explicitly from all participants before starting the interview. The ICF included an overview of the study ("Stakeholder Value Integration in Threshold Matrix for Road Transportation Flood Resilience in Tambaram, Chennai") and described what participation entailed: a ~60 minute interview about their views on road system performance under flooding. Crucially, the consent form highlighted that participation was voluntary and that the participant could withdraw at any time or skip any question they were uncomfortable with. It also explained how data would be handled confidentially (discussed more in Appendix B). The form had a table of checkboxes for various consent items (e.g., “I understand the study information,” “I consent to participate,” “I agree that my anonymized quotes may be used in publications,” etc.). Participants signalled their consent by checking “Yes” to all items and providing a signature (signing on a digital document).

At the interview’s start, it was confirmed that the participant had read and signed the consent form. The researcher then verbally reiterated key points: that the interview was voluntary, would not be recorded audio-visually, and that only written notes would be taken. This was done to ensure participants were comfortable and to build trust. All participants agreed to proceed under these terms.

Each interview was scheduled at a time convenient for the participant, typically outside of their work hours (many were done in the evening IST or on weekends). The interviews were conducted in a mix of English and Tamil (the local language) depending on participant comfort responses given in Tamil were translated to English in the notes by the researcher. The interviews were one-on-one and lasted between 50 minutes to 75 minutes, averaging about an hour. The interview began with formally introducing the study again, emphasizing the exploratory nature and that there were “no right or wrong answers.” This was important to encourage participants to share honest opinions and even uncertainties.

The decision to not record audio and video was a conscious choice and was communicated in the consent form: “The interview will not be recorded and transcribed; instead, interview notes will be taken during the interview”. The rationale for not recording was twofold:

(1) to encourage free conversation (some participants might be more candid if they know they are not being taped) and

(2) to provide an anonymized summary for participant validation afterward (thus ensuring accuracy in another way).

During the interview, detailed notes were taken, almost in transcript form but categorised in parts. These notes captured key points, specific phrases or quotes that stood out, and all numeric values the participant provided for the thresholds. To ensure completeness, especially when noting a numeric threshold or a rationale were often repeated back or summarized what the participant said, thus performing a real-time member check. This practice helped mitigate the risk of misunderstandings due to not recording.

Immediately after each interview, the notes were expanded, adding details and organizing them according to the question topics. This was done to create a coherent interview summary while the conversation was fresh in memory. These summaries were typically, 2 pages of text per interview. Before asking the main questions, it was ensured that all participants had a common understanding of key terms and the scenario context:

- The terms Low, Medium, and High flood severity were explained. For example, a Low flood severity might be described as localized waterlogging (perhaps under 15 cm of water on streets), Medium as more widespread flooding in the zone (streets around the station and low lying areas submerged, 25–30 cm water), and High severity as severe flooding (major roads impassable, water >30cm in many areas). These descriptions were of depth of inundations. Providing these standard descriptions allowed participants to envision roughly similar scenarios when giving thresholds.

- The three system functionalities Safety, Connectivity, and Travel Time Reliability were explained as per the definition adopted for this study. This explanation ensured that the participant understood each system functionality for which they were later asked to assign performance thresholds under various flood intensities

- Also, participants were informed to consider the give minimum acceptable performance percentage from the system's perspective during morning peak period (6 AM to 12 PM) on weekdays (Monday to Friday) and focus on travel within a 2 km radius of Tambaram railway station (a central reference point in the town). This scope was chosen to standardize responses: morning peak is typically when people commute (hence critical), and the 2 km radius from the station covers Tambaram's core areas where traffic is busiest. By fixing the timeframe and area, participants would be thinking about similar traffic conditions (peak hour congestion) and a consistent geographic context (urban roads around the station) when assessing acceptable performance. This helps make their threshold values comparable. The instruction was, for example: "Imagine it's a weekday morning commute in Tambaram, and there is [low/medium/high] flooding in the area roughly within 2 km of the railway station. I'd like to know what minimum level of road performance you would consider acceptable in terms of safety, connectivity, and reliability, despite the flooding."
  This scenario based framing anchored their responses to realistic conditions and their own experience. It also avoided overly abstract answers; people could picture actual roads and typical congestion levels.

The interview was conducted while remaining neutral and avoiding leading questions. Probing questions were used such as "Could you explain the reason and rationale behind the threshold value for the functionality X?" or "What make you say that 60% connectivity is acceptable under Y flood scenario?" to get deeper insights. The semi-structured format meant that while there was a predefined set of questions (refer Appendix A), the order and phrasing could vary, and the interviewer sometimes asked spontaneous follow ups if a participant introduced a new idea (consistent with good interview practice).

At the end of the questions, participants were asked if they had anything to add anything to the interview regarding their values and the collected data was repeated again to make sure the participants are satisfied with their response. Many participants used this opportunity to share general comments on flooding in the city or to express appreciation for the research topic. It was also mentioned again that each participant would receive a summary of their interview for review and that once the study is completed, they would be sent a brief of the results if they were interested.

3.5 Interview Protocol

A semi structured interview guide was prepared to ensure consistency across interviews while allowing flexibility. The guide contained a series of main questions and suggested probes. The main topics corresponded to the key variables of interest (the threshold values for three functionalities under three flood scenarios) as well as some introductory and closing questions. The interview guide was pre-tested with a colleague for clarity before use. Below is an outline of the interview protocol and the core questions are given in Appendix A:

The interview is structured into five main parts:

- **Part 1 (Introduction):** This part of the interview begins with the with a self introduction of the researcher and introduction form the interviewee. In this section it was confirmed that whether the interviewee is a user of Tambaram road network and whether the participant resides in one of the five zones in Tambaram. Besides, a brief overview of the study was provided to all interviewees to ensure that both parties are aligned on the goals and expectations for the discussion.

- **Part 2:** Interviewees experience with flooding were discussed to get the participant reflecting on the topic and possibly identify any particularly salient experiences. This helped later in understanding their mindset when giving thresholds.

- **Part 3 (core section):** The core section questions were organized by functionality under each flood severity (refer section 2.4, above). At first the interviewees were asked to give minimum acceptable performance percentages for the scenario normal operations scenario. Then the researcher proceeded to ask about functionalities under various flood hazard intensities. To avoid confusion, the interview was structured by functionality, not by flood scenario. This means the interviewer would take one functionality at a time (say, connectivity) and ask about acceptable performance for all three flood severity for that functionality, then move to the next functionality. This approach allowed the participant to mentally simulate that functionality fully without comparing across functionalities across different scenarios. The order of scenarios was from low to high severity, as it felt natural to escalate the situation. Throughout these, the interviewer was careful not to suggest numbers. All participants were able to provide numeric answers after some thought, though the interviewer occasionally helped by ensuring they understood the 0–100% scale.

- **Part 4 (Overall observation):** In this section the stakeholders were asked follow-up questions to capture their reasoning for their minimum acceptable percentage for the functionalities. Also to see if stakeholders heavily prioritize one dimension (e.g., some might say "safety first, I don't care if I am late as long as I am safe"). This question informs whether the study should weight one aspect more when creating composite indices or in recommendations. If a participant answered that one aspect was more critical, a follow-up might be: "So, for example, would you be willing to accept a much lower reliability if safety is high? Can you elaborate?" This helped clarify their value trade-offs.

- **Part 5 (Closing):** Interviewees were if they would like to add anything regarding this context. The interview then ended with thanks and reiteration of the follow-up plan (member checking at the end of the interview and eventual sharing of results). And small feedback was asked to improve further interviews by the researcher.

This above mentioned structure is the overview of the interview guide. However, given the semi-structured nature, the exact wording and sequence could vary. For example, if a participant pre-emptively discussed medium and high floods while talking about low, the interviewer adapted and perhaps cover those without strictly following the order. The guide ensured all topics were eventually covered.

The interview questions are provided in Appendix A, for reference. It includes the introductory script, the main questions, and an example probe. This ensures transparency of the methodology and allows others to replicate or assess the method.

Overall, this interview protocol was designed to elicit both quantitative estimates (the threshold percentages) and qualitative justifications (the reasoning and rationale behind those values). This dual output was intentional to serve the mixed method design of the research.

3.6 Data Analysis

Data analysis consisted of two intertwined parts: a qualitative analysis of the interview content (notes and summaries) and a quantitative analysis to calculate the threshold matrix. The processes were undertaken in parallel to some extent, informing each other. The qualitative analysis provided context and helped interpret the quantitative results, while the quantitative aggregation allowed identification of patterns that were further explained by qualitative findings. Each is described below.

3.6.1 Quantitative Analysis of Interview Data: Formulating threshold matrix

The quantitative aspect of analysis focused on deriving the threshold matrix from the numerical values provided by participants for each functionality under each flood severity. The matrix is essentially of percentage values for each system functionality, representing the collective user defined performance thresholds under various flood severities. Each cell of the matrix needed to be computed from the 15 individual responses.

From the interviews, each participant gave 12 numbers. These were organized in a data table where rows were participants (1 to 15) and columns were: Safety_low, Safety_medium, Safety_high, Connectivity_low, Connectivity_medium, Connectivity_high, Reliability_low, Reliability_medium and Reliability_high. If a participant did not directly give a number for a particular cell or only qualitatively described it, the researcher deduced a reasonable number based on their description and confirmed the percentage value. For example, if someone said, "in a severe flood, safety would be maybe half of normal," that was recorded. By the end, a complete numerical dataset was in place.

To aggregate individual responses into a single threshold value for each matrix cell, weighted average method was used. The weighted average is a common technique to combine inputs, especially when considering different groups or criteria (Zhu et al., 2024). In this context, the "weights" could conceptually be assigned to each participant or group if needed. However, since the research ethic was to "treat all participants (and zones) equally," the simplest approach was to give equal weight to each participant's input. This effectively reduces to a simple arithmetic mean of the percentages for each cell.

Mathematically, for a given functionality f and flood severity s, the threshold value $T(f,s)$ was calculated as:

$$T(f,s) = \frac{\sum_{i=1}^{15} w_i \times x_i(f,s)}{\sum_{i=1}^{15} w_i}$$

Where x_i (*f*, *s*) is the percentage given by participant *i* for functionality *f* under severity *s*, and w_i is the weight for participant *i*. In this case, for all *i*, so this simplifies to T (*f, s*) = $\frac{1}{15}\sum_{i=1}^{15} x_i(f,s)$. Each participant thus contributes equally to the final value, aligning with the principle of fairness in stakeholder inclusion.

The decision for equal weighting was straightforward since each interviewee was considered an equally valid representative of user perspective. There were no objective reasons to weight one person's opinion more (e.g., everyone was a road user, not an "expert vs novice" scenario). Moreover, although the sample was stratified by zone, the intent was to reflect the collective threshold for Tambaram as a whole. To ensure that zones with more interviewees did not disproportionately influence the average.

The individual percentages were averaged and then rounded to a meaningful precision (round final thresholds to the nearest whole number) for ease of interpretation, as the data itself wouldn't justify more precise decimals. This methodology emphasized that all aspects are treated equally. In other words, no functionality was prioritized over another in the output; the matrix keeps them separate. The question of which is more important is handled qualitatively rather than by numeric weighting. This study strictly looked at the minimum performance percentages users can accept during disruption. Thus, the matrix addresses performance thresholds exclusively. This scope choice is clarified so that the results focus on defining the boundary between acceptable and unacceptable performance (essentially a performance threshold) under various flood hazard. This decision was driven by feasibility and to fill the specific gap of threshold setting.

The final stage of analysis was to interpret the threshold matrix using the qualitative themes. Each cell of the matrix was annotated with key points from interviews explaining why that threshold might be what it is. This step doesn't change the numbers but enriches their meaning, ensuring the matrix is not viewed in isolation.

Although the study's numbers come from subjective judgments (not measurements), treating them quantitatively is still meaningful as a form of aggregated expert elicitation (where the "experts" are the local users). The validity here is more about face validity and aggregation. Individual data points that seemed off were cross checked with the interviewees. If one person's answer was dramatically different from others, that interview was revisited to ensure it was recorded correctly and to note the reason (maybe they had a unique situation). The average is thus an acknowledgement of variance. Sophisticated statistical analysis was not applied (like confidence intervals) due to the sample size and non-random nature; instead, the emphasis is on the combination of numbers and narrative.

To sum up, the quantitative analysis was straightforward but carefully executed: taking the user inputs and computing the average acceptable performance for each flood hazard intensity. The resulting threshold matrix is the key output of the study, and it is robust in the sense that it directly stems from user data and treats all inputs impartially. The use of weighted average (with equal weights) aligns with the equitable inclusion of all participants' voices in the outcome.

3.6.2 Qualitative Analysis of Interview Data

All interview notes/summaries were analyzed using an inductive qualitative coding approach, following principles of the Gioia methodology to ensure rigor. The Gioia method, as outlined by Gioia, Corley & Hamilton (2013), is well regarded for bringing systematic rigor to inductive research by clearly linking raw data to higher level themes. It involves a multi-step coding: first identifying first order concepts (staying close to participants' own words), then distilling those into second order themes (more abstract, researcher interpreted categories), and finally grouping themes into overarching dimensions if applicable (Gioia et al., 2013). Employing this approach helps demonstrate transparency in how conclusions are derived from data, thus strengthening credibility.

The interview texts were highlighted line by line (in practice, segment by segment, as many summaries were structured by question). At this stage, no coding software was used instead the phrases of the interviewees were highlighted from the interview summaries, meaning using participants' own phrases as labels or very descriptive phases closely mirroring what was said refer table 7. This approach keeps the analysis grounded in participants' terms. At this stage, no attempt was made to limit or categorize the codes; the goal was to capture all distinct ideas or points (thus generating a comprehensive list of first order concepts). As Gioia methodology literature notes, this usually results in a large number of initial codes.

All first order codes were compiled in a spreadsheet alongside reviewed for commonalities for concepts. According to Gioia methodology, this involves looking for recurrent words, phrases, or sentiments across participants. This spreadsheet was used to look for overlaps or identical concepts expressed by different participants, which was late used to indicate patterns. And at the same time, to identify unique views. Such divergent views were also noted.

In the next step, the first order codes were examined to group them into broader themes. This was an iterative, interpretive process moving from the descriptive to a more conceptual level. These second order themes were not predetermined but emerged from the data through constant comparison. Whenever a theme was posited, the data was revisited to check if it really held up or if exceptions existed. This back and forth ensures the themes are truly reflective of the data (a form of constant comparative method from grounded theory).

Final step was to find a relation between these themes and link it to a higher level theoretical construct, thereby formulating aggregate dimensions. Gioia et al. (2013) describe aggregate dimensions as overarching concepts that emerge when second order themes coalesce into a more general theoretical category. The outcome of this coding process was a data structure linking raw data to themes, similar to Gioia et. al.'s recommended practice. For transparency, a figure illustrating this data structure (with first order concepts, second order themes, and their relationships) is provided in table 7. This visual demonstrates how, for instance, individual statements (first order) roll into a theme, which in turn might be part of a larger dimension.

By employing the Gioia methodology, the study ensured qualitative rigor. It encouraged clearly distinguishing between the participants' voice and the researcher's interpretation. First order codes are participant centric and second order themes are researcher centric. This dual step makes the analysis more systematic and credible to readers, who can see that the conclusions (themes) indeed arise from multiple participants' statements. As Gioia et al. (2013) argue, such an approach lends credibility and plausibility to inductive findings by showing the chain of evidence from raw data to concepts.

In this study, this is particularly important because the aim of the study is to influence how resilience is assessed having a transparent link from stakeholder quotes to the final recommendations can convince planners that these thresholds are well founded.

To further enhance credibility (internal validity of qualitative findings), the study implemented a form of member checking. At the end of an interview the participants were asked to check their inputs both qualitative and quantitative data. They were invited to correct any inaccuracies or add clarifications. Several participants responded with minor clarifications or confirmations such as "Yes, that's exactly what I meant," and none disagreed with their input. This process helped ensure that the researcher's understanding of each interview was accurate and that no major misinterpretations occurred. Additionally, once the preliminary themes were developed, a short summary of key findings (in general, not by name) was shared with a few participants asking if the conclusions resonated with their perspective. This informal validation found that participants generally agreed with how their input was characterized.

3.6.3 Integration of Quantitative and Qualitative Analysis

To operationalize dynamic thresholds (refer sub-section 3.2.1) informed by users, this research employs a mixed methods approach, combining quantitative and qualitative techniques. Mixed methods research is valuable in resilience studies because it allows one to capture both the measurable aspects of system performance and the contextual insights (rationales, perceptions, etc) behind those numbers. In the context of transportation resilience, a mixed approach might involve collecting numerical data on acceptable performance levels (e.g. via surveys or structured/semi structured interview questions) and gathering narrative explanations or preferences through open ended discussion. By integrating these, a more comprehensive understanding of the data is achieved than what the quantitative data alone tell us what thresholds users set, and what the qualitative data alone tell us why they set them at those levels.

In this thesis, semi-structured interviews will be the primary tool for data collection, designed to elicit both kinds of information from road network users in Tambaram, Chennai. Each interview will include questions that ask users to quantify the minimum acceptable performance of functionality under different flood scenarios (for instance, "What performance percentage of functionality "X" do you consider acceptable during a medium flood?"). This yields quantitative estimates (percentage thresholds) for each predefined functionality (safety, connectivity and travel time reliability) at various hazard intensities. At the same time, the interviews will probe the reasoning and justifications behind those numbers, e.g. "Why do you feel this performance for a certain functionality is acceptable?" or "What concerns lead you to require at least X% of certain functionality during a specific flood hazard intensity?". These open-ended questions produce qualitative data that reveals users' underlying values and expectations.

The integration of these methods follows a concurrent triangulation design where qualitative and quantitative findings are brought together in analysis. One way the integration occurs is through creating a "threshold matrix" as mentioned above, using the numeric inputs, and then interpreting that matrix with themes from the qualitative insights. For example, if many stakeholders insist on a high safety functionality (say ≥90% of roads must remain safe), the qualitative comments might reveal themes driving that strict requirement. The qualitative analysis is carried out via thematic coding of interview transcripts, following standard procedures for identifying recurrent themes and patterns in textual data. This is akin to approaches seen in other infrastructure resilience studies that blend stakeholder surveys and interviews. Petersen et al. (2020), for instance, used a questionnaire to gather public tolerance levels (quantitative) and engaged with stakeholders to understand why those tolerance levels took the shape they did. The result was a richer interpretation of resilience criteria not just what levels of service were acceptable, but for whom and under what assumptions.

A mixed methods strategy has multiple benefits in this research. First, it helps validate and contextualize the quantitative thresholds. Purely numeric thresholds could be misleading or lack buy-in if story behind them is not known. By examining qualitative explanations, it can be ensured that the aggregated "threshold values" truly reflect users' intentions. This alignment is crucial for producing a meaningful Threshold index. In the literature, scholars have warned that quantitative resilience metrics need to reflect actual stakeholder values to be useful (Wen et al., 2019). The qualitative component acts as a check and enriches the interpretation of the quantitative data. Second, the mixed approach enhances credibility and acceptance of the findings among diverse audiences (engineers, policymakers, community members, etc). Numbers backed by human reasonings are often more persuasive in decision making. For instance, if the analysis finds that connectivity can drop to 50% in a severe flood without people feeling unsafe, having interview quotes about "We can manage with half the roads if we are warned in advance" provides a narrative justification that decision makers can understand and trust.

Notably, mixed method designs are increasingly common in resilience and climate adaptation research, where both hard data and human factors matter. A recent study by Zhu and Feng (2025) on urban climate resilience policy used a mixed method framework, scoring policies quantitatively and then conducting interviews to explain the scores. The interviews shed light on governance and social factors that the quantitative scoring alone could not capture. By analogy, this study's interviews will illuminate factors like what level of performance loss is societally tolerable or how quickly the users expect recovery, which raw performance metrics alone would miss. This complementary use of numbers and narratives exemplifies what mixed methods offer: breadth and depth. The breadth of stakeholder opinions is captured in a comparable way (percentages that can be averaged, weighted and compared) and the depth of individual perspectives and reasoning (through thematic analysis).

In practical terms, the data integration will occur during analysis by converting stakeholder inputs into a weighted average threshold matrix (quantitative aggregation) and simultaneously summarizing their qualitative rationale under each functionality and flood scenario. Literature on multi-criteria decision analysis supports using weighted aggregation to combine inputs, as it captures the collective priority while allowing differential influence if justified (Wen et al., 2019). At the same time, qualitative findings will be explaining what concerns led to higher or lower thresholds. This mirrors mixed method integration strategies where quantitative results are explained or expanded upon by qualitative findings.

