The Resilience of South African Road Infrastructure to Floods

O Sithole

orcid.org 0000-0002-8313-1895

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Supervisor: Prof LD Nemakonde

Co-supervisor: Dr F Mangara

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ABSTRACT

Natural hazards pose a persistent threat to the world's transport infrastructure, which serves as the backbone of every country's economic prosperity. Reliable transportation networks are essential for the smooth movement of goods, services, and people, thus directly influencing economic growth and development. However, in recent years, extreme weather events — particularly floods — have caused significant damage to transport systems, leading to substantial economic losses, disruptions in supply chains, and decreased mobility. In light of these challenges, it has become increasingly clear that building a more resilient transportation system is not just necessary, but also urgent. Cities and regions that fail to strengthen their transport infrastructure risk severe economic setbacks and social disruptions. A resilient transportation network must be designed to withstand and quickly recover from the impacts of disasters, ensuring continuity in mobility and economic activities. Thus, transportation infrastructure must be adaptive, robust, and capable of withstanding future hazards. Investing in resilient transport systems through better planning, innovative engineering solutions, and climate-adaptive policies will be critical in safeguarding economies and communities from the growing risks posed by disasters.

This study aimed to gain insights into the resilience of South African road transport infrastructure (RTI) to floods. To achieve this aim, both theoretical and empirical approaches were employed. Initially, a literature review was conducted to develop a theoretical understanding of resilience concerning road transport infrastructure and conceptualise floods and their impacts on this infrastructure. Secondly, officials' (SANRAL, Department of Transport, CSIR, South African Road Federation and private consulting companies) perspectives regarding road transport infrastructure resilience in South Africa were sought. The study employed a resilience model based on the R4 framework, which encompasses Robustness, Redundancy, Resourcefulness, and Rapidity, to evaluate the resilience of the country's road transport infrastructure from the officials' viewpoint.

To effectively address the objectives, a mixed-methods research design was adopted, which allows for comprehensive exploration of individual perspectives while ensuring reliability and precision. Data for the empirical study was collected through semi-structured, face-to-face interviews, facilitating thematic analysis of the information gathered. The insights derived from this phase led to the development of instruments for the quantitative component of the study, which utilised an online survey to gather data. A total of 25 practitioners from transport infrastructure institutions participated in the research.

The participants articulated the importance of ensuring the resilience of the transport system to floods and also identified factors such as political interference, negligence, lack of accountability, and insufficient funding, which hindered the implementation of resilience programmes. The empirical findings also revealed that only road redundancy is fully functional, whereas road rapidity, robustness, and resourcefulness are inadequate. In addition, the findings point out that road rapidity and redundancy depend on the availability of resources. Thus, resourcefulness plays a significant role in achieving RTI's resilience. Meanwhile, participants recommended the appointment of zealous leaders, restricting political intervention, availability of finance, and granting full authority to engineers to enhance road resilience. Through an evaluation of the resilience of South African road infrastructure to floods, this study contributes significantly to highlighting the importance of road transport infrastructure's resilience in South Africa.

Keywords: Resilience, floods, road transport infrastructure, robustness, resourcefulness, redundancy, rapidity.

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CHAPTER 1: ORIENTATION AND PROBLEM STATEMENT

1.1 INTRODUCTION

Road Transport Infrastructure (RTI) including roads and bridges is regularly affected by natural hazards, particularly floods, intensive rainfall and landslides, resulting in a decline in the quality and reliability of services (Serulle *et al.,* 2011:22). According to Rebally *et al.* (2021:2), floods have long-term and short-term effects on transportation networks, including the disruption of transportation, the damage to infrastructure, the recovery effort, and the potential for economic impact. This also reduces the capacity to provide safe, reliable, efficient, and accessible means of transport for all citizens, especially in emergencies during floods. In South Africa, there is still a need for a systematic approach to addressing natural hazards in the transport sector. An increase in the frequency and magnitude of natural hazards, particularly those of hydro-meteorological origin, such as floods and intensive rainfall, is attributed to climate change variability, inadequate planning of infrastructure and drainage facilities (World Bank, 2015). The durability of road transport systems is therefore significantly influenced by the resilience of the infrastructure due to the effects of environmental factors on roadway performance. Resilient road infrastructure is essential for ensuring the continuity of access to essential services during disasters, so that individuals, households, communities, and businesses are resilient to hazards (UN, 2021:4; ESCAP, 2021:8). For instance, the UN (2021:5) indicates that roads built with resilient material and design can withstand extreme weather conditions such as flooding and temperature variations and will not be easily damaged or destroyed by natural hazards.