To summarize, the mixed methods integration in this research ensures that the concept of dynamic threshold values is not applied in a vacuum but is firmly anchored in users' reality. The quantitative part yields the Threshold index, a novel metric indicating resilience performance aligned with what users' value (e.g., how far performance can drop before it's unacceptable, per flood severity). The qualitative part ensures interpretation and validity of that metric, and it provides rich insights into user priorities. Together, this method contributes to a literature backed, theoretically sound yet grounded approach to assessing road transport resilience.

Chapter 4

Findings

4.1 Quantitative Analysis

The table 5 below represents the quantitative data collected from all 15 interviewees. Each row explicitly shows the minimum acceptable performance percentage given by users during the interview for different flood hazard intensities (low, medium and high flood) across system functionalities (safety, connectivity and travel time reliability).

Interview No.	System Functionalities											
	Safety				Connectivity				Travel time reliability			
	Normal Operation (%)	Low (%)	Medium (%)	High (%)	Normal Operation (%)	Low (%)	Medium (%)	High (%)	Normal Operation (%)	Low (%)	Medium (%)	High (%)
1	95	95	92	98	90	90	87	85	98	98	95	90
2	80	80	80	90	85	85	75	60	90	90	80	70
3	80	80	70	50	95	95	80	60	95	95	80	60
4	95	90	87	80	90	85	82	78	85	80	77	70
5	90	90	90	75	70	70	70	55	80	80	80	65
6	90	60	45	20	80	50	35	20	75	55	45	25
7	95	90	80	75	80	80	75	70	80	80	70	50
8	92	80	73	63	90	84	74	66	90	82	74	66
9	80	75	50	30	90	90	70	45	90	75	70	45
10	90	90	80	50	90	90	80	60	90	90	80	70
11	90	80	75	70	85	85	80	75	90	75	65	60
12	90	85	80	60	70	65	60	40	80	65	60	50
13	75	60	50	30	75	60	50	30	75	60	50	30
14	60	80	100	100	100	60	60	100	80	100	100	80
15	90	90	80	80	85	80	80	75	80	80	75	70

Table 5. *Quantitative Data*

After compiling the acceptable performance percentages from the 15 interviewees, a final threshold matrix was derived by weighted average aggregation (with equal weight for each stakeholder). Table 6 presents the aggregated acceptable performance thresholds for the three system functionalities, Safety, Connectivity, and Travel Time Reliability under three flood conditions (Low, Medium and High) including normal operation i.e. no flood scenario. These values represent the aggregated minimum acceptable performance percentage of road network, as defined by users in Tambaram:

System Functionality	Normal Operation (%)	Low Flood (%)	Medium Flood (%)	High Flood (%)
Safety	86%	82%	75%	65%
Connectivity	85%	78%	70%	61%
Travel Time Reliability	85%	80%	73%	60%

Table 6. *Threshold matrix (Aggregated Minimum Acceptable Performance %)*

These aggregated values indicate that, on average, users expect the road transport system to maintain around 85–90% of normal performance in low severity floods, with only minimal acceptance for performance loss. Even under medium floods, the aggregated thresholds remain relatively high (approximately 70–75% of normal functionality). Only in high flood conditions do users accept substantial performance degradation yet even then, the average acceptable performance is around 60–65%, meaning users still expect the system to provide more than half of its normal performance of safety, connectivity, and reliability despite severe inundation.

Notably, the weighted average acts as a “group aggregation” mechanism, capturing the minimum acceptable percentage while preserving the variability around that average. In other words, the final matrix reflects what the average road user in this sample deems acceptable performance, without imposing any external biases or arbitrary adjustments. Each input is represented equally in the outcome, aligning with best practices for participatory decision metrics in resilience studies.

4.1.1 Patterns

Several clear patterns emerged in the quantitative data (refer Table 5). First, Normal operation expectations are very high across all functionalities (~85–86%) (refer table 6), indicating that under non-flood conditions users expect near optimal performance (virtually no disruption). In everyday conditions, users assume the road network should function almost fully, with only minor delays or safety risks (e.g. due to typical traffic or human factors). For instance, one interviewee noted that "in normal operation having safety at 80% is pretty good because users can still drive in ways that compromise safety, so the system must ensure ~80% safety is guaranteed". Meanwhile, others expected even stricter normal performance: "every link in the road network should be functioning at 100% under normal operation", argued one interviewee, emphasizing that any routine closures or inefficiencies should be minimal. The aggregated normal thresholds around 85% reflect these high baseline expectations, tempered slightly by recognition of everyday uncertainties (accidents, traffic signals, minor delays). For example, one of the interviewees (an outlier discussed later) accepted 60% safety in normal times, "the biggest factor in safety is user behavior", but that perspective was atypical; most participants clustered near the upper 80's or 90's for normal conditions.

Under Low flood conditions, the average acceptable performance remains almost as high as normal about 82% for safety and reliability, and ~78% for connectivity (refer table 6). In other words, on average users are willing to accept at most a 15–20% drop in functionality in a low flood. Many interviewees explicitly stated that a low level flood should not significantly disrupt the system performance, given proper maintenance and preparedness. "Safety, travel time reliability and connectivity should remain the same during a low flood…this level of water should be easily managed by the system. I cannot tolerate any drop in performance" explained one participant. Another concurred that with only ~15 cm of water, "the system should provide the same performance as normal", assuming adequate drainage and infrastructure. This dominant reasoning is reflected in minimal average decreases. Indeed, a majority of interviewees (9 out of 15) gave identical thresholds for Normal and Low flood, effectively expecting no performance loss at all in low floods which reflects a static threshold view. This static threshold view where the system's performance is assumed to diminish under greater stress. This view can be a reflection of the type of organisation, role in an organisation, nature of work and culture in the participants region. This finding is further discussed in sub section 4.2.1.1.

A few participants did allow slight drops at low flood (e.g. 5–10% lower), often citing caution due to reduced visibility or minor slowdowns. For example, one interviewee reduced safety by 5% in low flood, acknowledging "a 5% loss due to reduced visibility". However, the a low flood should not greatly affect travel: connectivity and reliability remain near 80–85%, meaning the system should still get people where they need to go with only negligible delays. This aligns with literature noting that connectivity and reliability are core indicators of transportation network resilience users expect an urban road network to maintain connections and predictable travel times even under minor disruptions. Safety, while often treated in traditional risk analysis separately, is also perceived as "a key indicator to be considered in resilience assessment"; indeed, users clearly did consider safety as fundamental to resilience, insisting on high safety percentage (avg. ~82%) in low floods as well.

In the case of a medium flood (e.g. inundation ~25–30 cm), the aggregated acceptable thresholds do show a drop but still indicate a majority expecting substantial functionality. Safety's average threshold falls to ~75.5%, connectivity to ~70.5%, and reliability to ~73.4%. These values imply that even in a moderate flood scenario that causes some road closures and slower traffic, users collectively expect roughly one third of normal performance to be preserved. This is a striking result despite the significant challenges posed by medium floods, the "average" road user in this sample only tolerates about a 25–30% degradation in performance. Many users justified this by arguing that the system should be designed for at least medium floods, i.e. the drainage, road infrastructure, and management strategies should handle such events with limited performance loss. "I cannot accept loss in performance for just a 30 cm water level… the system should provide the same performance as normal up to medium flood" declared one participant. Others echoed that medium floods ought to be manageable: "a 30cm rise should be handled by the system using proper drainage".

This suggests that people are somewhat more willing to accept loss of some routes or links in the network at this stage, as long as overall safety is protected and travel times remain somewhat predictable on the remaining routes. From the interviews it was identified that several users indeed prioritized maintaining safety and reasonable travel times over keeping every road open. For instance, one person said in a medium flood they would "accept a 10% drop in connectivity due to taking longer routes to stay safe," acknowledging that detours might be necessary if certain roads are closed. Another noted they are "willing to see several secondary roads sacrificed if it keeps emergency routes clear" during a medium flood. These comments align with the idea of redundancy in resilience: as long as alternative paths exist, losing some links is tolerable (Ahmed & Dey, 2020). By contrast, travel time reliability was often expected to remain fairly high at medium flood, under the assumption that with planning and information, delays can be mitigated. One stakeholder argued that "once you publish a proper detour plan early, I can plan accordingly and reach my destination with a longer path – reliability stays high". This explains why the average reliability threshold (73.4%) slightly exceeds connectivity's at medium level. Users seem to value predictability: even if they must take a longer route (lower connectivity), they want the arrival time to still be reasonably dependable (high reliability). Safety remains the top functionality in the average at medium flood (~75%), reflecting that no matter the flood, the system should minimize safety risks. As one interviewee stated, "in medium flood I would like to be safe first, because water levels are high" a sentiment many shared. In fact, more than half of the participants (8 of 15) gave equal or higher safety thresholds compared to the other two functionalities at medium intensity, indicating low tolerance for safety compromises even as conditions worsen.

Finally, under High flood conditions (severe inundation), the aggregated acceptable thresholds drop the most, yet they remain well above 50%. The aggregated minimum acceptable performance is ~65% for Safety, ~61% for Connectivity, and ~60% for Travel Time Reliability. In other words, even in an extreme flood scenario, the average stakeholder expects the road transport system to retain roughly two-third of its normal safety performance, and around 60%

of its connectivity and reliability. This is a notable finding: despite acknowledging that a major flood will inevitably disrupt the network, users still demand a significant level of functionality rather than a near total collapse. Safety continues to be the highest priority functionality on average at high flood (64.7% acceptable performance, versus ~60% for reliability). This reflects a commonality: “If I have to travel in a high flood due to emergency, I want to be safe, whatever happens I want to be safe”. Many interviewees stressed that in a life threatening flood scenario, preserving life and avoiding injury is number one, even if it means delays or detours. For example, one stakeholder said they “will only travel due to emergency in high flood, and what is the point of using the road network if I won’t be safe during the travel… Instead of dying at home I will die during travel that’s unacceptable”. Such strong reasonings underscores why the aggregated safety threshold remains the highest users require a baseline of protection (roughly two-third of normal safety performance) even when nature overwhelms the system. At the same time, the average acceptable connectivity (61%) in high floods is only a few points lower than safety. This indicates that avoiding isolation is also critically important to the public. Users generally felt that even in a major flood, the city must ensure that most areas remain reachable (if not via the usual route, then via some alternative path or evacuation route). For instance, one participant noted, “being stuck with no way in or out is a nightmare”, arguing that connectivity should take second priority after safety in floods. Another interviewee explicitly stated that in a high flood, “every possible route should offer connectivity to another place there should be connectivity to evacuation sites, hospitals, etc., from all areas”. This perspective that no area within the network should be completely cut off likely drove the connectivity threshold to ~61%, relatively high mean. Even those who focused on safety recognized connectivity’s role.

Lastly, travel time reliability in high floods received the lowest average (~60%). This suggests that, collectively, users are most willing to sacrifice schedule predictability in an extreme event. Indeed, many interviewees accepted that delays in a catastrophic flood are inevitable and less critical than safety or access. “During a flood I cannot expect to reach a place without delays. So, travel time reliability gets third priority always” said one participant. Another noted that in a high flood, “people don’t expect to be on time, they just need a usable estimated time of arrival”. Thus, the users are prepared for longer and more variable travel times in extreme floods (hence the lowest threshold), so long as they can still travel (connectivity) and do so with reasonable safety. This ordering is intuitive and aligns with basic needs: in a disaster, being safe and having access to critical destinations (medical care, safe zones) outweighs punctuality.

4.1.2 Outliers

The analysis of outliers among stakeholders provides critical insights into the diverse expectations for system performance during flood events, enriching the understanding derived from aggregated values. While the primary matrix reflects a central tendency by averaging stakeholder inputs, examining individual deviations reveals unique rationales, special considerations, and conflicting philosophies that are vital for comprehensive planning and policy formulation. This qualitative exploration serves two key purposes:

(1) first, to ensure that extreme individual views did not unduly skew the overall average; and
(2) second, to unearth underlying motivations or experiences that drive such significant differences in perceived acceptable performance thresholds.

4.1.2.1 Optimistic Outliers (High Threshold)

A distinct category of interviewees expressed minimal tolerance for performance degradation, even in severe flood scenarios, consistently setting higher thresholds than the group average. These "optimistic outliers" often articulated a demand for near perfect functionality.

One of the interviewees (refer interview no. 14, Table 5) serves as the most prominent example of this perspective, demonstrating a highly adaptive yet unyielding philosophy towards system performance. His responses diverged dramatically from the typical pattern of gradual decline in acceptable performance across flood scenarios. For normal operations, he demanded 100% connectivity, reasoning that the fundamental purpose of infrastructure like a road network is to fully link destinations. This highlights a foundational expectation of absolute functionality under ideal conditions.

As flood severity increased, his prioritization shifted strategically. In a low flood scenario, while he accepted a reduction in connectivity to 60% due to the closure of minor links, he insisted on 100% reliability (zero delays) and 80% safety. This indicates a willingness to compromise on minor access points provided that primary travel remains predictable and largely safe. His rationale here was satisfaction as long as the network facilitates reaching his destination. Moving to a medium flood, his emphasis again shifted decisively towards critical functions, demanding 100% safety (zero fatalities) and 100% reliability, contingent on a robust detour plan, while still tolerating 60% connectivity. This reflects a pragmatic approach to network management during disruption, prioritizing main arteries and the preservation of life over comprehensive access. Finally, in a high flood, he maintained 100% safety and 100% connectivity, accepting only 80% reliability. This ultimate demand for full safety and access in a catastrophic event underscores a "no compromise" stance on life saving measures and area accessibility.

This overarching philosophy was to "push each functionality to its ceiling when its failure becomes life critical and relax it when another functionality can carry the load". He explicitly stated that in normal conditions, the network's role is efficient movement, but as water rises, safety takes priority, demanding maximum performance. This approach, termed "adaptive prioritization", is internally consistent but contrasts with the more uniform gradual declines accepted by other participants. His viewpoint resonates with a "zero failure tolerance" approach often embedded in engineering standards for life safety, suggesting that certain functions, particularly safety and critical connectivity, become non-negotiable at higher flood levels. While his individual input was moderate due to being a single voice among 15 stakeholders, it did notably elevate the average connectivity and safety means for high floods, and reliability for low/medium floods. But this interview reflected to the concept of dynamic thresholds. Having lower or higher performance with respect to the need and expectations of system functionalities in each scenario. This interview also gave rise to the questions such as: does type of organisation, nature of work and role in organisation affects the expectations and tolerance? This question emerged from the observation that, participants who gave decreasing thresholds as the flood hazard intensity increases were employees in an organisation with exception of 2 interviewees (refer interview no. 1 & 2, Table 5) who still gave increasing values despite being employees (mentioned below) and the participant who mentioned he demands adaptive prioritisation (dynamic thresholds) is an employer, has his own firm. But, to deeply understand if this observation is valid, extensive research on does behaviour, organisation culture, regional culture and role in an organisation influences expectation from a system should be conducted.

Also, two other interviewees (employees who gave increasing values) prominently highlighted an extreme safety first mindset. First interviewee (refer interview no. 1, Table 5) set an exceptionally high acceptable safety performance of 98% in a high flood, implying an expectation of near perfection safety even amidst a disaster. His reasoning was based on the premise that travel during high floods would only occur in emergencies, making safety paramount: "I am fine with extra distance and extra time, but in the end, I want to be safe". He unequivocally stated that connectivity or reliability is useless without safety, thereby asserting safety as the "number one priority" even at an almost unattainable 98%. This indicates an unwillingness to compromise on safety for any other benefit, effectively setting an exceedingly high bar for the system during floods.

Similarly, another participant (refer interview no. 2, Table 5) not only maintained 80% safety for normal and medium floods but increased it to 90% for high floods. This counterintuitive elevation suggests an expectation that the system should implement additional safety measures in extreme events to compensate for challenging conditions like reduced visibility. He argued that the system must "take necessary measures; reflective cones, barricades, etc. to compensate" for worsening conditions, reinforcing the idea that greater risk needs greater safety efforts.

The collective impact of these optimistic outliers (refer interview no. 1, 2 & 14, Table 5) was to pull the average safety threshold for high floods upward, from an approximate 60% to around

65%. This reinforces a crucial insight: a significant segment of users demands an exceptionally high degree of protection regardless of the environmental conditions. This stance highlights a potential expectation gap, where some users may assume that continuous, near absolute safety can be achieved through advanced technology or design (e.g., warning systems, strict controls), even when natural forces are overwhelmingly severe.

4.1.2.2 Pessimistic Outliers (Low Threshold)

In contrast to the optimistic views, another group of users exhibited a much more pessimistic view on system performance during floods. These "pessimistic outliers" consistently provided much lower acceptable thresholds than the group average, often reflecting past negative experiences or a deep distrust in system resilience.

The most prominent instance when an interviewee (refer interview no. 6, Table 5) whose thresholds were consistently the lowest across all scenarios and functionalities in the sample. He was willing to accept low performance levels: 60% safety, 50% connectivity, and 55% reliability for a low flood; dropping to 45%–35% for a medium flood; and a mere 20% safety, 20% connectivity, and 25% reliability for a high flood. This meant he tolerated an 80% performance loss in safety by high flood, drastically lower than the 65% group average. His reasoning emerged from a highly cautious perspective. He considered even a low flood (15 cm of water) as "already a bit high for cars," citing reduced visibility and inability to identify hazards like potholes. Consequently, he pre-emptively halved his expectations for performance at low flood. For medium floods, he assumed conditions would be so severe that he "can accept more than 50% drop in performance from normal", intending to avoid the road network entirely unless for emergencies, for which he desired "at least half of its performance". In a high flood, his assessment was, "travel is not possible". Yet, he still articulated an expectation: if someone must travel, the system should offer "a minimum of 15–20% performance," because "more than 20% drop cannot be tolerated, and it makes the system unusable, so there is no point in having a road network which cannot provide at least 20% performance in high flood". This contradictory justification expecting near total failure but demanding a minimum operationality to even justify the system's existence reveals profound lack of confidence in the systems resilience.

Crucially, his thresholds were deeply rooted in his firsthand experiences of floods, including vanishing roads, stranded vehicles, and unseen dangers like open manholes and downed power lines. His perspective reflects a survival oriented mindset, where any functionality beyond the absolute bare minimum is perceived as an unexpected bonus. His inputs significantly pulled down the average thresholds, particularly for low and medium floods, where most users had much higher expectations. For instance, his 60% value for low flood safety contributed to lowering the average to approximately 82%. From a stakeholder theory standpoint, his values strongly indicate prior negative experiences where the system demonstrably failed him, leading to a highly risk averse attitude aimed at managing disappointment or danger. This aligns with risk management literature which states that stakeholders' past experiences heavily influence their risk tolerance. In contexts like Tambaram, Chennai, a city with a history of significant flood events (e.g., the 2015 flood), individuals with high flood exposure would naturally set lower performance thresholds given the historical collapse of the system.

Another notable low end outlier (refer interview no. 13, Table 5) displayed a unique approach by assigning the same thresholds for all three functionalities (safety, connectivity, reliability) across all flood scenarios: 75% for normal, 60% for low, 50% for medium, and 30% for high. This uniform degradation across functionalities contrasts with the typical prioritizations made by other users. Furthermore, his baseline expectation for normal operations (75%) was remarkably lower than any other participant's, most of whom anticipated near perfect performance (85–100%) in everyday conditions. This suggests a generally lower bar for system performance, perhaps reflecting a highly constrained view of what is truly achievable.

His explanation revealed a nuanced understanding rooted in acknowledging uncertainty and the influence of human factors. He argued that "expecting the system to provide at least 75% performance in normal operation is fair… There can be situations where even if the system maintains functionalities, an issue can occur. So, I accept 75% of all functionalities in normal". This recognition of unpredictability, even in no flood conditions, sets him apart from others who expected near perfection. He specifically highlighted how users’ behavior during disruptions can effectively reduce system effectiveness, even if the system remains sound. For instance, in a low flood, while vehicles might technically be able to move, "drivers often respond with excessive caution, reducing their speed and thereby increasing overall travel time". This, in his view, leads to a perceived reduction in reliability and users self imposing limitations, justifying "it is reasonable to accept a 15% reduction in performance during low floods" because "the actual demand during such events is lower than what the system could deliver".

His perspective introduces a critical point: if users’ behavior in a crisis naturally lowers effective performance (e.g., widespread caution reducing throughput), then why should the system be held to a higher functional standard than what users will naturally realize? His uniform drop across functionalities implies he views them as co-dependent; if safety driven caution leads to slower driving, both connectivity and travel time reliability inevitably suffer together. This highlights the human element in resilience engineering, where people's trust, reactions, and collective behaviors can lead to "demand surges" or, conversely, under-utilization of capacity. His input mildly lowered the aggregated averages, particularly for normal and low values, given his unique acceptance of 75% functionality even on a clear day. His views underscore that not all users expect or even desire 100% efficiency; some inherently factor in imperfections and personal caution, which can subsequently reduce the required system performance.

In summary, the analysis of user's perspectives reveals adoption of static view or pessimistic view on threshold values. A strong expectation on high system performance expectations up to medium flood scenarios, with only negligible degradation deemed acceptable was noted. This widely shared view reflects a low risk appetite for flooding. Furthermore, many users recognized the interdependence of functionalities, often treating connectivity and reliability as a pair, while viewing safety as somewhat independent and more volatile.

The analysis identified significant outliers that provide crucial insights. Some stakeholders exhibited high threshold expectations, demanding near perfect performance even in extreme floods, particularly for critical functions like safety and connectivity. Conversely, pessimistic outliers revealed lower trust in resilience of the system, from prior negative experiences or acknowledgment of human factors and user behavior in crises impacting performance. These divergences highlight a range of risk tolerances and perceived system limitations.

Crucially, the weighted averaging method effectively balanced these extremes, yielding a collectively reasonable estimate of acceptable thresholds. While normal and low flood thresholds show high robustness due to minimal variability, the greater divergence for high flood scenarios suggests potential for further refinement with larger samples. Nevertheless, the derived thresholds unequivocally indicate that the users do not accept complete system failure even during catastrophic events, presenting significant implications for resilience planning and investment.

4.1.3 Managing Outliers

Now that the outliers are identified which introduces variability in the quantitative data, the question arises **whether to include these outliers in the aggregation of minimum acceptable thresholds?** The determination of whether to include or exclude outlier data ultimately rests with the decision makers. This judgment should be informed not only by statistical considerations but also by the contextual relevance and interpretive value of the data. Decision makers must weigh the potential impact of outliers on analytical outcomes against the rationale for their presence, ensuring that exclusions are methodologically sound and not arbitrarily imposed.

For this research such quantitative data is include in the aggregation because of considerations that the users who are identified as outlier are part of the users of the road transportation in Tambaram. Also, excluding outlier for the sake of arriving at the resultant aggregate value provides minimum robustness to outlier identification/ignorance. But, in this research each outlier data has a strong rationale or reasoning behind it. These qualitative backings force the inclusion of outliers in the aggregation process, as it is an insightful extreme. Such outliers cannot be treated as errors as they can indicate diverse value priorities that are important for comprehensive resilience planning.

The decision to accept, reject, or adjust outlier data should not be based solely on its numerical deviation from the dataset (methods like interquartile range, z-score, etc can be used to identify numerical outliers). It is equally important to consider the qualitative context and underlying rationale that may justify the presence of such data points. Treating data as an outlier purely on the basis of statistical variability, without accounting for its substantive justification, risks overlooking meaningful insights. Outliers supported by valid reasoning should be retained, as their exclusion, particularly when stakeholders gain a deeper understanding of the contextual factors involves distortion of the interpretiveness. Conversely, data lacking sufficient rationale or contextual grounding may be reasonably excluded to mitigate undue volatility and preserve analytical integrity.

Furthermore, when stakeholders from specific urban zones are identified as statistical outliers, this may serve as a critical indicator of underlying vulnerabilities within those areas. Rather than dismissing such data, its presence should prompt a closer examination of contextual factors and systemic disparities. Recognizing these outliers can inform the development and implementation of targeted resilience strategies aimed at mitigating potential disruptions and enhancing adaptive capacity in the affected zones. This process necessitates a comprehensive analysis of the qualitative data underpinning the identified outliers. By examining the contextual and experiential dimensions associated with these data points, nuanced insights can be uncovered that may not be evident through quantitative measures alone. The following section presents an in-depth exploration of the qualitative findings related to the observed patterns and outliers, and critically examines their alignment with, or divergence from, established concepts.

4.2 Qualitative Analysis

In the context of stakeholder values in road transportation flood resilience, the Gioia et al. (2013), methodology is highly pertinent. Resilience of road network under flooding is a complex socio technical domain where stakeholders (e.g. road users, commuters) hold implicit values and expectations about acceptable performance under adverse conditions. Traditional engineering metrics alone cannot capture these social dimensions of resilience. An inductive, theory building approach allows to explore how people make sense of concepts like safety, connectivity, and travel time reliability during floods, and how they decide what is “acceptable” performance. The Gioia et al. (2013), method provides a systematic way to surface these user defined thresholds and link them to broader theoretical ideas. By applying this methodology to 15 in-depth interview notes, this study aims to develop a nuanced understanding of users’ acceptance in flood prone road transportation. Thus, contributing to resilience theory from a bottom up, user driven perspective. This approach aligns with calls for qualitative rigor in inductive research ensuring that theoretical insights and related constructs are well evidenced and traceable back to what users actually said. In sum, the Gioia et al. (2013), methodology is appropriate here to bridge empirical insights and theory: it helps to build a grounded conceptual model of how stakeholders evaluate and accept (or reject) the performance of road transport systems under flood.

4.2.1 Data Structure Development

The data structure follows a step by step inductive coding approach to develop a data structure from the 15 semi structured interview notes. Each interview centered on the interviewee’s perspective of road network performance under different flood hazard intensities (low, medium and high flood) across system functionalities (safety, connectivity and travel time reliability). The goal was to elicit first order concepts in the interviewees’ own words, then group those into second order themes. Finally aggregate to broader dimensions. The process was iterative and closely aligned with Gioia et al. (2013) recommendations for inductive theory building. Table 7 below illustrates the grouping of interview instances/quotes for first order concepts to second order themes to aggregate dimensions.

SI no.	first order concepts (Interview Quote)	Second Order Theme	Aggregate Dimension
1	"No performance drop will be accepted for a low flood as the water level increase is very low…"	Tolerance Performance for Loss	Acceptance
2	"Safety, travel time reliability and connectivity should remain the same during the low flood situation… So I cannot tolerate any drop in performance of the system."	Tolerance Performance for Loss	Acceptance
3	"I cannot accept loss in performance even in medium flood… The system should provide same performance as normal operation in low and medium flood. I cannot accept loss in performance for just a 30 cm water level."	Tolerance Performance for Loss	Acceptance
4	"In medium and high floods I cannot tolerate any drop in performance of safety even though there will be reduced visibility of the road. I want the system to ensure that it takes necessary measures (like reflective cones, barricades, etc.)	Tolerance Performance for Loss	Acceptance
5	"More than 20% drop [in performance] cannot be tolerated and it makes the system unusable… there is no point in having a road network which cannot provide at least 20% performance during an extreme event."	Tolerance Performance for Loss	Acceptance
6	"I will not use the system if there is a drop in performance below 80% and 60% for both connectivity and travel time reliability in medium and high floods respectively. Using the system becomes pointless if performance… cannot be maintained or the drop… minimised as much as possible."	Tolerance Performance for Loss	Acceptance
7	"I can only tolerate 20% loss in performance of safety during floods as it will greatly affect my confidence if it is more."	Tolerance Performance for Loss	Acceptance

SI no.	first order concepts (Interview Quote)	Second Order Theme	Aggregate Dimension
8	"So I can accept a maximum of 15% drop in safety during high flood… The reason why I am not expecting the same performance for low flood and I have accepted a 5% drop in performance is due to the reduction in visibility, a very minor reduction."	Tolerance Performance for Loss	Acceptance
9	"So, in this situation I can accept a 10% drop in performance for the travel time reliability of the system. I won't travel during high floods but if I have to travel due to emergency then I would prefer at least 70% travel time reliability."	Tolerance Performance for Loss	Acceptance
10	"I will accept a huge performance loss in travel time reliability because I can at least plan accordingly… I can accept up to 30% loss in travel time reliability because I have to reach a place even with delays."	Tolerance Performance for Loss	Acceptance
11	"A performance level of 75% is often regarded as acceptable… Therefore, I find it reasonable to accept up to a 15% reduction in performance during low flood scenarios."	Tolerance Performance for Loss	Acceptance
12	"In medium flood I can accept a 10% loss in performance… further reduction in performance… is deemed unacceptable."	Tolerance Performance for Loss	Acceptance
13	"I can accept a 5% loss in connectivity because the terrain is not flat… So a 5% loss is acceptable."	Tolerance Performance for Loss	Acceptance
14	"Threshold is about how much loss I can tolerate before calling it failed."	Tolerance Performance for Loss	Acceptance

SI no.	first order concepts (Interview Quote)	Second Order Theme	Aggregate Dimension
15	"I expect the system to provide at least 90% performance in normal operation and low floods, and 80% in medium floods. I can only tolerate a 10% loss in performance of the functionalities…"	Performance Expectations	Acceptance
16	"I expect the system to provide 95% of performance for connectivity and travel time reliability [in normal operation] because the system has control over these two functionalities unlike safety."	Performance Expectations	Acceptance
17	"If the road is maintained properly without potholes and [has proper] drainage… I would expect the same percentage of functionality in low flood with respect to normal operation."	Performance Expectations	Acceptance
18	"Medium flood situation is when evacuation may begin so I want the system to maintain the same connectivity as in low flood, but safety is a volatile factor so I can accept a 10% loss in performance… a minimal loss is still acceptable."	Performance Expectations	Acceptance
19	"In high floods, I will push the system to have high performance… I want the system to maintain connectivity between major areas and locations. Also I can only accept a minimal loss in connectivity and travel time reliability…"	Performance Expectations	Acceptance
20	"In high flood scenarios… a system which can maintain ~30% of its performance under these extreme weather conditions is a well designed system."	Performance Expectations	Acceptance
21	"The system should drain the water as fast as possible and increase the visibility of the road such that the system can provide more safety or make sure there is less drop in safety during medium floods."	Performance Expectations	Acceptance

SI no.	first order concepts (Interview Quote)	Second Order Theme	Aggregate Dimension
22	“During high floods, I would expect the system to deploy various methods, strategies or increase the number of emergency responders, thereby increasing the performance of safety.”	Performance Expectations	Acceptance
23	“I expect a road system to provide a safe travel and offer connectivity… which will in turn provide an acceptable and predictable travel time.”	Performance Expectations	Acceptance
24	“Even in normal operation I want to be safe first. So the system has to provide at least 90% of safety… Then comes reliability… Third comes connectivity…”	Performance Expectations	Acceptance
25	“The system must ensure that 80% safety is guaranteed. What I mean by guarantee is that the system takes enough measure to make the user have a certain amount of confidence in using the road network.”	System Guarantees	Acceptance
26	“The system should… make sure this loss in visibility is compensated by lets say reflective cones, barricades, etc. Also, I can accept no loss in safety performance even in medium and high flood.”	System Guarantees	Acceptance
27	“Only if safety is guaranteed to a certain level I can travel or use the road network without any discomfort.”	System Guarantees	Acceptance
28	“I know that I won’t get 100% performance from the system. But at least the system should make me trust and give me the confidence that the system can provide 90% and 80% in low and medium floods respectively.”	System Guarantees	Acceptance
29	“Only if the system can provide at least 50% safety in high floods will I be able to trust the system and make use of the road network… Without 50% safety I won’t…	System Guarantees	Acceptance

SI no.	first order concepts (Interview Quote)	Second Order Theme	Aggregate Dimension
	use the road network even if the system can maintain 60–70% of connectivity and reliability."		
30	"With proper roads, well designed and efficient drainage and strong enforcement of rules and regulations the system can provide safety and connectivity of desired level at a low flood scenario easily."	System Guarantees	Acceptance
31	"Also only if the system can fulfil the above mentioned thresholds (my acceptance percentages) I will be confident enough to use the road network. The system should provide me confidence that even in 30 cm water level I will be able to receive the same performance…"	Confidence	Acceptance
32	"I will not use the system if performance drops below X%… I will not use the system if there is a drop in performance below 80%… in medium and 60% in high floods."	Confidence	Acceptance
33	"Using the system becomes pointless if… connectivity and travel time reliability cannot be maintained or the drop in expected performance percentage is minimised as much as possible."	Confidence	Acceptance
34	"Basically the confidence level goes down if the system cannot keep the loss in performance below 20% of its normal operation."	Confidence	Acceptance
35	"If I know I won't be safe I won't use the road network or I will avoid the unsafe areas of the road network during my travel."	Confidence	Acceptance

SI no.	first order concepts (Interview Quote)	Second Order Theme	Aggregate Dimension
36	“Even if the system has good drainage… potholes [mean] there will be water stagnation which will reduce my confidence to use the system during floods and I won’t use the road network to travel to avoid accidents.”	Confidence	Acceptance
37	“Safety is a key functionality which builds confidence for me as a user to use that system under disruption.”	Confidence	Acceptance
38	“For me safety comes first. That is the reason why I have low tolerance for safety compared to other functionalities and also the high acceptable performance percentage for normal operation.”	Value Hierarchy	Value Prioritization
39	“For me safety comes first… So safety is first priority. Then comes connectivity because I should be able to reach a place only then I can think about travel time. But it’s a paradox between connectivity and travel time reliability… even with connectivity if there is a huge delay then the network becomes useless.”	Value Hierarchy	Value Prioritization
40	“Safety wins every time, no debate.”	Value Hierarchy	Value Prioritization
41	“Without safety having 100% connectivity or travel time reliability is useless and pointless.”	Value Hierarchy	Value Prioritization
42	“Connectivity without safety is useless. So I have given a lesser acceptance percentage for connectivity compared to safety.”	Value Hierarchy	Value Prioritization
43	“If I am not safe what is the point of having connectivity and travel time reliability.”	Value Hierarchy	Value Prioritization

SI no.	first order concepts (Interview Quote)	Second Order Theme	Aggregate Dimension
44	"Generally safety comes first but I prefer travel time reliability because I would reach the place in the expected time… then I wouldn't exceed speed limit, break rules or rash drive… which increases safety."	Value Hierarchy	Value Prioritization
45	"This is the reason why I give higher priority to travel time reliability than connectivity and safety in low flood. But in medium and high flood… I would like to prioritise safety over other functionalities."	Value Hierarchy	Value Prioritization
46	"Without safety… 100% connectivity or reliability is useless… I accept lower performance for safety than connectivity and reliability from a threshold perspective, **but** while comparing functionalities I would prefer safety over others."	Value Hierarchy	Value Prioritization
47	"My priorities would change according to the situation… I give equal priority to connectivity and travel time reliability in low and medium floods and higher priority to safety in high floods… Also… there is no use in having connectivity or reliability without safety. So I expect the system to maintain at least 50% safety – this will be my number one priority in high floods."	Value Hierarchy	Value Prioritization
48	"I don't want to be isolated from any area… So connectivity gets slightly more importance when compared to reliability. But percentage wise I can accept 60% minimum performance. This is the reason to give higher priority to connectivity even though the acceptable performance values are the same for connectivity and travel time reliability. In high floods both connectivity and travel time reliability are equally important, but I want higher performance for travel time reliability of the system."	Value Hierarchy	Value Prioritization

SI no.	first order concepts (Interview Quote)	Second Order Theme	Aggregate Dimension
49	“Connectivity takes the second priority. Being stuck with no way in or out is a nightmare. Travel time reliability gets third priority always. During a flood I cannot expect to reach a place without delays…”	Value Hierarchy	Value Prioritization
50	“I feel like safety should be the number one priority but I cannot expect the system to provide safety during normal and extreme weather conditions. So I would prioritize connectivity and travel time reliability. I would rather [have] less tolerance towards the other two functionalities than safety which greatly depends on the users of the system.”	Value Hierarchy	Value Prioritization

Table 7. *Data structure table*

1. **First Order Concepts:** The interview notes and summaries were thoroughly read, and the interviewees phrases were highlighted to form the initial code. In this initial phase, the wording was not changed or altered instead it was kept as true as possible to the participants' own language. For example, when an interviewee said, "No performance drop will be accepted for a low flood as the water level increase is very low", it was coded as a first order concept of "no tolerance for performance loss". Another interviewee noted that "I cannot tolerate any drop in performance of safety even in medium and high floods" and that the system should compensate reduced visibility with measures like reflective cones, this was captured as "zero tolerance for safety degradation". Statements such as "I expect at least 90% predictability in travel time to ensure efficient and dependable mobility" were coded as "high expected travel time reliability". Similarly, dozens of such first order codes were identified across the interviews. At this stage, imposing any pre-existing theory or terminology was deliberately avoided. Instead, the interviewees' own articulations of their values and reasoning were mirrored. This yielded a long list of raw concepts essentially a reflection of each meaningful idea mentioned by the users in relation to how they value road functionality under flood conditions.

   After coding, all 15 interview notes were compiled and reviewed for commonalities in first order concepts. According to Gioia et al. (2013) methodology, this involves looking for recurrent words, phrases, or sentiments across participants. Strong recurring ideas were noticed (refer table 7, above). For instance, many participants used the terms "tolerate" or "accept" to talk about how much drop in performance they would withstand. One participant explicitly defined a "threshold as, how much loss I can tolerate before calling it failed". Another common idea was what users "expect" the system to provide, often expressed as a percentage. The notion of "guarantee" also emerged, with interviewees saying the system must guarantee a certain level of safety or service to earn their confidence. Finally, "confidence" (or trust) was a term used to describe their feeling of functionality and willingness to use the roads under flood conditions; for example, "confidence level goes down if the system cannot keep the loss in performance below 20% of normal operation". These repeated ideas signaled that while participants described them in their own ways, there were underlying conceptual commonalities forming.

   To manage the volume of first order codes, similar codes were clustered together. The integrity of the participants wordings was maintained (per Gioia et al. guidance to use informant centric terms) but began noting provisional labels for groups of first order concepts. For instance, statements about not accepting drops, the percentage of performance loss one "can tolerate", and conditions for calling the system "failed" were grouped into a provisional category around "tolerance for performance loss." Quotes about what the system "should provide" or what participants "expect" in various scenarios formed a category of "performance expectations." References to the system "guaranteeing" safety or reliability or needing the system to take measures (drain water quickly, provide signage, etc.) were grouped as "system guarantees/assurances." And comments about the interviewee's "confidence to use the road network" often tied to whether a certain functionality is assured were collected as another group. The first order categories that essentially echoed with the user's perspective were identified (informant centric concepts). This reflects the completion of the first step of Gioia et al. (2013) analysis: where the first order concepts were distilled from raw data but retaining the perspective of the interviewees.

2. **Second Order Themes:** In this phase, the analytical lens shifted to theoretical significance in the first order categories. Meaning, what concept is this an instance of? Why might these participants terms be important? to examine the first order groups for patterns and relationships. Four prominent second order themes became apparent, each corresponding to the repeated ideas: Tolerance, Expectations, Guarantees, and Confidence. These were not arbitrary labels; they arose from the language stakeholders themselves used, but it had elevated them to a slightly more abstract level to capture the essence of each cluster of ideas. Second order theme were defined as follows, with grounding in the data and literature:

    - **Tolerance for Performance Loss:** This theme encapsulates the degree to which stakeholders are willing to endure reductions in road system functionality (safety, connectivity and travel time reliability) during floods. It reflects their acceptable loss in performance of the system. For example, one interviewee stated plainly, "Threshold is about how much loss I can tolerate before calling it failed", indicating a cutoff point for acceptability. Many participants provided specific percentages of performance drop they could live with in different scenarios (e.g. "I will take a 30% drop in Safety because perfect protection is not possible"; "I can only tolerate 20% loss in safety performance during floods as it will greatly affect my confidence if more"). This theme connects to the concept of acceptable risk in the literature. The idea that there is a level of risk or performance degradation deemed acceptable to individuals or society before an intervention is needed. For instance, in flood risk management, decisions about safety standards often revolve around what level of risk is tolerable or "acceptable" to stakeholders. Vrijling et al. (1998) note that determining acceptable risk involves criteria that should be stringent and aligned with societal values. From the collected data, tolerance emerged as a nuanced theme: it varied by context (hazard severity) and by functionality. Users expressed zero or very low tolerance at low flood levels "No performance drop will be accepted for a low flood", essentially saying minor floods should not cause any noticeable performance loss. In contrary, for medium floods, some were willing to accept a small drop, and by high floods many voiced high tolerance for loss in certain functions (travel time, connectivity) if basic safety was preserved. This indicates that tolerance increase as conditions worsen. This is elaborated in the findings, how this tolerance is articulated.