Since its introduction in socio-ecological systems by Holling in 1973, the concept of resilience has been applied across a wide range of fields, such as psychology, material science, engineering and economics (McAslan, 2010:11). In the previous two decades or so, the concept found its way into the field of transport infrastructure. The commonality in conceptualising the term across the fields lies in the premise that resilience is the ability of any system to survive disturbances while retaining its basic structure and operating principles (Zhou *et al.,* 2019:4262) and can self-organise and the ability to adapt to change and stress. This study sought to evaluate the resilience of South Africa's road transport infrastructure to floods. This is especially important and relevant in the South African context, as flooding affects many roads yearly. For example, the national routes (N) N2 and N3 highways suffered considerable damage during flooding (IFRC, 2023:2-3). Alongside an outline of the problem investigated, an overview of the study is presented in this chapter. As part of this chapter, the research objectives are also discussed. In addition to providing an overview of the research method, this chapter addresses factors such as research philosophy, research design, sampling methods, data collection processes, and data analysis. As the chapter concludes, the limitations and delimitations of the study, ethical considerations and significance of the study are discussed.

1.2 PROBLEM STATEMENT

In 2022, the floods that destroyed infrastructure, such as buildings, roads, and bridges, in the KwaZulu-Natal (KZN) province of South Africa were a classic example of the impact of natural hazards on infrastructure (IFRC, 2022:3; Mudefi, 2023:15). Following the devastating floods in April 2022, the South African government estimated that repairing the damaged roads in KwaZulu-Natal (KZN) would cost R5.1 billion — a figure significantly exceeding the initial budget allocation of R2.6 billion (IFRC, 2023:8). This substantial financial shortfall highlights the severe impact of the disaster on critical infrastructure and underscores the urgent need for enhanced disaster preparedness and resilient infrastructure planning. Similarly, roads, bridges, health and school facilities, houses, water plants, and farms in Mpumalanga province have suffered massive damage due to persistent rain and resultant floods in 2023 (Mpumalanga Provincial Government, 2023). In the past, the Montagu Floods of 2003 damaged 11km of the Kogmanskloof Pass (Western Cape), which cost the Department of Transport and Public Works (DTPW) approximately R66.2 million to repair (Chikodzi, 2021; De Kock *et al.,* 2019:15; Holloway *et al.,* 2010). Similarly, the Kaaimans River Pass was damaged by floods in 2006 due to two cut-off lows (Tluczek, 2009:17). As evidenced in the examples provided here, following disasters, government funds are diverted to infrastructure repairs, thus reducing funds available for socio-economic development matters that help to address vulnerabilities and drivers of disaster risk (Allaire, 2018:19). In this regard, floods are an example of natural hazards that have caused severe impacts on road infrastructures, leading to high economic costs, as well as affecting both the users and the society at large.

Floods are expected to occur more frequently and with more intensity due to climate change, variability and land use changes, such developments along roads have a negative impact on road transport infrastructure. Once affected by floods, the transport infrastructure would result in a decline in the quality and reliability of services. Amongst other things, this reduces the capacity to provide safe, reliable, efficient, and accessible means of transport for all citizens, especially in emergencies. Flood events have also led to individuals reducing, diverting, or cancelling their travel plans because roads have been submerged, closed or were unsafe to use (Diakakis *et al.,* 2016:122; Douglas, 2017:38; Rebally *et al*., 2021:3). Sea level rise, flooding, and increased storm events may possibly affect infrastructure, such as bridges, roads, and railways, and adaptation plans should be developed to accommodate these events (Zhou *et al.,* 2018:7). In daily life, people rely heavily on the transport network. Historically, many secondary roads with low traffic volumes were designed for five, ten, or twenty-year flood frequencies. The areas these roads serve have subsequently been densified, making the road more susceptible to flood risk affecting more people.