The key is that tolerance represents stakeholders' capacity to endure degraded performance, a concept resonant with risk appetite in organizational terms (how much bad outcome one is willing to bear) and with "acceptable performance" thresholds in resilience.

- **Performance Expectations:** This theme captures what users demand or what they expect the system to deliver under various flood severities. It is closely related to tolerance, but tolerance focuses on the downside (how much loss I'll accept), expectations focus on the baseline (what I believe should be delivered). Participants frequently used phrases like "I expect the system to provide…" a certain level of safety, connectivity, or travel time reliability. For example, one person in normal conditions expected "at least 90% predictability in travel time to ensure efficient and dependable mobility", acknowledging minor delays but still a high level of service. Under low flood conditions, many expected essentially no change from normal: "The system should perform the same at low disruptions, I expect the same percentage of functionality in low flood as normal operations". This reflects a belief that the system should handle very minor disruptions without noticeable impact. As floods worsen, expectations often adjusted downward: e.g. "During high floods, my realistic expectations would be bare minimum as the system cannot do anything to provide certain performance". Another interviewee bluntly said, "In high floods I know I won't be safe. The system cannot maintain expected level of safety. So, I would rather expect reduced delays than to expect safety during that journey". This theme links to literature on service level expectations and satisfaction. In transport research, users have certain expectations for level of service (e.g. a certain travel time) and when reality falls below that expectation, satisfaction drops (Parasuraman et al., 1985) in service quality theory. Here, stakeholders articulate their expected performance benchmarks for the road system's resilience. These expectations are also grounded in what the users perceive as reasonable or feasible. Some participants tempered their expectations by acknowledging constraints (e.g. "I cannot expect 100% safety; I want at least 90%"; "you cannot expect to reach without delays in a flood, but the delays should be minimal".

  Thus, expectations as a theme represent a more proactive stance: what people believe the system should strive to provide, which in turn defines the baseline for acceptance. Grounded theory literature often discusses how participants carry "theoretical expectations" of phenomena; here it was literally seen as expected performance (if expectations aren't met, users lose trust/confidence).

- **System Guarantees (Assurance):** The third theme revolves around users' desire for assurance that the system will deliver critical functions, under adverse conditions. Interviewees used the word "guarantee" in the sense of the system ensuring a minimum level of performance. One participant explained, "80% safety should be guaranteed. By guarantee I mean the system takes enough measures to give the user a certain amount of confidence in using the road network". This illuminates how guarantee is tied to concrete actions (maintenance, flood management measures, enforcement, etc) that system must undertake so that users feel secure. Another noted that "I expect the system to guarantee certain percentage of safety, connectivity and travel time reliability", emphasizing that some performance level should be assured by design or response.

  However, participants recognized limits: "As water level increases, the system cannot guarantee safety, but it can ensure connectivity and reliability" here distinguishing that safety is harder to guarantee due to external factors (human behavior, chaotic conditions, etc) whereas connectivity and travel time can be managed through planning and infrastructure. This aligns with many interviewees' reasoning that safety is partly in the users' hands, so they doubt a full guarantee on safety, whereas they demand the system guarantee other functionalities (like keeping main routes open and providing alternate routes to maintain connectivity). The theme of guarantee connects to trust and accountability in literature. It echoes the concept of a "social contract" between users and providers. People expect that systems are designed with safety factors and contingency such that certain failures are highly unlikely. In resilience terms, this is similar to performance standards or service guarantees, e.g. a transport agency might guarantee that even in a 1 in 10 year flood, primary roads will remain 80% operational. The participants of this research, in an inductive way, voiced a need for such assurances. This theme also links to risk communication and trust: previous research suggests that when systems clearly guarantee certain protections (or transparently acknowledge what cannot be guaranteed), it affects public acceptance and trust (Slovic, 1993; Siegrist & Cvetkovich, 2000). Here, when participants say they want the system to guarantee safety to a level, they are implicitly expressing a need for trust in institutional provisions. They want evidence of preparedness: e.g. pre-installed flood drainage, proper road maintenance (fix potholes, as several mentioned), emergency response readiness. If those guarantees are perceived as in place, it increases their willingness to use the system in a flood.

- **Confidence (Trust in System):** The fourth second order theme is the confidence of users to use the transport system under flood conditions. This theme is essentially the outcome or consequence of the other three: if expectations are met and basic guarantees are in place (with tolerance not exceeded), users gain or retain confidence to travel; if not, their confidence decreases. "Basically, the confidence level goes down if the system cannot keep the loss in performance below 20% of its normal operation" one interviewee explained, adding "I won't use the road network during floods to avoid accidents when performance drops too much". Another stated, "Only if safety is guaranteed to a certain level can I use the road network without discomfort", directly relating safety assurance to confidence.

Conversely, participants described how if certain conditions are met, they will have confidence to venture out: e.g. "If the road is maintained properly then there will be less accidents, which will increase connectivity by avoiding closures. I will have confidence that even during flood I can travel through that route". Confidence here means trust in one's personal safety and trust in the network's reliability.

In broader theoretical terms, this connects to risk perception and protective action decision models eople decide whether to evacuate, stay home, or travel in hazardous conditions based on their confidence (or lack of confidence) in the system and in their own safety. In this context, if users lack confidence that a flooded road is safe or passable, they will avoid using it (which in turn affects the resilience of the system in terms of usage). Confidence also relates to psychological comfort. Several interviews indicated that anxiety or fear would prevent them from driving if, say, water is above a certain level or if they're not sure about safety. One participant illustrated this: "For example, if there is water flowing under the bridge, I should have the confidence to use the bridge. So, safety is my first priority". This underscores that confidence is derived from the perception of safety.

In summary, confidence as a second order theme captures the trust and comfort level users have in using the transport system when it's under stress, which is a key human factor in resilience (a perfectly intact road network is not truly resilient if people refuse to use it out of fear). Lee and Boniface (2000) mentioned this as "people need to trust that the system will not put them in undue danger".

- **Value Hierarchy:** The fifth second order theme (also known as priority trade-offs) captures how users rank system functionalities safety, connectivity and travel time reliability when forced to make trade-offs. Nearly every interviewee explicitly compared the importance of these functionalities under different flood scenarios. A consistent pattern emerged: safety is almost universally deemed the top priority, usually followed by connectivity, with travel time reliability ranked last during floods. One participant directly mentioned, "Safety wins every time, no debate," underscoring that other benefits mean little if one is not safe. Another noted, "Without safety, having 100% connectivity or travel time reliability is useless and pointless," highlighting the sentiment that if safety isn't assured, other functionalities hold no value. Connectivity is typically given the second priority because being completely cut off is seen as unacceptable: "Connectivity takes the second priority. Being stuck with no way in or out is a nightmare. Travel time reliability gets third priority always during a flood" one interviewee explained. This common sentiment reflects a fear of isolation outweighing the inconvenience of delay. Thus, travel time reliability while valued in normal conditions was often considered a "luxury" in flood conditions, to be sacrificed first when necessary. In the words of several stakeholders, mentioned that they would "rather be late than to be unsafe" in a disaster scenario.

At the same time, participants frequently discussed a "connectivity vs. reliability" dilemma. Because connectivity (having an open route) is a prerequisite for mobility, it must come first "I should be able to reach a place only then I can think about travel time" as one put it. Yet, if connectivity is achieved but delays are extreme, the network becomes useless. As one interviewee noted, "even with connectivity, if there is a huge delay then the network becomes useless". Conversely, great reliability means nothing if roads are closed. Users navigate this dilemma by generally prioritizing connectivity (access) slightly over promptness, except in special cases. Some acknowledged that in life critical situations, speed can be as crucial as access, for example, reaching a hospital in time can directly affect survival, temporarily bumping up the priority of travel time reliability. Indeed, one person in a high flood scenario gave equal priority to safety and connectivity but then remarked "in high floods both connectivity and travel time reliability are equally important, but I want higher performance for travel time reliability". This illustrates that during emergencies, once a minimal level of connectivity is secured, stakeholders do desire improved reliability (faster travel) an insight consistent with disaster management literature that time can become critical when lives are at stake. On the whole, however, the prevailing hierarchy in floods was safety first, connectivity second, reliability third. Even those who in low risk situations ranked reliability above safety did so only because they assumed safety was already guaranteed in a minor flood. For instance, a couple of participants gave safety a lower rank (2) in low flood, reasoning that if flooding is minimal "safety is not actually at risk," so minimizing delay took precedence in that context. This again demonstrates that priority weights are context dependent under mild conditions people expect normal convenience, but under severe conditions they focus on survival and access. As one interviewee summarized, "I can travel extra distance or time, but I want to be safe in the end".

Notably, while safety is conceptually non-negotiable, many stakeholders set high tolerance for performance thresholds for safety than for connectivity. They recognized that perfect safety in a flood is unrealistic, so they were reluctantly willing to tolerate a larger drop in safety performance. In other words, they value safety most but also expect it to degrade the most when push comes to shove. One interviewee explicitly reflected on this trade-off, saying safety "should be number one priority but I cannot expect the system to provide safety fully" and have "less tolerance towards the other two functionalities than safety". This reveals a pragmatic understanding: because they doubt whether the system can guarantee safety in extreme floods, they hold the system more accountable for maintaining connectivity and travel time reliability, which are seen as more controllable functionalities. Similarly, another participant described accepting a 30% drop in safety performance but only 10% in connectivity, reasoning that some safety loss is inevitable, whereas losing connectivity "affects" more. This counterintuitive inversion allowing a bigger drop in the value they conceptually hold highest was noted across multiple interviews. It highlights that stakeholders balance their ideal priorities with realistic expectations of system limits. In essence, people prioritize what matters most but set their performance acceptance thresholds by considering which failures they can personally cope with and which trade-offs they are willing to make. Thus, Value Hierarchy theme captures the priority trade-offs underlying such decisions.

In summary, Value Hierarchy reflects a complex, but coherent trade-offs voiced by users, wherein safety is paramount but understood as imperfect and connectivity is vital for maintaining basic functioning. This theme enriches the understanding of user values by showing why certain performance losses are tolerated: it depends on what people refuse to compromise versus what they are prepared to sacrifice.

Having identified these five second order themes: Tolerance, Expectations, Guarantee, Confidence and Value Hierarchy, and double checked them against the data to ensure each theme is well supported (this often involves an iterative return to the data, which is called constant comparison). This constant comparison was done to make sure that these themes held or if new themes were needed. For instance, one interview was far more forgiving across the board, expecting only 75% performance even in normal conditions due to realism about uncertainties. This initially seemed like a new theme (e.g. perhaps a theme of "realism" or "resilience thinking"). However, upon closer analysis, it was actually another expression of expectations and tolerance. The participant simply had a generally lower performance expectation and higher tolerance for the system. Thus, all concepts in the interview notes were accommodated under these five identified themes, with some variation in how they were expressed. Also, the constant comparison process continued until theoretical saturation was reached, i.e., additional data did not reveal new themes, only nuances of the existing ones. At that point, the identified second order themes robustly represented the interview data.

3. **Aggregate Dimensions:** The final step was to look at how these second order themes relate to one another and to higher level theoretical constructs, thereby formulating aggregate dimensions. Gioia et al. (2013) describe aggregate dimensions as overarching concepts that emerge when second order themes coalesce into a more general theoretical category. From the analysis, one clear aggregate dimension that surfaced was "Acceptance". It is labelled as such to denote the overall idea of users' acceptance

of system performance under flood different hazard intensities. Essentially, acceptance here means the degree to which stakeholders are willing to live with the transport system's performance (and continue to use it or support it) across varying flood scenarios. The identified theme: tolerance, expectations, guarantee, and confidence all interrelate to shape this notion of acceptance. They are each facets of how acceptance is constructed:

- *Tolerance* defines boundaries of acceptance (how much worse can things get before I no longer accept it?).

- *Expectations* define the baseline of acceptance (what I require as a minimum from the system).

- *Guarantees* relate to the conditions for acceptance (what assurances or measures must be in place for me to accept the risk of traveling).

- *Confidence* is the outcome or consequence of acceptance (if the other factors are satisfied, I feel confident i.e., I effectively accept the situation and proceed to use the system).

Thus, **Acceptance** was theorised as an aggregate dimension of themes. This aligns with how the term "acceptance" is used in risk literature: for example, Saunders et al. (2012) argued that determining what safety outcomes are acceptable requires understanding stakeholders' risk perceptions and tolerances. For this case, acceptance of flood impacts on functionalities is very much a synthesis of perceiving that the situation is within one's tolerance, meets one's expectations (or adjusted expectations), and that the system has provided reasonable guarantees such that one can confidently proceed. This is further discussed in the findings section.

Notably, when users talked about what they "accept" or "cannot accept," they often implicitly invoked multiple themes at once (e.g. "I cannot accept loss in performance even in medium flood. The system should provide same performance", combining expectation and zero tolerance; or "I will only travel in high flood due to emergency and what is the point of using the network if I won't be safe" or "I can only accept minimal loss in connectivity and reliability (in a particular scenario)". Thus, linking expectation of safety, tolerance for loss in others, and condition of emergency. These multi-faceted statements indicated that the aggregate concept of Acceptance was indeed at play.

Besides acceptance, the research remained open to other aggregate dimensions emerging inductively. One additional aggregate dimension that did emerge from the analysis was related to Value Hierarchy. This concept captures how stakeholders prioritize different values (safety, connectivity and travel time reliability) when trade-offs must be made. It was noticed that beyond discussing acceptable performance levels, almost every interviewee explicitly ranked or compared the importance of the three functionalities under various conditions (often using a priority ranking of 1, 2 and 3 for safety, connectivity and travel time reliability). This was sometimes discussed as a dilemma. For example, one interviewee mentioned, "It's a dilemma between connectivity and travel time reliability: even with connectivity, if there is a huge delay then the network becomes useless". Many stated unequivocally that "safety comes first" or "Safety wins every time, no debate", yet some also acknowledged that in practice they set lower performance thresholds for safety than for connectivity due to the uncontrollable and volatile nature of safety. This indicates a complex value hierarchy: conceptually safety is the top priority (a fundamental value), but practically, they sometimes accept more safety degradation than, say, connectivity because they recognize limits of the system and personal control. This recurrent theme of value hierarchy, lead to another an aggregate dimension about users' values, **Value Prioritisation**.

In addition, confidence is not only a consequence of tolerance, system guarantee and performance expectation but it also a contributing theme for the aggregate dimension **Value Prioritisation**. Given an ultimatum, the users of the road network considered confidence of that the system provides to them as an evaluation criterion to set priorities. One of the interviewees stated that, "If I know I won't be safe I won't use the road network, or I will avoid the unsafe areas of the road network during my travel". Another interviewee mentioned that "Basically the confidence level goes down if the system cannot keep the loss in performance below 20% of its normal operation". Similarly, there are many instances where confidence of the user for the road system has significantly impacted the prioritisation of the functionalities under disruption as mentioned above where connectivity and travel time reliability are less prioritised to enhance safety. Therefore, confidence is not limited to the consequence of tolerance, system guarantee and performance expectation, but it is also a factor which influences the prioritisation of the functionalities. Thus, confidence greatly contributes to the aggregate dimension Value Prioritisation. In other words, the second order theme confidence plays a major role as the deciding factor during trade-offs.

Thus, the second aggregate dimension, **Value Prioritisation** explains how people balance different system functionalities. It is related to acceptance but not identical. One can accept a certain outcome only after deciding which value is more important to uphold. For example, if forced to choose, most participants would sacrifice travel time reliability to preserve safety and connectivity during floods; that is a prioritization decision. In theoretical terms, this dimension connects to multicriteria decision making and utility trade-offs in the face of risk (Keeney & Raiffa, 1993). It also resonates with the idea in resilience literature that resilience is multi-dimensional, and stakeholders may prioritize some dimensions over others depending on context (Bruijn et al., 2017).

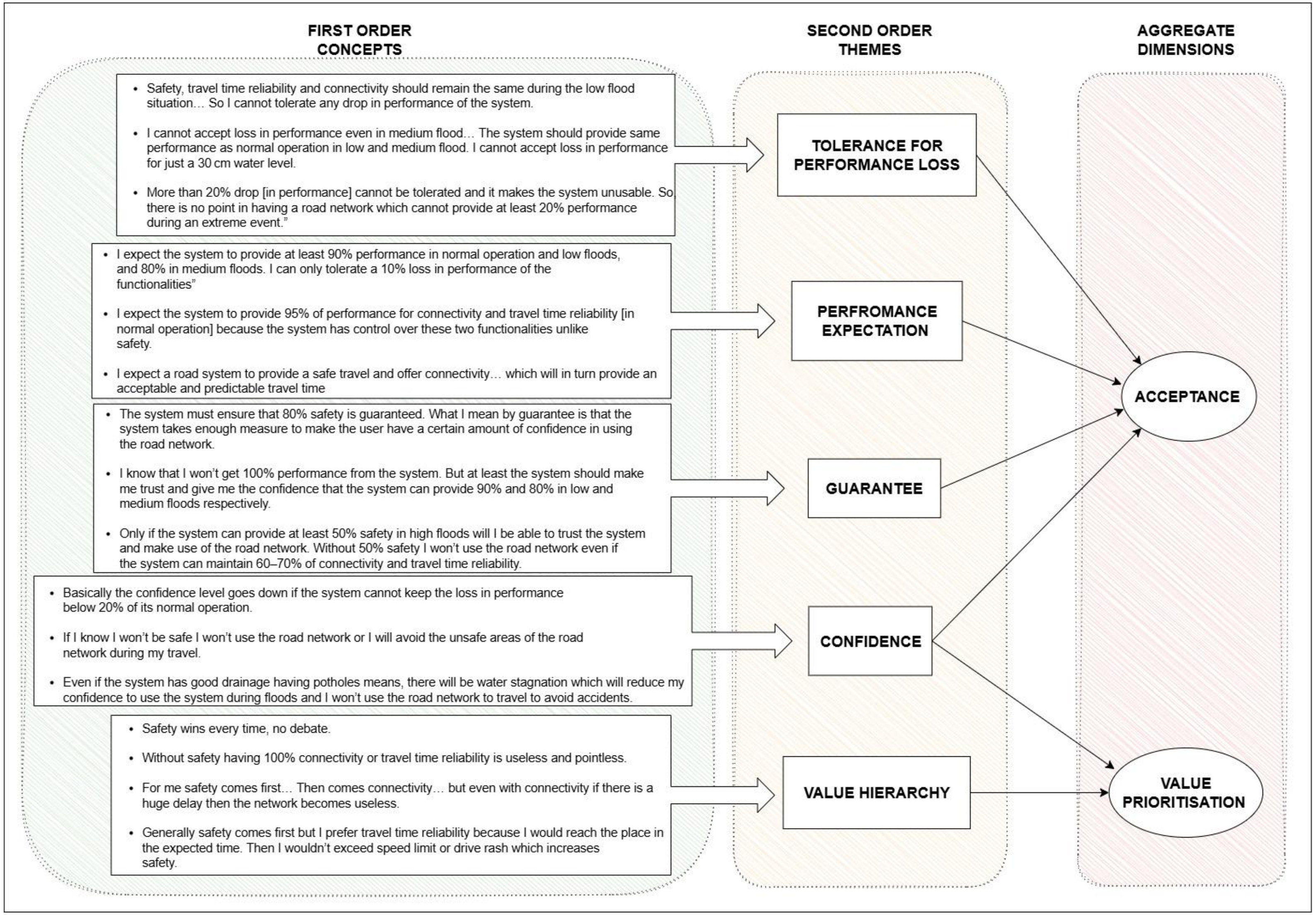

Figure 3. *Illustrates the data structure, mapping how numerous interviewee quotes cluster into our themes and how those relate to the aggregate dimensions.*

By the end of the coding process, a set of first order concepts (dozens of specific users' statements), were grouped into four second order themes (Tolerance, Expectations, Guarantees, Confidence and Value Hierarchy) and these in turn informed two main aggregate dimensions: **Acceptance** (of system performance under flood conditions) and **Value Prioritization** (under different flood hazard intensities).

This qualitative analysis, employing the systematic Gioia et al. (2013) methodology on 15 in-depth interview notes, successfully developed a nuanced, bottom-up understanding of user acceptance and value prioritization in road network resilience during flood events. By inductively surfacing first order concepts from participants' own words, the study identified five robust second order themes: Tolerance for Performance Loss, Performance Expectations, System Guarantees (Assurance), Confidence (Trust in System), and Value Hierarchy. These themes collectively coalesce into two overarching aggregate dimensions: Acceptance of system performance under flood conditions and Value Prioritization when trade-offs are necessary.

An important finding is the consistent value hierarchy: safety is universally paramount, followed by connectivity, with travel time reliability consistently ranked lowest during floods. However, this conceptual priority is pragmatically balanced by an observed, often counterintuitive, higher tolerance for safety performance degradation compared to connectivity, as users acknowledge the inherent limitations of achieving perfect safety in extreme conditions. Confidence emerged not only as a consequence of other themes but also as a direct influence on this prioritization. These findings comprehensively illuminate **the rationale and reason behind certain performance losses tolerance, and what people refuse to compromise** *versus* **what they are prepared to sacrifice.**

Chapter 5

An Approach to Integrate Stakeholder Value in a Threshold Matrix for Resilience Assessment

5.1 The Approach

To integrate stakeholder value in a threshold matrix for resilience assessment, a phased approach is proposed. This approach outlines the step by step process used in this study (focused on the Tambaram, Chennai case) to arrive at a stakeholder value integrated threshold matrix, highlighting the complexities encountered at each step and the mitigation measures adopted and recommended for future studies. The rationale behind each methodological decision is explained to guide future research in similar contexts.

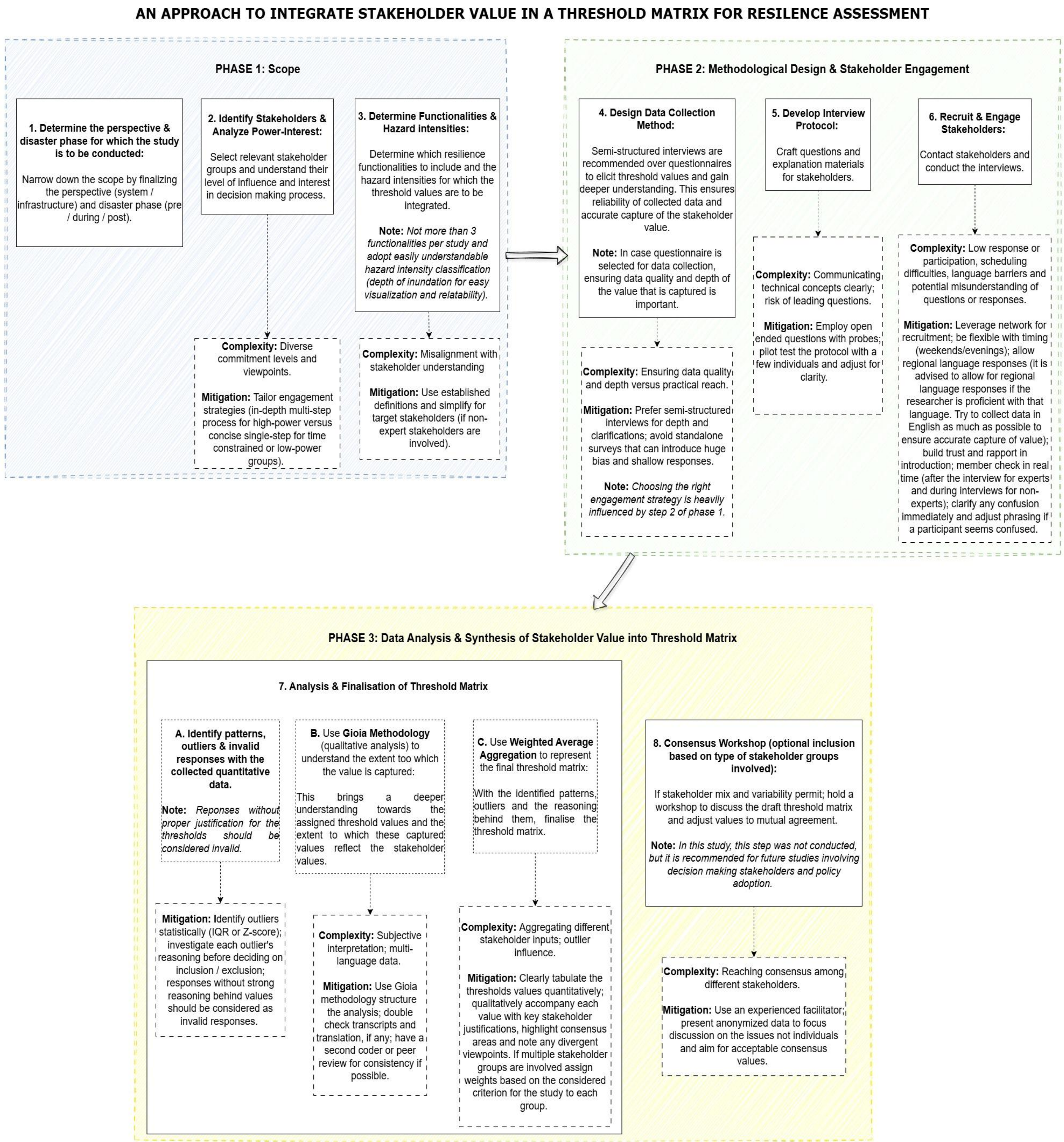

Figure 4. *An approach to integrate stakeholder value in a threshold matrix for resilience assessment*

Note: *To further understand, an illustration of approach using this research is given below with the identified complexities during the research and the mitigation strategies used and recommendations for future research for diverse stakeholder involvement.*

Phase 1: Scope

The *first step* is to make the scope manageable by determining the perspective and the disaster phase in which the stakeholder value is to be integrated.

1. **Perspective**: It was decided whether to focus on the transport system's performance (service delivery to users) or the infrastructure's performance (physical asset resilience). In this study, system's perspective was emphasized, since the stakeholder group consisted of road users for relatability and scenario visualisation (refer section 5.2).

2. **Phase of Disaster**: The time frame of the interest was also clarified by focusing on particular phase of the disaster. For example, whether stakeholders are considering performance in pre disaster, during disaster or post disaster phase. For Tambaram, stakeholders were primarily asked about performance during a disaster for the same reason, to introduce relatability and for scenario visualisation (refer section 5.2).

   By explicitly stating the phase and/or perspective in which each functionality is considered, stakeholders could focus on the relevant context when providing their thresholds. In addition, the exact days and time of the day was communicated and location in which this scenario is to be imagined was also informed to help stakeholders visualise the scenario. This focus made it easier for stakeholders to give meaningful input based on their knowledge and experience.

The *second step* involves the identification of relevant stakeholders pertinent to the study. Given the inaccessibility of expert participants, road users are designated as the primary stakeholder group for this study. Subsequently, a power-interest analysis is conducted to evaluate the relative influence and decision making authority of each stakeholder group, particularly in contexts where multiple groups are engaged. This step is elaborated in Phase 2 to establish the connection between stakeholder type and their impact on the design and adoption of the data collection procedure.

The *third step* is to determine the functionalities for which stakeholder value is to be integrated (minimum acceptable performance thresholds). These functionalities represent key dimensions of resilience for transportation sector. Rather than deriving these dimensions from scratch, the study leveraged existing research for consistency. Nipa and Kermanshachi (2019) identified 18 resilience functionalities for the transportation sector in their work, providing a comprehensive starting list. Adopting established definitions or a refined subset of them ensures that the study builds on validated concepts and makes it easier to communicate with stakeholders.

A major challenge was ensuring the chosen functionalities were meaningful and understandable to stakeholders. As stakeholders might misinterpret them or conflate multiple concepts. For example, a lay stakeholder might mix “mobility” with “accessibility” if the terms are not clearly defined, leading to confusion when providing threshold values. Additionally, attempting to derive functionalities purely from stakeholder feedback (a bottom up approach) would require a very large sample and extensive analysis, since each stakeholder might express expectations in different terms. Interpreting and clustering such open ended inputs into formal resilience dimensions would be tedious and potentially ambiguous. One person’s description of a “safety issue” could be categorized by researchers under a completely different functionality like “emergency response,” and vice versa.

To address these issues, the study adopted pre-defined set of system functionalities before engaging stakeholders. For lay stakeholders it is advised to describe each functionality in non-technical terms to facilitate understanding. This top down approach (grounded in literature but simplified for practical use) prevented misinterpretation and kept stakeholders focused. It also ensured that stakeholder inputs (their minimum acceptable performance thresholds) directly corresponded to known resilience dimensions, avoiding the need to retrospectively map diverse stakeholder statements to technical categories. Furthermore, the selected perspective and disaster phase helps to adopt and explain functionalities as the functionalities were framed within specific categories.

The type of stakeholder (expert/non-expert) influenced how each functionality was communicated. Technical experts (e.g., engineers or planners) can understand and debate sophisticated definitions, whereas lay stakeholders need more intuitive descriptions. If the definition was too complex for a given stakeholder, there is a risk they would provide misguided thresholds or merge multiple issues into one.

To mitigate this risk the functionality definition was tailored to the stakeholder group’s expertise. In this study, since the participants were road users (lay stakeholders), the definitions were kept simple. Each functionality was explained with real life context. This helped participants confidently give a minimum acceptable performance level (percentage threshold) for that functionality. In future studies with technical stakeholders, more precise or technical definitions could be used, but for the purposes of this study, clarity and simplicity took priority.

Furthermore, this study adopts depth of inundation as the primary criterion for classifying flood hazard intensity into three categories: low, medium, and high. While alternative classification methods exist (see Section 2.5), the use of inundation depth offers a straightforward and intuitive approach, facilitating clearer interpretation and scenario visualization for both experts and lay stakeholders.

By the end of Phase 1, the study had a clear pre-defined set of functionalities, scoped to the perspective, relevant disaster phase and classified hazard intensities, ready for stakeholder evaluation. This groundwork mitigated the risk of confusion and ensured that subsequent stakeholder discussions would be aligned and focused.

Phase 2: Methodology Design and Stakeholder Engagement

With the functionalities established, the next phase involved designing the data collection methodology to elicit stakeholder defined threshold values. Several critical considerations guided this phase: the choice of data collection method, the power-interest of stakeholders, practical recruitment challenges, and communication (language) issues. Each consideration presented its own complexities and required careful mitigation strategies, as detailed below.

- **Selecting a Data Collection Method (Interviews or Questionnaires):**

One of the earliest methodological decisions was how to collect data from stakeholders (interviews or survey). Each approach has advantages and drawbacks in the context of capturing nuanced stakeholder values for uncertain scenarios like disasters.

- **Interviews** ***(Preferred Approach):*** The study opted for semi-structured interviews as the primary data collection method. Interviews allow the researcher to clearly communicate the context (explaining the scenario, the defined functionalities, and the concept of performance thresholds) and to clarify any doubts on the spot. This two-way interaction was critical given the complexity of the topic. Participants could ask for clarification, and the interviewer could probe for reasoning without leading the interviewee. As a result, richer and more reliable data were obtained. Interviews also inherently reduce certain biases, there is no predefined numeric scale that might skew responses (participants state their threshold in their own terms or percentage, guided by open questions). Additionally, the interviewer can observe cues and ensure the participant stays on the question's scope. It was found that interviews enabled participants to provide deep insights and logical reasoning behind their chosen threshold values; this qualitative context is invaluable for interpreting the numbers.
  Finally, interviews made it feasible to incorporate immediate validation of responses. In this study, an on-spot member checking was done, during the interview and at the end of each interview. The interviewer summarized the key points and the stated thresholds to the participant, to verify accuracy. This instant validation ensured that the recorded data was what the stakeholder truly meant, reducing the risk of later misinterpretation.

For future studies a workshop can be conducted after collecting individual inputs. The data could be presented in a group setting for discussion and consensus building, which can directly inform practice (In high engagement contexts, a stakeholder workshop can help reconcile differing views and produce a consensus threshold value that everyone supports).

- **Questionnaires were considered but rejected due to the following reasons:**

  First, explaining the complex context in a written form is challenging, a questionnaire would have to contain extensive instructions, definitions of functionalities, and hypothetical scenarios, making it very lengthy and potentially confusing. Without an interviewer present, respondents might misinterpret questions or skip important details, yielding low quality data.

  Second, a questionnaire offers no opportunity to clarify stakeholder doubts in real time. Participants might answer based on a flawed understanding of a functionality, and there will be no chance to correct it after submitting the response.

  Third, purely quantitative questionnaires encourage blunt answers. Stakeholders could simply fill in a number for a threshold without providing any rationale ("this is just what I want" is not a sufficient explanation). This lack of reasoning would undermine the ability to interpret the results or validate outlier responses (refer section 4.1.3).

  Fatigue and engagement were additional concerns. By taking a survey for more than 10–15 minutes risks participants losing interest and giving careless answers just to finish quickly. Particularly problematic is the use of predefined scales in questionnaires. If a reference scale is provided for performance (say, describing 90% functionality as "only 5 users out of 100 cannot travel safely"), there is a huge risk of anchoring everyone's answers at a high performance level. In pilot discussions, for example, it was realized that if stakeholders see an option implying any loss of life or safety (even a small number), they would simply choose 100% as their acceptable threshold to ensure "everyone stays safe". This results in skewed data with clustered responses (e.g., everyone might answer 95–100% for safety), which fails to reveal true priorities or trade-offs.

  Essentially, a questionnaire could introduce bias and eliminate variability in responses, negating the value of the exercise. It also precludes asking follow-up questions to understand the reason behind a participant's particular threshold value.

Given these considerations, the study adopted semi-structured interviews as the data collection method to ensure clarity, depth, and reliability of the data. The interview protocol was carefully designed to introduce the scenario and each functionality step by step (refer section 3.4 & 3.5), check for understanding, and then record the stakeholder's threshold percentage along with their reasoning. By avoiding a rigid questionnaire, the risk of miscommunication and bias was reduced. The interview setting also helped build rapport, making participants comfortable in expressing honest opinions (including any extreme views, which are important data points). For research capturing stakeholder values in highly uncertain or complex contexts, interviews are recommended over questionnaires to obtain nuanced and credible inputs.

- **Recruit and engage stakeholders:**

Stakeholder selection and engagement were guided by a power-interest analysis. Different types of stakeholders (e.g., government officials, engineers, everyday users) have varying levels of power in decision-making and interest in the issue. This influences both their willingness to participate and the way they should be involved.

- ***High-Power High-Interest Stakeholders:*** Those who have decision-making authority and are very invested in resilience can provide expert insights and also stand to use the study's results. Such stakeholders, if available, can be engaged in a more extensive process. The interview process might involve multiple stages, an initial interview, a follow-up verification after preliminary analysis, and possibly a group workshop to discuss and reach consensus on threshold values. The rationale is that these stakeholders have the influence to implement changes based on the findings, so ensuring they deeply understand and agree with the results is valuable. Moreover, they are often willing to dedicate time to a research process that could inform their decisions.

- ***Low-Power High-Interest Stakeholders:*** In this study, road users fell into this category. They do not hold decision making power but have a keen interest in transport resilience (since they are directly affected by disruptions). Such stakeholders were very willing to share their experiences and expectations, but it was found that they have practical limits on their time and engagement. Many of the users who were approached had busy daily schedules (some commuted 2–3 hours and worked full days), which meant they could spare time for a single interview but were reluctant to commit to any lengthy process beyond that. For this group, the engagement was tailored to be concise and convenient. interviews were scheduled at times comfortable for them (even weekends for about one-third of participants) and kept to a reasonable length (~75 minutes maximum). On spot member checking was adopted because requesting them to review findings later or attend a second meeting would likely fail. This approach ensured the gathering of quality data without overburdening the participants. The willingness of users to contribute despite their low power underscores their high interest; however, it was crucial to respect their time limitations to maintain goodwill and get authentic responses.

- ***High-Power Low-Interest (or Low-Power Low-Interest) Stakeholders:*** Some stakeholders either have limited interest in the research or are too busy to participate, even if the topic is related to their work. In this context, one of the key decision making stakeholders identified were considered to be high power but turned out to have low interest in participating (perhaps due to workload or other priorities). Such stakeholders may prefer to observe outcomes rather than actively contribute. It was found that certain officials were interested in knowing the stakeholder feedback from others (like users) but were not prepared to be interviewed themselves. This could be because they trust their own expertise but still want to gauge public sentiment before making decisions. For stakeholders in this category, a feasible approach is to keep them informed of the study's findings and possibly involve them in a later stage of discussion or validation (for example, sharing an executive summary or inviting them to a workshop to hear the collective results). While they might not provide input directly, acknowledging their perspective and ensuring the research captures a holistic view, which will make the results more acceptable to them.

The power-interest insights meant a one-size-fits-all approach is not possible. The depth of the interview protocol and validation process had to be adapted. High-power high-interest stakeholders, if participating, could be asked for a more detailed interview and later engaged in result validation (like confirming the aggregated thresholds or participating in consensus workshops). In contrast, low-power stakeholders needed a streamlined process. This approach is flexible enough to mitigate complexity. In practice, for this study focusing on road users (low-power high-interest stakeholders) a single round interview with on-spot validation, as described was used. If high-power stakeholders were secured, then the methodology would have been altered to conduct follow-up meetings to verify their inputs and perhaps facilitate a multi-stakeholder workshop to reconcile any differences between groups.

Stakeholder Recruitment Challenges and Mitigation:

One practical challenge was simply getting stakeholders to participate especially those with decision making power. Initially, it was sought to include local officials and disaster management authorities in Tambaram, as they have the expertise and authority in road transport resilience. However, reaching them proved difficult. The official Disaster Management Contact Directory (2024–2025) for Chnegalpattu District provided only general office phone numbers and, in a few cases, WhatsApp numbers. Dedicated email addresses for specific officers were not available (only a general department email was listed, which likely receives an overwhelming volume of messages). Repeated phone calls often went unanswered, and messages sent via WhatsApp sometimes failed or received no response, in some cases, the numbers were outdated or not tied to active WhatsApp accounts. Only one official could be reached by phone, and he indicated that he could only consider participation if approached in-person, and he declined an online interview outright due to his tight schedule. This reflects a common scenario in developing urban contexts as key stakeholders are extremely busy with on ground responsibilities and may not prioritize academic research, especially if the approach is not face to face.

To cope with these recruitment hurdles, the study pivoted to alternative stakeholders who were more accessible yet still relevant. Road users, who although not in authority, provide a critical perspective on resilience as the end beneficiaries. Recruiting users was more feasible through local community networks in Tambaram area. Additionally, their high interest in the subject (being directly affected by flooding and road disruptions) meant they were willing to engage when approached properly. To further facilitate participation, stakeholders' schedules were accommodated, for example, conducting interviews on weekends or after work hours for those who had long commutes and busy weekdays. This flexibility was essential in securing a sufficient sample (15 participants in this case). While this shift meant that the gathered insights were primarily from a user perspective, it provided valuable data that might otherwise have been unattainable given the constraints.

In future studies, a mitigation strategy for involving hard to reach high-power stakeholders could include securing support from a higher authority (e.g., a letter of cooperation from a government department) or aligning the research with an ongoing official initiative to make it a mutual interest. In this study, resource limitation made such strategies unviable, so focusing on users was the practical solution. Another important consideration was the language of communication during interviews. In a diverse region like Chennai, many stakeholders, especially community members, prefer to express their thoughts in their native language (Tamil) rather than English. Even those who understand English might be more comfortable articulating nuanced opinions in their mother tongue. On the other hand, some stakeholders (particularly younger professionals or students) were perfectly at ease with English. The mix of languages could introduce challenges in data interpretation as direct translations might miss context and the researcher's own proficiency in the local language becomes critical. The interviewer (researcher) was proficient in the regional language, which enabled participants to choose their preferred language for the interview. Many participants used a mix of Tamil and English. To ensure accurate interpretation of the qualitative data, the interviewer employed active probing and paraphrasing during the conversation. For example, if a participant explained their reasoning in Tamil, the interviewer would occasionally restate it in English to confirm understanding: "So, if I understood correctly, you set the threshold at 80% because you believe so and so, right?" Participants could then affirm or clarify the point. This real time cross checking mitigated the risk of misinterpretation of responses. Additionally, notes were taken in English and care was taken during transcription and coding to maintain the original meaning. Through these measures, the study respected participants' comfort with language while preserving the accuracy of the information gathered.