Since road infrastructure networks serve as lifelines that provide access to impacted areas to support emergency responses and long-term recovery operations after or during a disaster, a stable functionality of transportation networks is important from both economic and welfare perspectives (Zhou *et al.,* 2018:2). For instance, road infrastructure plays a vital role in society as it connects people and goods to their destinations. Rehak *et al.* (2022:2) point out that other subsystems can be negatively impacted if an element's performance is disrupted. For example, a disruption of a major motorway section, a tunnel, a bridge, a level crossing on a railway, or an intersection can negatively impact the performance of other subsystems (Rehak *et al.,* 2022:3). Consequently, these disruptions have the potential to have far-reaching consequences on overall system performance. Rebally *et al.* (2021:1) emphasise that road transport infrastructure is directly adversely affected by floods. On the other hand, indirect impacts result from a negative impact cascade, such as a damage to bridges and washed away roads (Rebally *et al*., 2021:2). As a result of such disruptions to road transport infrastructure, the dependent subsystem is also impacted, and its performance is consequently reduced (Rehak *et al.,* 2022:4). This should not be underestimated as it can have a significant and long-lasting impact on the overall system. In this regard, the South African RTI's resilience to floods is particularly important in this study. This is especially relevant in the South African context, as flooding affects many roads each year.

Meanwhile, transport systems play a crucial role in sustaining society's standard of living (Jelti *et al.,* 2023:3), as well as development and economic growth. For this reason, the infrastructure on which transport relies must be resilient. The concept of resilience has become a buzzword in recent years, both in infrastructure and international policy (Brown, 2015:18; Bruneau *et al.,* 2003:15; Leviäkangas & Aapaoja, 2015:83; Little, 2003:6; UNISDR, 2022:18). It is due to the increased frequency of disasters that organisations recognise the need for more resilient infrastructure and policies. Interestingly, McAslan (2010:2) notes that resilience is descended from the Latin verb "resilire", which means to rebound or recoil. Whenever a system is exposed to adversity, an invisible characteristic known as resilience is revealed (Juntunen, 2014:7). Ever since Holling introduced the concept in Ecology in 1973, it has been widely adopted in various disciplines, including psychology, material science, engineering, and economics. The commonality in conceptualising the term across the fields lies in the premise that resilience is the capacity of a social or ecological system to survive disturbances while retaining its basic structure and operating principles (Zhou *et al*., 2019:4262), and its ability to both self-organise and adapt to change and stress (Leviäkangas & Aapaoja, 2015:84).

In the last two decades or so, this concept has gained popularity in the transportation industry (Zhou *et al.,* 2019). According to Renne *et al.* (2020:10), the notion of resilience has become increasingly prevalent in the context of transportation systems. This is mainly because the concept assures that a transportation system will continue to operate despite disruptions or unforeseeable weather conditions (Leviäkangas & Aapaoja, 2015:83). In this regard, road transport infrastructures are complex systems of various connected components like bridges, roads, tunnels, embankments, retaining walls in the case of a highway system, or wharfs, cranes, buildings, and utility systems in the case of port facilities (Pitilakis *et al.,* 2016:1336). These infrastructures are designed, built, and maintained in a manner that takes potential risks into account and can withstand natural hazards as well as other disruptions without causing grave damage or disruptions to services (Carlson *et al.,* 2012:13).