By the end of Phase 2, a set of stakeholders (road users) ready to provide input, an interview protocol tailored to their profile, and strategies in place to handle logistical and communication challenges. This groundwork set the stage for collecting high-quality data that truly reflects stakeholder values.

Phase 3: Data Analysis and Synthesis of Stakeholder Value into a Threshold Matrix

After conducting the interviews and gathering stakeholder inputs on minimum acceptable performance levels for each functionality, the next phase was to analyze these data and synthesize them into a usable form, the threshold matrix. This phase involved quantitative aggregation of the various stakeholder inputs and qualitative analysis to interpret and validate the findings. Throughout the analysis, particular attention was paid to identifying any anomalies (outlier responses or conflicting views) and understanding their implications, as well as ensuring that the integrated results remained true to the raw data. The following steps were undertaken:

- **Patterns and Outliers:**

In analyzing the responses, special attention was paid to outliers' values that were significantly higher or lower than the rest. Outliers in stakeholder responses are not necessarily "wrong", they can indicate a minority perspective or unique concern that others did not consider. From a statistical standpoint, methods like the interquartile range (IQR) or z-scores can flag outliers. However, deciding what to do with them is more than a statistical exercise; it requires understanding why the outlier occurred. Therefore, outliers should be retained for aggregation if they were backed by strong qualitative insights. In practice, that meant referring back to the interview transcripts for any outlier response. If the participant had given a clear, logical reasoning for their threshold, then this perspective was deemed valid and was included in the aggregation. The outliers were not excluded simply for being different, as it could represent a valid sub-group or a scenario that hadn't considered. On the other hand, if an outlier seemed to result from a misunderstanding, then that data should be treated with caution. In this study's results, no responses were discarded outright; every data point was examined in context. The qualitative explanations helped determine that all inputs were given intentionally and meaningfully, even if some were at the extremes. Therefore, the final aggregated values are reflective of the entire spectrum of stakeholder opinion, not just the median. The outcome of this quantitative step was a preliminary matrix of functionalities and threshold percentages, essentially capturing the average minimum performance stakeholders expect for each functionality under the given disruption scenario. However, those numbers alone only tell part of the story. To fully understand and trust these results needs to be interpreted through the lens of stakeholder experiences and reasoning which is where the qualitative analysis comes in.

- **Qualitative Analysis and Interpretation**

Beyond the numbers, the interviews provided rich narrative data on thresholds and what factors influenced their expectations. A structured qualitative analysis approach was adopted to extract themes and insights from these narratives. The study followed the qualitative data analysis method outlined by Gioia et al., (2013), which is designed to bring rigor to inductive research. In practice, this involved coding interview transcripts in multiple stages. This Gioia inspired coding structure allowed to systematically move from raw data to higher level insights. It ensured that the qualitative interpretation was grounded in the actual words and concerns of stakeholders, enhancing credibility. The qualitative findings were then used to explain and enrich the quantitative threshold matrix.

- **Aggregation of threshold values:**

Each interview yielded one threshold percentages per functionality per scenario. To create a single integrated threshold for each functionality, a Weighted Average Aggregation (WAA) was used. In this study, since all 15 participants belonged to the same stakeholder group (road users) each participant's input was given equal weight. The aggregate threshold was thus essentially the arithmetic mean of all responses for that functionality (after confirming all responses were on a comparable basis). This provided a baseline "stakeholder defined" minimum performance level for each resilience functionality under study. For future research involving a variety of stakeholder groups, simple averaging may not be appropriate. Different groups could justifiably carry different weights in the decision-making process. For instance, if officials, engineers, and users all provide thresholds, one might decide that official perspectives (high power) should have greater weight in the final number, or conversely that user perspectives (high interest) should be emphasized to ensure community needs are met. This introduces complexity in aggregation on how to assign weights fairly.

As a potential solution, researchers can assign weights based on objective criteria such as the stakeholder's role in decision-making, expertise, or degree of impact. For example, a weight could be proportional to a stakeholder group's influence on implementation (policy-makers higher weight) or to the size of population they represent (user group weight might depend on how many people they speak for). In this study, this was not an issue as all weights were equal.

Note: E*xplicitly documenting a weighting scheme is important when combining various voices, to maintain transparency and acceptance of results. The weighting scheme should be based on criterion considered for the study.*

By the end of Phase 3, a comprehensive understanding of stakeholder value integration: a quantitative threshold matrix for system functionalities and a set of qualitative themes explaining those thresholds was obtained. The two strands of analysis together form a robust stakeholder value integrated threshold matrix for resilience assessment.

In summary, the approach outlies the elicitation process to capture and understand the stakeholder value and indicates the complexities that arised during the operation of the research and ways in which these complexities were mitigated and considerations for future research will carrying out similar studies.

Chapter 6

Discussion

6.1 Data Reliability

Ensuring data reliability and that participants fully understood the interview context were fundamental. Several steps were taken to preserve credibility and avoid bias. First, the interview protocol itself was carefully structured: definitions of the system functionalities Safety, Connectivity, and Travel Time Reliability were explicitly read to each participant at the beginning. This ensured that all respondents shared a common understanding of the technical terms. The scenario-based framing anchored answers to realistic traffic conditions and peak hour experience. By providing these standard descriptions and clarifying scenario details (time, location, flood depth, etc), misinterpretations were minimized, and all participants were positioned within the same reference.

To minimize interviewer induced bias, neutrality was maintained and avoided leading prompts during the core questioning. The semi structured format allowed flexibility but with consistent core content across interviews. The question orders were deliberately structured by functionality, not by flood scenario. In practice, this meant asking all questions about Connectivity (under normal, low, medium, high floods sequentially) before moving on to Reliability then Safety and vice versa. While this could theoretically bias some responses (for instance, a participant might anchor on the first functionality addressed), it was chosen to reduce cognitive load and avoid confusion from switching back and forth across functionalities. Research on interviewing suggests that such structured order can reduce respondent fatigue and confusion, thereby improving reliability (Nielsen Norman Group, 2022). Indeed, all participants were able to provide numeric thresholds once they understood the scale (0 – 100%), and each value and reasoning was confirmed by repeating it back to the participant immediately. This in on spot member checking (respondent validation during the interview) was crucial. Whenever a respondent hesitated or gave an ambiguous answer, the answer was repeated back to the participant and meaning /insight was confirmed, ensuring accuracy. This on spot member checking also increased the consistency between the quantitative and qualitative data.

Interview language was another potential source of misunderstanding. Most of the participants were fluent with English which made recording insights easier and more accurate. When Tamil was used (regional language), the responses were translated into English notes on the fly and further developing it into a structured interview notes immediately after the interview. No audio/video recording was made (to put participants at ease and for ethical considerations), so notes were taken almost verbatim, especially noting every numeric threshold mentioned. The combination of detailed note taking and immediate post interview expansion helped preserve data integrity. For example, after each session notes were expanded into 1-2 page transcript like summary and followed up to clarify any ambiguous point. These practices creating an audit trail of detailed interview summaries and doing member checks are standard quality measures in qualitative research (Lincoln & Guba, 1985). They helped ensure that even when biases or misunderstandings could creep in, they were corrected quickly.

It was also considered whether the order of topics introduced any systematic bias. By not randomizing functionalities, one might worry that answering all questions about safety before reliability could prime participants to focus on safety issues first. In practice, participants often spontaneously ranked priorities when asked (e.g. "safety first, then connectivity" or vice versa), regardless of question order. Nevertheless, it is acknowledged that different sequencing (e.g., alternating functions) could result in slightly different framing. To guard against this, all interviews used the same order, making responses internally consistent. Moreover, at the end participants were explicitly asked if one functionality was more important than others, allowing them to reflect on their priorities after giving all thresholds. This check helped verify that no functionality had been inadvertently de-emphasized by question order.

The data reliability was promoted through standardization and transparency. By providing the same scenario, definitions, and consent information (in writing and verbally) to all participants. The researcher remained neutral, probes encouraged elaboration without suggesting answers, and any numeric value was immediately confirmed verbally. These practices mirror best practice guidelines for qualitative rigor (Gioia, Corley & Hamilton, 2013) and for interviews. By carefully managing the interview context and validating data as it was collected, the trustworthiness of the findings was maximized. This practice led to accurate capture of the stakeholder values but how to manage data collection in highly uncertain field of research, especially when the participants were non-experts. This collection of quality data in uncertain studies is further discussed in section 5.2.

Even so, responses did vary widely. Outliers were encountered at both ends. For instance, one interviewee (optimistic outlier) (refer interview no. 14, Table 5, above) insisted on near perfect system performance even in high floods demanding "100% connectivity" and "100% reliability" under normal and low flood conditions. Another participant (pessimistic outlier) (refer interview no. 6, Table 5, above) essentially distrusted the system entirely; he reported that he would only accept 20–25% reliability and safety in high floods, based on past harrowing experiences of roads disappearing. In each case, the reasoning were probed. The optimistic interviewee justified his high expectations by focusing on critical functions (he would sacrifice some connectivity but never safety), whereas the pessimistic interviewee explained a "survival oriented" mindset formed by actually seeing floodwaters cause major disruption on roads. By documenting these explanations, it was verified that their extreme values were indeed intentional, not errors. Critically, neither type of outlier unduly influenced the final results, because equal weighted averaging was used to formulate the threshold matrix, which by design smooths extreme inputs. At the same time, including outliers in analysis enriched the understanding: it highlighted the range of risk perceptions in the community, and it validated that the qualitative coding of themes correctly captured this diversity.

While speaking of uncertainties, it was also noted that 3 out of the 15 interviewees intuitively adopted the concept of dynamic thresholds. Having lower or higher performance with respect to the need and expectations of system functionalities in each scenario. This gave rise to the questions such as: does type of organisation, nature of work and role in organisation affects the expectations and tolerance? This question emerged from the observation that, participants who gave decreasing thresholds as the flood hazard intensity increases were employees in an organisation with exception of two interviewees who still gave increasing values despite being employees (two out of three participants mentioned above) and the participant who mentioned, he demands adaptive prioritisation (dynamic thresholds) is an employer, has his own firm. So, what lead them to understanding or adoption of concept of dynamic threshold or how did they do that or to further understand the mindset of interviewees of this kind further research on does behaviour, organisation culture, regional culture and role in an organisation influences expectation from a system should be conducted.

Also, **what made others not adopt a dynamic threshold?** A few possible factors emerge. Some may have taken a technically realistic stance, believing that certain losses are unavoidable as floodwaters rise. For them, it may seem unrealistic to demand higher performance (especially beyond what normal operations yield) under stress. Others may not have fully grasped the idea of raising targets; they answered based on conservative default expectations rather than strategic trade-offs. It is also possible that only a subset of interviewees understood or resonated with the dynamic thresholds concept. For example, Interviewee fourteen explicitly thought in terms of carrying capacities (“other functionality can carry the load”), whereas others spoke more descriptively about losses (e.g. “roads will close… I can accept X% drop”). In short, most respondents implicitly treated thresholds as non-adaptive benchmarks, reflecting an assumption of monotonic performance degradation. This aligns with resilience scholarship noting that fixed benchmarks often oversimplify stakeholder needs. The fact that only three out of fifteen embraced dynamic adjustments suggests that dynamic threshold reasoning is not yet intuitive for all stakeholders and may require explicit facilitation or education to surface in analysis.

6.2 Ensuring data quality

Interview based elicitation of values inherently involves uncertainty in whether data collected is of expected quality or not, especially when stakeholders are non-experts. Stakeholders often struggle to articulate precise performance levels or to quantify probabilities, and their answers may reflect gut feelings or memories of past events. In this study, participants sometimes expressed uncertainty explicitly. To address this, the interviews were treated as a conversation with opportunities for clarification rather than a one shot test of their knowledge. Multiple strategies were used to help stakeholders express their values under uncertain areas:

- **Scenario Visualization:** Questions were framed in concrete terms (weekday morning commute, specific flood depths) so respondents could visualize the context rather than answer abstractly. This kind of mental simulation is known to improve lay comprehension of risk scenarios in risk communication literature and was critical to this approach.

- **Definition Simplification:** The system functionalities (safety, connectivity and travel time reliability) were given simple operational definitions. Now, questions arise regarding the definition and understanding were clarified before moving on to data collection. If a participant hesitated, the interviewer explained in plain language ("By connectivity I mean, can you still get from point A to B?"). This iterative explanation approach is recommended when eliciting technical criteria from lay stakeholders (Morgan et al., 2001).

- **Analogical & Iterative Elaboration:** When stakeholders seemed uncertain, analogies or simple examples were used. For instance, one participant initially said "100% safety" in high flood, then we asked, "So you would accept only no injuries at all, meaning if it was a 30 cm of water level due to flood, would you be okay if there were one accident per hundred trips?" Such prompts forced reflection and sometimes revision of their thresholds. This kind of "what if" probing acts as an informal calibration, akin to aspects of the Delphi method, and helps lay respondents articulate values in a structured way (Montibeller & von Winterfeldt, 2015).

- **Structured Elicitation Ideas:** While the participants were not experts, concepts were borrowed from formal expert elicitation to increase rigor. Future work could explicitly include a mini-Delphi among stakeholder groups: after initial individual interviews, a workshop could show aggregated results back to participants and allow them to revise their values (a "social Delphi" or consensus discussion). Such consensus building steps should be documented to produce more considered judgments, even among non-experts.

Overall, the interview protocol itself functioned as a guided elicitation, with built-in redundancies to cope with uncertainty. The semi structured format allowed follow up questions that clarified misunderstandings (e.g. "Could you explain why you think 60% connectivity is acceptable?"). This is important because studies have found that an interactive, conversational approach tends to yield higher quality data from stakeholders who are not trained in giving expert risk estimates (Clemen & Reilly, 2001). In the collected data, themes like Guarantees and Confidence often emerged precisely when participants grappled with uncertainty. These qualitative insights show that respondents did in fact hold concrete beliefs, even if sometimes hidden under initial vagueness.

The lay stakeholder answers mix factual uncertainty with value judgements. As one "pessimistic" participant noted, his low thresholds were based on experience. This illustrates how personal experiences and heuristics dominate when precise prediction is impossible. A formal structured expert elicitation (SEE) typically requires calibration questions and training to mitigate such biases (Aspinall, 2010). This study did not have that luxury, but it was ensured through probing that this study captured the rationale behind answers, not just the raw numbers.

In structured expert elicitation, protocols like IDEA (Investigate Discuss Estimate Aggregate) and Delphi are used to reach consensus among experts. Adapting these ideas for stakeholders could mean several rounds of input and feedback. For example, future studies might first gather individual interviews, then hold a group discussion of the aggregated thresholds, and finally re-ask key questions (a mini-Delphi among users). This could help those who were uncertain refine their answers by hearing peers' reasoning. For this study a very basic form of the above mentioned method was conducted by interpreting and clarifying the reasonings and rationale of each participant during their interview for verification (a form of member check), and by sharing overall findings later. Such iterative validation is in line with qualitative best practice (Lincoln & Guba, 1985) and increases trust in the data under uncertainty.

It was recognized that eliciting numeric thresholds from non-experts is inherently uncertain. This can be mitigated by clear framing, iterative questioning, and member checking to ensure comprehension. This approach resembles a semi structured elicitation embedded in an interview combining conversational probing with attempts to quantify values. This hybrid method draws on uncertainty management literature: by blending qualitative narrative (to express uncertainty and justification) with forced quantitative answers (to anchor values), to produce data that acknowledge uncertainty while remaining actionable. The approach is not fully "expert elicitation," but by using structured techniques (clear definitions, repeated questions, on spot member checking, recording rationale and reasoning during the interview) it was approximated that rigor in a lay context.

6.3 Limitations of the study

While this study provides valuable insights, it is important to acknowledge its limitations and to outline how future research can extend and refine the work. Reflecting on the generalizability of the findings given the sample and context, the methodological constraints, and suggest ways to deepen and broaden the investigation. Key areas of discussion include the sample scope and generalizability (what 15 road users from Tambaram represent and what they don't), future quantification strategies (how to strengthen the quantitative aspect, possibly with larger samples or different approaches), and expanding stakeholder inclusion (involving more diverse stakeholders and integrating their perspectives, including how a "threshold index" could be applied in planning processes).

- Participants were primarily private car users recruited through local networks. This study did not explicitly include other stakeholder categories like public transit operators, freight delivery services, emergency service providers, or city officials. These groups might have differing perspectives. Thus, socio-economic profile of the participants could influence results; all being from one town means the study captured a certain demographic range, but not the full spectrum of Chennai's population. It was ensured to bring in variation by sampling across Tambaram's zones, which gives some spatial diversity, but there may be unrepresented voices (e.g., people with disabilities might have different concerns about safety in floods, or those without personal vehicles might emphasize public transport continuity differently). This is not to say that the findings are only applicable to Tambaram. Many patterns (safety first, etc.) are likely universally relevant as they echo fundamental human priorities. However, the context specific details (like references to local drainage issues or particular roads) are tailored to Tambaram's scenario. Thus, caution should be exercised in applying the exact numbers elsewhere without local validation.

- Another limitation of the study is the sample size and composition. This study interviewed 15 road users in Tambaram, Chennai. While this allowed for in-depth qualitative analysis and was sufficient to reach thematic saturation within that relatively homogeneous group (many common perspectives emerged by the 12th interview), it is still a small sample focused on a specific locality. As such, the exact threshold values and nuances found may not be directly generalizable to all road users in Chennai, let alone other cities or regions. Tambaram's context influenced respondents' answers. For instance, residents who have experienced regular floods might have different tolerances than those in a city with rare floods. Indeed, this study hypothesized that elsewhere stakeholders might demand nearer to 100% performance if they view floods as exceptional and preventable.

- Also, it was acknowledge that the aggregated values are high for this sample, but it cannot claim statistical representation of a larger population. The thresholds are "aggregated values" among those 15, not a statistically inferred mean of all Tambaram residents. This was mitigated this by stratifying sampling (covering different zones to include various flood exposures) and by noting that 15 interviews often suffice for thematic saturation in a homogeneous group. Nonetheless, for stronger generalizability, a larger survey could be conducted.

- Additionally, while performing weighted average aggregation each participant was given equal weightage. In reality one might argue that certain road users (e.g., public transport users versus car users, or experienced drivers versus novices) might have different levels of knowledge or stake that could be weighted. But all the voices were treated equally to get an average perspective. This is a limitation that this study did not differentiate or segment the results by sub groups (except qualitatively noting a few outliers). Future studies with larger samples could explore segmenting thresholds by demographic or commuter type.

- Finally, this research is a single case study in a Indian context. Cultural factors (such as risk tolerance shaped by past disaster experiences) might influence the findings. The relatively high demands might reflect for instance a frustration from prior poor system performance. In other contexts, people might be more resigned or more demanding. Therefore, while the methodology and broad insights are transferable, the specifics should not be uncritically transplanted without local data.

Therefore, while applying the threshold matrix in planning, future research can focus on developing tools for planners to use these thresholds. For instance, one could create a planning support tool or Geographic Information System (GIS) based model where planners input potential measures and it outputs expected performance against the threshold matrix. Then planners can easily see if a proposed action keeps performance in the "green" (acceptable) or "red" (unacceptable) zone from a stakeholder perspective. Future studies could test such a tool in a planning department, gathering feedback on how it influences decision making. This would be moving from research to practical implementation, but with research evaluation of that process. Thus, expanding stakeholder inclusion means both widening the pool of who is asked about thresholds (for broader legitimacy and insight) and deepening how these thresholds are incorporated into collaborative decision frameworks (for practical uptake). This will not only enhance the findings' robustness but also ensure that future resilience plans built on this approach are equitable and comprehensive.

In summary, every study has its bounds, and the limitations of this study has been outlined in terms of sample, context, and methodological choices. These limitations, however, pave the way for rich future work. The findings of this research for Tambaram serve as a proof of concept that integrating user values into resilience planning is both feasible and illuminating. Future research can take this concept to larger scales, different settings, and more complex decision models. If done, a clearer more democratic picture of “resilience” will emerge, one where the success of system under stress is measured not just by technical metrics but by meeting the needs and expectations of the people it serves. Through iterative research and application such as larger surveys, cross city studies, participatory planning, the idea of a stakeholder and user defined resilience threshold could become a standard part of how cities plan for and evaluate their preparedness for disasters. This continuous improvement cycle will address current limitations and help realize the full potential of aligning engineering goals with human values in the quest for truly resilient transportation systems.

6.4 Limitations of the approach

While this approach can reveal local expectations and preferences, it has several limitations. In particular, its format and scope may not suit all stakeholder types, alternative methods might yield richer data, and its assumptions about context and values may not generalize easily. Below, the elicitation method is critically examined across multiple dimensions. Drawing from the participatory methods, multi-criteria decision tools, and resilience planning to highlight how interviews can fall short and how the approach might be improved.

- **Applicability to other stakeholders**

Semi structured interviews are often well suited for non-expert stakeholders, but may be less effective for technical experts, government officials, or other high level decision makers. Experts and officials may respond differently to formal interview protocols compared to lay stakeholders. Technical stakeholders, for example, typically think in quantitative or system terms and may require detailed data or analytical framing to express their values. Government officials may be constrained by policy agendas or risk averse attitudes, making candid value statements difficult. The same set of questions may not resonate equally with all groups. Research on stakeholder methods notes that in-person interviews can capture individual perspectives well but are often based on small samples and yield results that are not statistically generalizable. In practice, a transportation engineer might interpret a “resilience” question in technical design terms, whereas a local resident might think in terms of daily commute inconvenience. An interview may therefore bias responses: for instance, experts might focus on technical performance metrics, while community members emphasize social impacts. Moreover, interviews can be influenced by how questions are framed and by interviewer presence. Closed or leading questions can steer stakeholders to particular answers. In a semi-structured elicitation setting, this means that the choice of which values to ask about and how thresholds are described can inadvertently prioritize some concerns. Technical experts may also feel constrained by formality or may prefer workshop style engagements (e.g. scenario exercises) over one on one interviews. Similarly, government officials often operate through formal committees; a lone researcher interview may not capture the negotiation and power dynamics of actual decision making. Finally, stakeholder power dynamics can skew results. High power stakeholders often dominate discourse. Without deliberate measures to balance voices, interviews may over sample more accessible or vocal groups and under sample marginalized ones. As engagement guidance suggests, inclusive processes require designed outreach (e.g. working with social inclusion experts) to reach low income, disabled, or minority groups. If the study's interviewee list is not carefully balanced, its elicited values may reflect only a subset of interests (for example, transport and commerce priorities over informal vendors' needs). In short, while interviews can work well for some groups, the approach may need adaptation for technical experts or officials, and it risks neglecting less organized populations.

- **Methodological alternatives**

The interview based elicitation in this study is only one of many participatory techniques. It is worth asking whether other methods might have been more robust or complementary. For example, Delphi methods use multiple anonymous rounds with experts to build consensus. Delphi can involve geographically dispersed experts and reduce groupthink, but it is time consuming and can dilute accountability. Delphi's anonymity eliminates potential sources of conflict and enables participants to express views freely, yet multiple rounds require a large time commitment and anonymity may lower the incentive for accountability. The thesis's single round interviews lack the iterative feedback of Delphi. So, participants cannot revise their views after seeing others' responses, so consensus (if needed) is harder to achieve.

Analytic Hierarchy Process (AHP) is another alternative for eliciting and weighting values. AHP uses structured pairwise comparisons of criteria and alternatives and can aggregate multiple stakeholder judgments into a quantitative ranking. This could provide a rigorous framework for weighting resilience factors. However, AHP has its own drawbacks as it requires experts to make many pairwise comparisons, which can be tedious and cognitively demanding. Hartwich (1999) notes that "the procedure of pairwise comparisons is time consuming" and "some interviewees may find it somewhat tedious to go through that amount". For a multi-factor threshold matrix, the number of comparisons grows quickly, risking fatigue or inconsistent answers. AHP also offers little guidance on how to structure the problem hierarchy; different hierarchies can yield contrasting results. In sum, while AHP can formalize stakeholder weights, it may not suit broad public engagement without simplification.

Participatory modeling or workshops represent a more interactive alternative. Techniques like fuzzy cognitive mapping or systems dynamics involve stakeholders co-creating causal models or scenarios. Such approaches can capture diverse knowledge and foster mutual learning. Yet they are resource intensive. Participatory modeling studies caution that the limitations include the increased time, resource (for both modellers and participants) and, therefore, expense of the process, as well as the need for models to remain simple (which risks oversimplification). In practice, convening a large cross section of stakeholders in workshops can be expensive and hard to coordinate, especially with experts. Moreover, participatory models may produce outputs that are difficult to generalize or quantify.

Other engagement tools could supplement interviews. For example, focus groups or citizen juries allow stakeholders to discuss and prioritize issues together, potentially revealing group dynamics. However, focus groups can be dominated by outspoken participants, and some individuals may be reticent to express opinions in a group setting. Questionnaires or surveys can reach more people but lose the depth of interviews where respondents cannot clarify their reasoning. Each method has trade-offs. In this research, a semi structured interview approach provided depth but at the cost of breadth. Alternative or mixed methods (e.g. combining interviews with a workshop or survey) might capture a more complete picture, though at higher cost. In all cases, the robustness of value elicitation depends on carefully matching the method to the stakeholders' communication styles and the expertise.

- **Transferability across contexts**

A key question is whether this elicitation approach can be replicated in other cities or regions with different social and institutional contexts. Methods that work in one locale often require adaptation elsewhere. Tambaram is a large suburban area in Chennai, India, with its own linguistic, cultural, and governance norms. In another Indian city or in rural India, stakeholders might interpret questions differently. Likewise, outside India, cultural frameworks for discussing risk and value may vary widely. The literature on inclusive engagement emphasizes that stakeholder identification and communication must be tailored to local diversity. In practice, this means that any interview guide would need to be translated (not just linguistically but culturally) and pre-tested to ensure relevance. For instance, questions about "flood resilience" in Chennai may assume certain knowledge of monsoon patterns and local infrastructure. In a non-monsoonal region, similar questions might miss the mark.

Socioeconomic factors like literacy levels, digital access, and community organization matter too. Engaging low income or illiterate populations often requires non-written methods or community facilitators. Thus, a straightforward interview schedule could be ineffective in a rural or poorer setting without visual aids or local mediators. Institutionally, the process depends on governance structures. Chennai has specific agencies (like the Chennai Metropolitan Development Authority) and civic groups. Replicating the study in Netherlands would involve different agencies, regulations, and often a greater emphasis on environmental impact analysis. The stakeholders themselves would change. The method would need to engage these entities appropriately. Moreover, political culture affects participation. In some places, citizens expect extensive public consultation; in others, they defer to experts. Even within India, the role of resident associations in Tambaram (as seen during flood relief work) may not exist elsewhere.

In summary, transferring the approach requires cultural and institutional translation. Practical steps would include adapting language and examples to local norms, re-mapping stakeholder categories to the new context, and possibly restructuring the interview format (e.g. using focus groups where social hierarchy limits individual speech). In Chennai, a semi-structured interview might capture values effectively; in a different context, alternative facilitation (community meetings, storytelling, media like photo elicitation) might be needed to uncover the same content. Ignoring such differences risks misinterpreting results. As stakeholder processes must be designed together with representatives from minority or under served groups to properly incorporate cultural and language differences. If this is not done, the elicited "values" may reflect only those groups that the method could comfortably reach.

- **Transferability to other hazards**

This study focused on road transport during floods, but could the same value elicitation method apply to other disasters like earthquakes, wildfires, etc? Conceptually, the idea of interviewing stakeholders to elicit resilience values is general, but the content and framing would need major adjustment. Each hazard has different dynamics, impacts, and relevant stakeholders. For example, earthquakes damage buildings and infrastructure suddenly, whereas floods are slower onset but more seasonal. Thus, stakeholder priorities and the "functionalities and the thresholds itself" that matter will differ.

Multi-hazard approaches can work but require expanded scope. In San Francisco Bay, the Adapting to Rising Tides project initially targeted flooding but stakeholders quickly pushed to include seismic risks as well. This required bringing in earthquake experts and considering how strategies for one hazard might affect another. The integrated process found synergies (shared data, combined planning) but also demanded more complex stakeholder coordination. Similarly, a road system assessment for earthquakes would involve civil engineers and disaster managers, whereas wildfires planning would include forest officers, etc. The elicitation interview guide would need new questions (e.g. about evacuation routes in an earthquake) and possibly new metrics.

Nonetheless, certain fundamental values (life safety, connectivity, rapidity, etc) often recur across hazards. A semi structured interview can still probe these, but with hazard specific examples. The clarity and relevance of the questions would hinge on stakeholder familiarity: a road vendor may easily relate to water blocked roads, but might not readily conceptualize a earthquake or wildfire's impact on transport. The method should be adapted by including scenario walkthroughs or visual aids to maintain relevance for non-familiar hazards. Finally, some hazards involve far more social and behavioral aspects; eliciting values around them may require attention to trust in institutions or social equity, which the original interview might not have covered. In short, while the interview based value elicitation is in principle portable, applying it to a new hazard type would necessitate updating both the stakeholder list and the content of the questions to reflect that hazard's unique context.

Furthermore, any stakeholder elicitation raises questions of power, representation, and fairness. Who gets invited to define "value" can greatly shape the outcomes. If the process over relies on "vocal" groups or official channels, less visible interests may be ignored. The risk of such exclusion is well known in participatory planning: without explicit effort, participatory spaces often repeat existing inequalities. Therefore, further research is needed to identify these inequalities and how to structure the decision making approach to provide a fair treatment to these inequalities. To be specific research on ethical and political dimension's influence in such a setting is required.

- **Extent to which value is captured**

Even with broad participation, any single method can only capture certain types of values. The semi structured interview in this study likely elicited concrete, present tense concerns (e.g. delays, road damage, emergency access). However, it may have missed subtler dimensions of value. Emotional values (fear of flood trauma, pride in community spirit) or cultural values (religious significance of certain routes, traditional knowledge) often lie outside direct questions. Likewise, intergenerational values; concerns for future children's safety or long term environmental change are abstract and may not surface unless explicitly probed. Research on values elicitation points out that "talking about values" is inherently difficult without context. Stakeholders may default to easily articulated metrics (time lost, money spent) and overlook intangible drivers.

More fundamentally, values are situational. An interviewee might claim that safety is paramount, but in practice trade it off for other gains when seated in a nuanced scenario. Le Dantec et al. (2009) argue that without real life context, value rankings are based on "spontaneous thoughts" and thus can be biased. For example, a commuter might say in an interview that "fast travel" is his top priority, but in a group discussion might reveal otherwise. The method may not capture such shifts. Intangible values like trust in government, social solidarity, or empathy are especially hard to quantify in an interview. Likewise, unique cultural values such as communal land or festival routes might not be mentioned unless the interview explicitly includes them. The study's approach of capturing and integrating values into a threshold matrix further risk simplifying complex values into numeric or categorical entries, potentially losing meaning.

In sum, the elicitation approach likely captured a useful but partial slice of stakeholder values. As values are abstract motivational constructs and can play different roles based on situational context. A single round of semi-structured questions can provide an overview of stakeholder priorities, but cannot fully uncover dynamic or latent values. Emotional or cultural dimensions may require qualitative narratives or workshops to reveal. Thus, the approach's boundary is its focus on explicit, present minded values.

Chapter 7

Conclusion and Recommendations

7.1 Conclusion

In conclusion, this research provides an approach for integrating stakeholder values in a threshold matrix for resilience assessments. By carefully selecting what to ask, whom to ask, and how to ask it and by rigorously analyzing the responses both quantitatively and qualitatively, researchers and practitioners can develop a performance threshold matrix that have real world legitimacy. The process is admittedly complex, as this study encountered challenges in stakeholder communication, recruitment, and data interpretation. However, each complexity can be managed through thoughtful methodological choices by simplifying concepts for clarity, favouring interactive data collection, tailoring engagement to stakeholder characteristics, and using structured analysis techniques. The experience from the Tambaram case study underscores the importance of flexibility and stakeholder centric design in research. Future studies can adopt and adapt this approach, remaining mindful of potential hurdles and the mitigation strategies outlined, to ensure that resilience assessment truly reflect the values and needs of the communities they serve. Thus, an approach to integrate stakeholder value in a threshold matrix for resilience assessment is proposed.

Answering the research question

The objectives of the study have been achieved by answering the following research questions. The section also provides a recap into the process followed in the research.

"How can user values be captured to assess road transportation resilience to flooding considering system functionalities and various hazard intensities in Tambaram, Chennai context?"

To comprehensively answer this, four sub-research questions were developed, each progressively building towards the final outcome.

Sub-research question 1:

"What are the system functionalities that define road transportation resilience during various flood severities?"

This was answered by adopting and refining three system functionalities drawn from the literature for Tambaram. By adopting these functionalities, linked to specific disaster phases and hazard intensities, the study ensured that stakeholders could meaningfully engage. This provided the conceptual foundation of the research by defining resilience dimensions in relevant terms.

Sub-research question 2:

"To which extent do performance thresholds capture user values for the predefined functionalities under different flood severities, and what is the reasoning behind the assigned thresholds?"

Through semi-structured interviews, the study elicited both quantitative thresholds and qualitative reasoning. Application of the Gioia methodology ensured these narratives were rigorously analysed, showing that thresholds reflected concrete user experiences. The findings confirmed that user defined thresholds captured values meaningfully, while also revealing boundaries such as challenges in articulating intangible or long-term priorities.

Sub-research question three 3:

"How do users prioritise these predefined functionalities under various flood intensities?"

The results showed that stakeholder priorities were dynamic: under severe flooding, safety dominated, while in lower severity conditions, connectivity and mobility took precedence. This highlighted the context dependency of stakeholder values and underscored the importance of incorporating scenario variation in threshold elicitation.

Sub-research question 4:

"What approach can be developed to systematically integrate stakeholder values into a threshold matrix for resilience assessment?"

This question synthesised the insights from SQ1–SQ3 into the proposed **three phase approach**. The approach specifies how to define scope (functionalities, hazard intensities, perspective, disaster phase), design engagement and data collection methods tailored to stakeholder types and integrate both quantitative and qualitative inputs into a final threshold matrix through aggregation. Importantly, it also identifies the complexities encountered such as recruitment challenges, language barriers, and differences in technical knowledge and outlines mitigation strategies, including on-the-spot validation, simplified definitions, and flexible engagement. The approach not only addresses how to operationalise stakeholder value integration but also embeds lessons for improving validity and inclusivity, along with recommendations for future refinement.

Together, the four sub-research questions provide a comprehensive answer to the main research question. SQ1–SQ3 developed the conceptual, empirical, and analytical foundations, while

SQ4 delivered the methodological synthesis: a replicable approach that demonstrates how stakeholder values can be systematically captured and translated into resilience thresholds.

7.2 Recommendations

Building on this experience, future stakeholder value integration in a threshold matrix study can further improve how uncertainty and comprehension are addressed. The following practice are recommended:

- The stakeholder elicitation approach should be tested across multiple disaster types, urban scales, and geographic settings. Future research can adapt the questions and scenarios to new hazards (e.g. seismic events, wildfires, etc) and different planning scales (from neighborhood to regional) demonstrating how context specific narratives can engage stakeholders effectively. Comparative pilot studies in other regions would reveal how elicited value thresholds vary by culture, climate, and governance. Researchers should customize the approach to each context and then compare results; this will show whether the elicitation process is robust or needs local calibration.

- A key recommendation is to broaden participation to include non-traditional and marginalized voices. Beyond planners and technical experts, future studies should actively recruit lay community members, informal actors, and underrepresented groups. In practice, researchers should assemble panels or workshop cohorts that span: Local community representatives (including low-income and culturally diverse neighborhoods), Sectoral experts and practitioners (e.g. urban planners, infrastructure engineers, public) and vulnerable groups (persons with disabilities, informal workers). This diversity ensures the threshold matrix reflects a fuller range of values and avoids biasing results toward any single group.

- To deepen value capture, the elicitation process should be complemented by rich engagement tools. Serious games can be designed where, the game mechanics and storylines reflect realistic multi-hazard scenarios which provide a risk free environment for experimentation, enabling stakeholders to explore trade-offs and learn from scenario outcomes. Equally, participatory mapping and story mapping can spatially link stakeholder priorities to physical risks. Future work should experiment with a mix of techniques (e.g. role playing, photovoice, scenario planning workshops) and assess which combinations yield the richest understanding of stakeholder values.

- Robust elicitation should use multiple methods in parallel. Researchers should triangulate stakeholder values with different decision analytic tools (e.g. Delphi, Analytic Hierarchy Process, Q-method, surveys) to check for consistency. Future research could run a Delphi process to identify thresholds, then use AHP to rank them, and also conduct Q-sorts or ranking surveys for comparison. This ensures consistent outcomes across methods and it strengthens validity, while discrepancies could highlight method specific biases. Comparative use of these methods can also reveal advantages and limits of the threshold approach. Overall, methodological pluralism will build confidence in the elicited results.

- It also important to compare subjective thresholds against objective risk data. Researchers should design studies to reveal gaps between how stakeholders feel about risk and what the data say. This might involve overlaying hazard maps (e.g. floodplains, seismic zones) or historical loss records with community risk perceptions collected in the elicitation. Identifying gaps in awareness between perceived and actual risks is critical. Longitudinal studies could further test if the elicited thresholds predict real world outcomes: do communities that set stricter thresholds actually experience fewer losses? Embedding such analytical checks into future research will help calibrate the method so that subjective values align more closely with measurable resilience targets.

- To ensure the approach's usefulness, it must be validated in new settings and measured for predictive power. Empirical pilots in different cities and hazard contexts will test transferability. Threshold matrices derived in one region should be applied elsewhere to see if they still make sense or need adaptation. Statistical or comparative analysis (where possible) can examine how well elicited thresholds correlate with independent resilience indicators. Future research should benchmark elicited values against existing resilience metrics and against observed disaster outcomes. By rigorously testing hypotheses the predictive utility and generalizability of the elicitation process can be assessed. The threshold elicitation process itself should be embedded in an iterative, participatory cycle. It is recommend holding repeated co-design workshops, cross sector exercises, and pilot tests to refine both the method and the results. By combining experts with residents in scenario planning exercises will expose the threshold matrix to a wide range of inputs. Importantly, feedback from each round should feed into the next, allowing thresholds to be co-refined. This iterative co-design will not only validate the thresholds in practice but also build stakeholder buy-in.

- It is essential to acknowledge the current approach's limitations and address them in future work. Any participatory elicitation risks subjectivity and bias. And small or non-representative samples may not capture the full range of community values. The novelty of the resilience threshold matrix also means there is no established study for direct comparison, so validity must be built empirically. To address these issues, future studies should use larger and more diverse stakeholder samples (possibly combining multiple Delphi or survey rounds) to improve reliability. Conduct reliability checks (e.g. repeat the elicitation after some time to test stability) and quantify uncertainty in the results.

Transparently document all methodological steps and potential biases, so that others can critique and refine the approach.

By systematically addressing these gaps through empirical case studies, cross method comparisons, and quantitative validation, researchers can strengthen the confidence in stakeholder derived thresholds ensuring that stakeholders' real values and concerns are articulated despite inherent ambiguity

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APPENDIX A

A.1 Protocol for semi-structured interviews:

Stakeholder Value Integration in Threshold Matrix for Road Transportation Flood Resilience in Tambaram, Chennai

This interview consists of five parts and will take approximately 60 minutes to complete.

Part 1: Self introduction and introduction of the interviewee with the confirmation of consent.

Q1. The interview started with the self introduction of the researcher:

Hello, I am Prethwin Rathnavelu, a master's student in Construction Management and Engineering at TU Delft. Currently, I am at the last phase of my studies pursuing graduation research in the above-mentioned topic. I am interested in resilience topics and stakeholder value integration in this topic, so I decided to pursue this research. In my free time, I enjoy playing cards or sweating it out by playing badminton or volleyball.

***Q2.* Introduction of the interviewee**

- Name:
- Age:
- Zone in which they reside in Tambaram:

Part 2: Past experience with flooding were discussed to ease the conversation

Part 3 & Part 4: Core section with overall observations

After explaining the context of the research, the researcher proceeded with:

I will ask two sets of questions. First, I will ask you to give minimum acceptable performance (as percentages) for three system functionalities; Safety, Connectivity, and Travel time reliability across four conditions: Normal (no flood), Low (≤15 cm), Medium (~25–30 cm), and High (more than 30 cm). Please answer with a percentage from 0–100 that indicates the minimum level of that functionality you would find acceptable. Second, you will be asked to rank the three functionalities by priority for each flood scenario (1 = highest priority; 3 = lowest). Please explain briefly why you chose the numbers. Your answers are anonymous; so, you can answer as honestly as possible.