While resilience in transport systems has been defined in various ways, this study draws heavily on Freckleton *et al.* (2012:110), who state that transport networks can absorb disruptive events gracefully and return a level of service equal to or greater than the pre-disruption level of service within a reasonable time frame. Other definitions focus on minimising disruptions' impact, duration, or magnitude (Carlson *et al.,* 2012:13; National Infrastructure Assessment Committee, 2009). However, there is no widely accepted measure for the resilience of transportation infrastructure for any mode of transportation (Pitilakis *et al.,* 2016:1337). This is why the R4 framework for resilience proposed by Tierney and Bruneau (2007:15) was used to evaluate the resilience of South African road infrastructure. The R4 attributes and determinants of resilience are robustness, redundancy, resourcefulness and rapidity (Tierney & Bruneau, 2007:15). Robustness is the efficient movement of vehicles in normal conditions and fast return to normal conditions after a disruption (Kermanshah & Derrible, 2017:152; Tierney & Bruneau, 2007:15). Redundancy looks at other alternatives when some links in the transport network are disrupted due to events such as floods, landslides, and car accidents (Jenelius, 2010:130). Resourcefulness is the ability to diagnose and prioritise problems and to initiate solutions by identifying and mobilising material, monetary, informational, technological, and human resources (Tierney & Bruneau, 2007:15). Rapidity is the capacity to restore functionality promptly, containing losses and avoiding disruptions (Tierney & Bruneau, 2007:15).

The concept of road infrastructure's resilience to floods in South Africa is rather new, despite the impacts of disasters on South African road transport infrastructure over the years. Moreover, many of the country's roads are situated in areas prone to hazards and, as such, the need to ensure that roads are resilient to hazards cannot be over-emphasised. The issue of road infrastructure resilience is even more pertinent as climate change and alteration to land use; effects are becoming more pronounced and extreme weather events are increasing. To bridge the gap, this study focused on assessing the resilience of South Africa's road transport infrastructure to floods. This was achieved by addressing the study's aim and objectives as outlined below.

1.3 RESEARCH OBJECTIVES

This study aimed to evaluate the resilience of South Africa's road transport infrastructure to floods. The study's aim was accomplished by addressing the following objectives:

- To provide a theoretical conceptualisation of resilience of RTI to the effects of floods.
- To assess the participants' perspectives on road transport infrastructure resilience, existing flood resilience measures and response strategies within the South African road transport sector.
- To evaluate South Africa's road infrastructure resilience using the R4 (robust, redundancy, resourcefulness and rapidity) resilience framework.

- To propose strategies and policy recommendations for enhancing the resilience of road transport infrastructure, ensuring long-term sustainability and improved disaster preparedness.

1.4 METHOD OF INVESTIGATION

A research methodology serves as a means of solving a research problem in a systematic manner (Kothari, 2004:8). Research methodology provides a framework and insight into how the research problem was addressed and how the research process unfolded (Kothari, 2004:8). The research methods applied in this study are outlined below.

1.4.1 Empirical study

The following sections outline the methods used to conduct the empirical study.

1.4.2 Research philosophy

This study was grounded in the philosophical assumptions of pragmatism. Pragmatism, in the view of Saunders (2003:109), seeks to contribute practical solutions to practice and to inform future efforts (Simpson, 2018:59). Thus, pragmatism was adopted because the study aimed to provide recommendations to the challenge of road transport damage due to flooding (Kelly & Cordeiro, 2020:1-2; Reason, 2003; Saunders *et al.,* 2003:109). In a broad sense, a pragmatic approach focuses on the problems people face, the questions to ask, and the outcomes of research (Reason, 2003:108). The importance of this is particularly apparent in times of budgetary constraints and economic challenges. A practical and cost-effective solution is required. In mixed methods research, qualitative and quantitative approaches are merged simultaneously, guided by philosophical assumptions. In pragmatic philosophy, 'the end justifies the means' is emphasised over the process, invoking the principle of 'the end justifies the means'. This pragmatic approach is based on the principle that theory and data alone cannot determine the direction of research, and it is recommended to employ the abduction technique, which involves moving back and forth between induction and deduction throughout the research process (Doyle *et al.,* 2009:178).