The core interview questions

Part A: Threshold matrix inputs (questions 1–3)

These three questions gather numeric thresholds for each functionality. The questions were asked one at a time, for each of the four scenarios. Record both the percentage and a rationale & reasoning for the threshold.

1. Safety thresholds (numeric + rationale & reasoning)

On a scale of 0–100%, what is the *minimum percentage of Safety* you would accept for the road system in each of these situations (normal/no flood, low, medium & high flood)? Kindly give four numbers (%) for Normal, Low, Medium & High and briefly explain why you chose each value.

2. Connectivity thresholds (numeric + rationale & reasoning)

Using the same 0–100% scale, what is the *minimum percentage of Connectivity* you would accept in Normal, Low, Medium and High flood situations? Kindly give the four numbers (%) and justify your acceptable performance percentage for each scenario.

3. Travel-time reliability thresholds (numeric + rationale & reasoning)

For Travel-time reliability, give the minimum acceptable percentages for Normal, Low, Medium and High floods (0–100%). Again, give a reason for each number.

***- Example* follow up questions based on the threshold values**
Please describe briefly why the threshold values *increase/decrease/higher threshold for one functionality compared to others/uniform decrease or increase* with increase severity of flood? (based on the threshold values given by the participants)

Part B: Ranking (questions 4 & 5)

These two questions collect priority rankings and the conditional rules that underpin acceptance (this captures trade-offs and the conditionality observed in the interviews).

4. Priority ranking by scenario (numeric ranking + justification)

For each flood scenario (Normal, Low, Medium, High), please rank the three functionalities Safety, Connectivity, Travel-time reliability from 1 (most important) to 3 (least important). Briefly explain the reason for ranking the functionalities under each scenario.

- If two are equally important, you may assign the same rank and please explain that choice.

5. Follow up question based on the shift in priority (*if observed*) from the input of the threshold matrix and ranking

a. When comparing functionalities under a specific scenario, does the prioritization of a specific functionality shift if its acceptable performance threshold is significantly lower than that of the others?

b. Does comparing functionality change their priority?

These five main questions were followed by the clarification questions to clarify and accurately capture the reasoning & rationale behind the thresholds and ranking during the interview. Maximum of 8-10 questions were asked including the five main interview questions. The clarification questions differ with each interview.

Part 5: Closing + on spot member checking

At the end of the interview the data collected during the interview was reviewed by the participants and any misinterpretation identified were communicated to the interviewer for rectification. This on spot member checking led to validation of the interview data. Considering the busy schedule of the participants on spot member checking was performed (many interviews were conducted on the weekends due to the tight schedule of the interviewees).

Also, the interviewees were informed about the that they had the option to receive their interview summary and research findings once the research is completed. In addition, the privacy protocols were communicated once again for clarification. And small feedback was asked to improve further interviews by the researcher.

APPENDIX B

B.1 Ethical Considerations

Ethical compliance and integrity were prioritized throughout the research. Since this study involves human participants (interviews with members of the public), it was subject to review and approval under TU Delft's Human Research Ethics procedures. The following outlines how ethical issues were addressed:

1. Ethics Approval

The project was screened using the TU Delft Human Research Ethics Checklist (Version Jan 2022) prior to data collection. Based on the checklist, this research was classified as minimal risk and did not involve sensitive personal data or interventions but nonetheless required adherence to standard ethical safeguards. The responsible researcher (supervisor) oversaw this process. Key points from the ethics checklist:

- The research did not involve any vulnerable populations (no children, prisoners, or others unable to consent).
- It took place in India (outside EU), which raised considerations about data transfer and local context, but there were no specific legal/ethical conflicts identified (India is not a dangerous or data restrictive country for this kind of study).
- Participants were in no dependent relationship with the researcher (they were not his students or employees).
- No deception was used, and participants were fully informed of the study's purpose and their rights.
- The study topic (flood resilience in road transportation) was not highly sensitive or likely to cause distress; at most, recalling flood experiences could be mildly upsetting, but participants were free to not answer any question that made them uncomfortable (none actually reported distress).

2. Informed Consent

Participants received a written ICF that clearly explained the study in plain language. They had the opportunity to ask questions. Consent was recorded through a signed form with specific checkboxes to confirm understanding of various aspects. This explicit consent form included items about data use, risks, voluntary nature, and confidentiality. By ticking “Yes” to all and signing, participants acknowledged their informed consent. This procedure complies with ethical standards for social research and was documented. No one was interviewed without a completed consent form on file. Picture below is the Informed Consent Form (ICF) used for this research.

INFORMED CONSENT FOR SEMI-STRUCTURED INTERVIEW

Stakeholder Value Integration in Threshold Matrix for Road Transportation Flood Resilience in Tambaram, Chennai

You are being invited to participate in a research study titled ‘Stakeholder Value Integration in Threshold Matrix for Road Transportation Flood Resilience in Tambaram, Chennai’. This study is conducted by Prethwin Rathnavelu, a Master’s student at TU Delft, Faculty of Civil Engineering & Geoscience. This research is part of the graduation thesis for the MSc. Construction Management & Engineering programme.

The purpose of this research study is to integrate stakeholder value in the process of flood resilience assessment for road transportation. Your participation will help identify the minimum acceptable percentage (threshold) of three system functionalities; safety, connectivity and reliability of road network under different flood severities and produce a threshold matrix which will serve as a threshold index for flood resilience assessment of road network. This interview will take you approximately 60 minutes to complete.

You will participate in a semi-structured interview with questions related to views or expectations regarding system functionalities and the minimum acceptable percentage of theses system functionalities under different flood severities. The interview will not be recorded and transcribed, instead interview notes will be taken during the interview, after which the findings will be prepared and shared with you for review. You are welcome to suggest modifications before it becomes publicly accessible as part of the MSc thesis. The collected data (interview notes) may also be reused for future research and educational purposes on flood resilience assessment, but all outputs will ensure your anonymity. All personal data will be deleted at the latest July 2026. All personal data will be stored on TU Delft’s institutional storage, accessible only to the research team. Data will be securely stored and managed in line with TU Delft’s data protection and ethics guidelines.

As with any online activity, there is a minimal risk of data breach, but we will take all necessary precautions to maintain confidentiality. No personal identifiers, such as names and mail id, will be included in the published results. Interview recordings will be securely stored on password-protected university servers, and all data will be anonymized during analysis and used solely for academic purposes.

Your participation is entirely voluntary, and you may withdraw from the study at any time without penalty. You may also choose to skip any questions. If you request, your data can be withdrawn up to two weeks after your interview.

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
A: GENERAL AGREEMENT – RESEARCH GOALS, PARTICPANT TASKS AND VOLUNTARY PARTICIPATION		
1. I have read and understood the study information dated [*DD/MM/YYYY*], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	☐	☐
2. I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	☐	☐

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
3. I understand the interview notes will be shared with other researchers involved in the project and this interview notes will be anonymised before sharing (interview notes will not contain name and mail id or any other person identifiable data)	☒	☐
B: POTENTIAL RISKS OF PARTICIPATING (INCLUDING DATA PROTECTION)		
4. I understand that taking part in the study involves the following risk of data breach. I understand that these will be mitigated by anonymizing data during analysis and using it solely for academic purposes.	☐	☐
5. I understand that taking part in the study also involves collecting specific personally identifiable information (PII) [contact] and associated personally identifiable research data (PIRD) [mail id] with the potential risk of my identity being revealed.	☐	☐
6. I understand that the following steps will be taken to minimise the threat of a data breach, and protect my identity in the event of such a breach [not publishing results with names or showing analysis for review before publishing]	☐	☐
7. I understand that personal information collected about me that can identify me, such as [name and mail id], will not be shared beyond the principal researcher.	☐	☐
8. I understand that the (identifiable) personal data I provide will be destroyed [July 2026]	☐	☐
C: RESEARCH PUBLICATION, DISSEMINATION AND APPLICATION		
9. I understand that after the research study the de-identified information I provide will be used for [Graduation thesis report and further research publications]	☐	☐
10. I agree that my responses, views or other input can be quoted anonymously in research outputs.	☐	☐

By participating in the interview, you acknowledge that you have read and understood this information and agree to participate in the study under the conditions stated above.

Signatures

Name of participant	Signature	Date

I, as researcher, have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Pxxxxxxx Rxxxxxxxxx	*******	xx/xx/2025
Researcher name	Signature	Date

Figure 5. *Informed Consent Form*

3. Privacy and Anonymity

To protect participants' identities, several measures were taken:

- Interviews were not audio/video recorded, as noted, which means no potentially identifying voice or image data was stored. Only written notes were kept.

- The notes and subsequent summaries did not include names or personal identifiers. Each participant was assigned a code (e.g., P1, P2, ... P15). The link between these codes and actual identities was kept separately and securely by the researcher and will be destroyed after the thesis completion.

- In writing up results, any direct quotes used are presented anonymously (e.g., "As one participant said, "…"). Care was taken that quotes do not contain identifying information. For instance, if someone said, "As a 45 year old shop owner next to Tambaram station, I…", the researcher would generalize it in reporting to "One interviewee mentioned that…".

- Personal data collected (minimal, mostly contact info like email addresses, and basic demographics if offered) are stored on a password protected university network drive accessible only to the researcher and supervisor, in accordance with TU Delft data management guidelines. The Data Management Plan (DMP) for the thesis outlines these storage and deletion plans (reference to Appendix C for DMP details).

- As per consent form, all personal identifying data will be deleted by July 2026, which is within one year of project completion, ensuring data are not kept longer than necessary. This includes deletion of the participant identity key. The anonymized interview content (notes without names) may be retained for academic purposes (e.g., to use in future research or publications), which participants were informed about, but such data will have no identifiers and thus pose minimal risk.

4. Risk Assessment

The potential risks to participants were very low. The main theoretical risk was a data breach of personal info or someone's opinions being linked back to them, which could be sensitive if, say, they criticized authorities. Mitigation steps followed are described:

- Data anonymization and secure storage. Participants were explicitly informed of these risks and how they are minimized.

- Another minimal risk was inconvenience or minor emotional discomfort recalling flood events. Participants were free to decline any question, and the interviewer was empathetic when discussing experiences of flooding.

In practice, participants were comfortable and often eager to discuss many treated it as an opportunity to voice their opinions.

5. Fair Treatment and Bias

The study committed to treating all participants and their input equitably. This is not just in analysis (equal weighting) but also in the interview experience. Each interviewee was given the same baseline information, the same approximate time, and the chance to share freely. The interviewer remained non-judgmental and thanked everyone for their contributions, regardless of what they shared. There was no hierarchy among participants; even though recruited via different channels, once in the study, each was just “a road user” voice. This upholds the principle of justice in research fair burden and benefits distribution. All got the same opportunity to influence the outcomes (which could eventually benefit the community including them).

6. Participant Feedback and Rights

Participants had the right to withdraw. None chose to formally withdraw data after the fact, but knowing they could possibly empowered them. They also had the right to receive a summary of interview notes (upon request) and the findings of research, and the researcher will honor that by sending an email update after thesis completion, as per what was promised in consent. This gave them a sense of ownership and respect, aligning with ethical best practice of respecting persons. Also, engaging them in on spot member checking provided clarity and validation of the data from the interviewees.

7. Documentation

Documentation like the signed consent forms and the ethics checklist are kept on record. The ethics checklist and research proposal were reviewed by the Faculty Ethics Officer and found to meet requirements, so no further full board review was necessary. This is typical for a master’s thesis of this nature at TU Delft.

8. Data Integrity

In terms of honesty in analysis, the researcher maintained an audit trail of how data was analyzed (data structure table). This ensures the findings can be traced back to source data, a practice which while methodological, is also an ethical issue of integrity and transparency. No fabrication or misrepresentation of data is involved; direct quotes are used to illustrate points genuinely emerging from the data, and any inference beyond what was said is clearly noted as researcher interpretation.

9. Conflict of Interest

The researcher had no conflicts of interest. Since topics were not highly personal or controversial, this likely did not impede openness. The researcher continually reminded participants to speak freely as independent respondents. There was no incentive for the researcher to skew results; the goal was academically to find out stakeholder values. This was communicated to participants, so they didn't feel they needed to give any "desired" answer (and indeed, the range of answers suggests they spoke their mind, not what they thought the researcher wanted).

In conclusion, the methodology was carried out with strong ethical safeguards, aligning with the principle of "do no harm" and respecting participant autonomy and privacy. By obtaining informed consent, ensuring confidentiality, treating participants fairly, and validating findings with them, the study enhances its ethical rigor. This not only protects participants but also improves the quality of data (people tend to respond more honestly when they trust the process is ethical).

APPENDIX C

C.1 Data Management Plan (DMP)

The DMP for this research is given below in detail.

Stakeholder Value Integration in Threshold Matrix for Road Transportation Flood Resilience in Tambaram, Chennai

0. Adminstrative questions

1. Provide the name of the data management support staff consulted during the preparation of this plan and the date of consultation. Please also mention if you consulted any other support staff.

Ms. Xinyan Fan, Data Steward at the faculty of Civil Engineering and Geoscience, has reviewed my DMP on 27/06/2025

2. Is TU Delft the lead institution for this project?

- Yes, the only institution involved

I. Data/code description and collection or re-use

3. Provide a general description of the types of data/code you will be working with, including any re-used data/code.

Type of data/code	File format(s)	How will data/code be collected/generated? *For re-used data/code: what are the sources and terms of use?*	Purpose of processing	Storage location	Who will have access to the data/code?
Informed consent	.pdf .docx	through mail	Interviewees will sign the consent form or give their written consent before/ during the semi-structured interview where they share insights about the road network in Tambaram, Chennai	tu delft one drive	thesis researcher prethwin rathnavelu, supervisors maria nogal macho and johan ninan,
Interview notes	.docx	Notes taken during the interview	the interview notes will be developed into interview summary with no personal data in the summary for code in the thesis report. these notes will serve as summary of insights of the interviews to analyse the stakeholder perspective. (no personal data will be included in the interview notes and summary)	tu delft one drive	thesis researcher prethwin rathnavelu, supervisors and thesis chair - maria nogal macho, johan ninan, ming yang and two postdocs zhaowen liu and erica arango patino
Contact information	.xls	Through personal and professional network	contacting stakeholders	tu delft one drive	corresponding researcher Prethwin Rathnavelu
code through Atlas.ti	.xls .pdf	the notes taken during the interview will be developed into a interview summary to generate code.	to use the interview notes in the research output.	tu delft one drive	corresponding researcher Prethwin Rathnavelu

II. Storage and backup during the research process

4. How much data/code storage will you require during the project lifetime?

- < 250 GB

5. Where will the data/code be stored and backed-up during the project lifetime? (Select all that apply.)

- TU Delft OneDrive

III. Data/code documentation

6. What documentation will accompany data/code? (Select all that apply.)

- Data – Methodology of data collection

Qualitative findings from the literature review and quantitative findings from semi-structured interviews presented in the Master
thesis report.

IV. Legal and ethical requirements, code of conducts

7. Does your research involve human subjects or third-party datasets collected from human participants?

If you are working with a human subject(s), you will need to obtain the HREC approval for your research project.

- Yes – please provide details in the additional information box below

I intend to submit HREC approval.

8. Will you work with personal data? (This is information about an identified or identifiable natural person, either for research or project administration purposes.)

- Yes

I will collect the name and email id for administrative purpose.

9. Will you work with any other types of confidential or classified data or code as listed

below? (Select all that apply and provide additional details below.)

If you are not sure which option to select, ask your Faculty Data Steward for advice.

- No, I will not work with any other types of confidential or classified data/code

10. How will ownership of the data and intellectual property rights to the data be managed?

For projects involving commercially-sensitive research or research involving third parties, seek advice of your Faculty Contract Manager when answering this question.

This project is an internal TUD MSc thesis project, in the context of the ongoing research project Resilient hydro twin project. Therefore, the interview notes shall be shared with other researchers working in the project.

11. Which personal data or data from human participants do you work with? (Select all that apply.)

- Proof of consent (such as signed consent materials which contain name and signature)
- Telephone number, email addresses and/or other addresses as contact details for administrative purposes
- Names as contact details for administrative purposes

The informed consent shall be obtained in one of the two ways, considering the busy nature of the professionals:

1. the interviewees signing and sharing informed consent document
2. the interviewees responding to the concerns, and finally consenting to the empirical research process by written mail, before the interview is conducted.

It is communicated to the participants that all their associated personal identifiable information (name, telephone number, mail id and mail responses) shall be erased by July 2026.

Detailed procedure for informed consent is explained in question 17.

12. Please list the categories of data subjects and their geographical location.

The category of data subjects are daily users of road network in Tambaram, Chennai, India. All stakeholders are in the geographical location Tambaram, Chennai, India.

13. Will you be receiving personal data from or transferring personal data to third parties (groups of individuals or organisations)?

- No

16. What are the legal grounds for personal data processing?

- Informed consent

17. Please describe the informed consent procedure you will follow below.

An information sheet about the objectives of the research and an informed consent form (that highlights the personal data that are being processed and for what purpose) will be sent out to participants to read. The informed consent shall be obtained in one of the two ways, considering the busy nature of the professionals:

1. the interviewees signing and sharing informed consent document
2. the interviewees responding to the concerns, and finally consenting to the empirical research process by written mail, before the interview is conducted. for this process the participants will be informed of the processing of data, the purpose, the duration for which it will be used, how data will be anonymized, reuse for future research and right to withdraw consent in accordance with GDPR.

It is communicated to the participants that all their associated personal identifiable information (name, telephone number, mail id and mail responses) shall be erased by July 2026. Also the anonymized interview summary will be shared with the participants for review of the summary and to make corresponding changes if there is a misinterpretation of the information exchanged during the interview. And consent for reuse of the summary for further research will also be mentioned in the informed consent form in addition to verbal consent to reuse of notes at the end of the interview.

18. Where will you store the physical/digital signed consent forms or other types of proof of consent (such as recording of verbal consent)?

tu delft one drive

19. Does the processing of the personal data result in a high risk to the data subjects? (Select all that apply.)

If the processing of the personal data results in a high risk to the data subjects, it is required to perform a Data Protection Impact Assessment (DPIA). In order to determine if there is a high risk for the data subjects, please check if any of the options below that are applicable to the processing of the personal data in your research project.

If any category applies, please provide additional information in the box below. Likewise, if you collect other type of potentially sensitive data, or if you have any additional comments, include these in the box below.

If one or more options listed below apply, your project might need a DPIA. Please get in touch with the Privacy team (privacy-tud@tudelft.nl) to get advice as to whether DPIA is

necessary.

- None of the above apply

23. What will happen with the personal data used in the research after the end of the research project?

- Other – please explain below
- Anonymised or aggregated data will be shared with others.

  Anonymized quotations shall be used in the research report. Further, the findings shall be shared among the participants with no personal data involved. The risk of re-identification is already mentioned in the informed consent form shared to them, and their approval is received.

24. For how long will personal research data (including pseudonymised data) be stored?

- Personal data will be deleted at the end of the research project

Deleted by July 2026.

25. How will your study participants be asked for their consent for data sharing?

- In the informed consent form: participants are informed that their personal data will be anonymised and that the anonymised dataset is shared publicly

Their views during the interview will be analyzed as anonymous user insights.

V. Data sharing and long term preservation

27. Apart from personal data mentioned in question 23, will any other data be publicly shared?

Please provide a list of data/code you are going to share under 'Additional Information'.

- No other data/code can be publicly shared – please explain below why data/code cannot be publicly shared

VI. Data management responsibilities and resources

33. If you leave TU Delft (or are unavailable), who is going to be responsible for the data/code resulting from this project?

My supervisor, Assistant Professor Dr. Johan Ninan (J.Ninan@tudelft.nl).

34. What resources (for example financial and time) will be dedicated to data management and ensuring that data will be FAIR (Findable, Accessible, Interoperable, Re-usable)?

For this MSc. Thesis, the conducting researcher (Prethwin Rathnavelu) will be responsible for data management in the project. No financial resources or additional time are expected to be necessary.

35. Which faculty do you belong to?

- Faculty of Civil Engineering and Geosciences (CEG)

Figure 6. *Data Management Plan*

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