1.4.3 Research design

This study adopted a mixed-methods research design. This is because mixed methods offer the complementary benefits of collecting qualitative and quantitative data (Tatakkori & Creswell, 2007:3). Specifically, exploratory mixed-methods research was applied. The exploratory mixed-methods research allows for greater flexibility and richness of data, resulting in more nuanced results and insights into the phenomenon of interest (Kimmons, 2022:123; Sabharwal *et al.,* 2020:251). Guest and Fleming (2015:582) point out that mixed-methods design enables simultaneous meaning and quantity. As Polkinghorne (2005:140) explains, it results in a type of triangulation that promotes the exploration of experiences beyond a single perspective and aids in understanding those experiences (Creswell, 2003, 2014). Research using mixed methods allows the researcher to identify a methodologically sound approach to dealing with complex practical issues (research objectives). Thus, by enhancing meaningful change and facilitating the transferability of interventions and actions, the researcher can provide a solid foundation for meaningful change (Ivankova, 2015). By integrating quantitative and qualitative methods, mixed methods research develops new and enhanced methods for understanding the subject matter (Ivankova & Wingo, 2018: 986) and allows a thorough understanding to be achieved.

Specifically, a constructivist approach of exploratory sequential design was applied wherein qualitative data was collected first, and the qualitative findings informed the development of the quantitative data collection instrument (Creswell, 2009:18). As part of this process, the research topic was actively explored, data collected, interpreted, and the research question refined to gain a deeper understanding of the problem at hand. The first step of this design consisted of the collection and analysis of qualitative data, followed by the collection and analysis of quantitative data (Dawadi *et al.,* 2021:27; Schoonenboom & Johnson, 2017:108; Shorten & Smith, 2017:74-75). As a result of this design, qualitative data was collected and analysed first. A quantitative measure or instrument was developed based on qualitative findings (Terrell, 2012:264; Wisdom & Creswell, 2013:3), followed by a quantitative test of the variables identified (Terrell, 2012) the researcher then interpreted the quantitative data in terms of generalisations and extensions of qualitative findings.

1.4.4 Sampling

The study was conducted using a multistage sampling method, thus involving several stages. At each stage, the sampling units became smaller and smaller (Creswell & Clark, 2018:90). The sample size played a crucial role in sampling. In qualitative research, however, Creswell (2014) contends that sample size is not a critical concern, but rather the study saturation should be considered. An individual sample was selected from a primary unit and a secondary unit within the primary unit in a two-stage sampling design. To ensure the study's validity, only institutions specialising in road infrastructure were selected for participation. These institutions included the South African National Roads Agency Limited (SANRAL), the Department of Transport (DoT), The South African Road Federation, the Council for Scientific and Industrial Research (CSIR), and Leo Consulting, as well as AG Traffic and Transportation Engineering Consultancy. Additionally, participants in management positions, specifically senior managers, engineers and operations managers within these institutions, were selected to participate in the study. A total of 25 participants shared their views on the resilience of South Africa's road transport infrastructure. 14 participants took part in the face-to-face interviews, while 16 completed the online survey, despite it being sent to over 30 potential participants. As such, the quantitative survey was applied to the larger sample. It is important to note that 5 participants of the face-to-face interviews also partook in the online survey. Thus, a total of 25 participants formed a part of this study.

1.4.5 Data collection

This study adopted exploratory sequential mixed methods and was qualitatively biased, qualitative data was collected first through face-to-face, semi-structured interviews with the selected participants. Secondly, quantitative data was collected through an online questionnaire (Saunders *et al*., 2023:1) using close-ended and open-ended questions with Likert scale ratings. As mentioned above, this study was qualitatively biased, therefore qualitative data was collected and analysed first, and then a quantitative questionnaire was developed based on qualitative findings (Terrell, 2012; Wisdom & Creswell, 2013:3). Importantly, using mixed methods offered the researcher in this study the potential for triangulation, which is the process of collecting and validating qualitative data with quantitative data (Saunders *et al.,* 1997) and allowed the study to move beyond a single view of experience, thereby deepening understanding.

1.4.6 Data analysis

An integrated mixed-methods approach was also employed in the analysis (Creswell & Clark, 2011:218). Thematic analysis (TA) and descriptive statistics were utilised to analyse and present qualitative and quantitative data, respectively. During the qualitative data analysis, valuable quotes, codes, and themes were identified (Creswell & Clark, 2011) to develop variables and scales for the quantitative experiment. To make use transcription, coding was applied, and the codes were combined and organised into themes (Maxwell, 2018:23). Maxwell (2018:20) points out that coding is the main method for categorising qualitative research. Coding does not aim to produce counts of things, but rather to "fracture" the data and arrange it to facilitate comparison between items in the same category and between categories. Braun and Clarke (2012:2-3) indicate that thematic analysis can identify, organise, and provide insight into meaningful patterns. By focusing on meaning across a dataset, TA facilitates the perception and understanding of collective meanings and experiences (Bryman & Burgess, 1994). More importantly, verbatim quotes strengthened qualitative data. Furthermore, graphs and tables were used in descriptive statistics to present quantitative results (Kaur *et al.,* 2018:60; Sharma, 2019:4). Through presenting data in a visual format such as graphs and tables, researchers can quickly spot patterns, trends, and anomalies in the data, and gain insights that would otherwise be difficult to identify (Kaur *et al.,* 2018:62; Sharma, 2019:4). A logical analysis of data was used in this type of analysis (Teddlie & Tashakkori, 2011:286), in which one strand is analysed based on the previous one.

1.5 LIMITATIONS AND DELIMITATIONS

This study contains certain limitations as it relies on subjective judgments of participants. The amount of time required for data collection and the availability of participants affected the number of participants involved in the study. As participants came from different provinces, the researcher was compelled to distribute the survey to those from afar through online means. Due to the limited number of participants from all provinces, it was difficult to generalise the findings to the entire country.

However, the study still provides important findings on the resilience of South Africa's road transport infrastructure to flooding.

1.6 ETHICAL CONSIDERATION

Resnik (2015) defines ethical considerations as a collection of values and principles that address what is good and undesirable. Each research study must adhere to ethical principles to protect the well-being of human subjects. During the process of conducting a qualitative study, ethical considerations played a particularly important role. In research, new knowledge is created, and existing knowledge is challenged. Despite the research's admirable purpose, the welfare of study participants cannot be sacrificed. Thus, all participants were informed about anonymity and confidentiality to accommodate ethical considerations. The study's participants were assured that their personal information would be used for educational purposes, remain anonymous, and that the information they provided during both the face-to-face interviews, and the online survey would remain confidential. Please refer to the institution's ethical clearance number: N W U-0 1 3 0 3-2 3-A 9 (see annexure E).

1.7 SIGNIFICANCE OF THE STUDY

The study aimed to assess the resilience of the South African road infrastructure to floods. Since the concept of road infrastructure's resilience to floods is relatively uncommon in South Africa, there are few studies on it. The significance of this study lies in the fact that it provides information rarely addressed in discussions of disaster impacts on South African road transport infrastructures. Further, many of the country's roads are located in areas prone to hazards, which makes the need for roads to be resilient to hazards even more crucial. In light of the increasing severity of weather events and climate change impacts, the issue of the resilience of road infrastructure has become even more pertinent. This study intends to contribute to the resilience of the South African road infrastructure to floods through recommendations to improve the resilience of South African roads.

1.8 PROPOSED CHAPTER DIVISION

Chapter 1: Orientation and Problem Statement

The purpose of this chapter was to provide an overview of the study. It outlined the problem under investigation, the aim and objectives of the study, and the methods applied.

Chapter 2: Floods and their impact on road transport infrastructure

This chapter focuses on flooding and its impact on road transport infrastructure.

Chapter 3: Theoretical conceptualisation of resilience in relation to road transport infrastructure

This chapter provides a literature review on the resilience of road transport infrastructure. A detailed analysis of the existing literature on resilience, with a particular focus on the R4 framework, was delineated.

Chapter 4: The resilience of road transport infrastructure to floods in South Africa: Empirical findings

The chapter presents, analyses, and discusses the findings of the study.

Chapter 5: Conclusion and recommendations of the study

The chapter discusses the study results and conclusions and ultimately provides recommendations.

CHAPTER 2: FLOODS AND THEIR IMPACTS ON ROAD TRANSPORT INFRASTRUCTURE

2.1 INTRODUCTION

Among climate-related hazards, floods pose one of the greatest threats to humanity and the physical infrastructure they rely on, including roads, communication networks, buildings, and social services (Njogu, 2021). In addition to the loss of lives and livelihoods, disruptions to the infrastructure may lead to increased power outages, communication difficulties, and flooding vulnerability. Flood damage leads to accelerated deterioration and aging of infrastructure, which increase maintenance and replacement costs. Due to floods, the foundation of structures is weakened, which damages and disrupts services provided by the infrastructure (Njogu, 2021:1; United Nations, 1999:8). Furthermore, Njogu (2021:2) argues that the extent of the flooded area determines the extent of infrastructure damage and the degree of service disruption, which determines the cost of infrastructure maintenance. Thus, floods have long-term consequences that negatively impact infrastructure and the economy. Compared to other natural hazards, floods and droughts have had the largest impact in Africa over the past 30 years (Lukamba, 2010:478-79). However, flood disasters have surpassed droughts as Africa's most devastating phenomenon in recent years (Lumbroso, 2020:1).

This chapter addresses the study's second objective by describing floods as a theoretical conceptualisation and how they affect road transport infrastructure. Following this introduction, the chapter discusses the types of floods and the role of extreme weather conditions. Afterwards, floods and their impacts on road transport infrastructure (RTI) systems are discussed. Then, the chapter discusses the adaptations that can be made to the future design of strategic road transport infrastructure. Before concluding, the chapter elaborates on the South African existing legislations and policies in the transport sector.

2.2 TYPES OF FLOODS AND THE ROLE OF EXTREME WEATHER EVENTS IN INCREASING FLOOD EVENTS

Intense rainfall events and the resultant floods are among the most destructive weather phenomena worldwide, causing tens of billions of dollars in economic losses annually and resulting in thousands of fatalities, as well as widespread damage to infrastructure (Kuang & Liao, 2020:1; Kundzewicz *et al.,* 2019:1; Wang *et al.,* 2022:1). Floods are incidents in which excessive amounts of water flow into normally dry areas. The rainfall exceeding the land's capacity to absorb surface water can cause direct and indirect flooding, for example when rivers overflow (Luino, 2016:344; Musyoki *et al.,* 2016:2; Whitfield, 2012:336). On the other hand, Javadinejad (2022:173) defines flooding as the physical overflow of rivers and their tributaries, which may cause damage to public structures and human and animal deaths. The presence of water at the wrong time or place can have negative consequences, even though water is fundamental to life. In the opinion of Smith (2001), invasive water in areas intended for other purposes poses the greatest risk to humans. As a result, understanding the potential environmental impacts is imperative to minimise the risks associated with flooding. Property and infrastructure are severely damaged in many affected communities due to flooding. It is undeniable that floods can damage bridges and road infrastructure and disrupt power supplies and communication systems. Depending on their severity and extent, floods can also destroy infrastructure that provides shelter and assistance during flooding (Len *et al.,* 2018:31). Each year, floods are the most frequent natural calamity, inflicting enormous property damage and loss of life (Kuang & Liao, 2020:1).

Floods caused by flash floods occur within six hours of heavy rainfall, requiring immediate action to ensure the safety of people and property (Bauer *et al.,* 2019:2). While flash floods occur immediately after heavy rainfall has ended, typical river floods often occur several hours afterward (Bauer *et al.,* 2019:2; Sharif *et al.,* 2012:312). There is no doubt that flash floods are one of nature's most common and dangerous hazards, occurring frequently and often causing many deaths as well as extensive damage to property (roads, houses, hospitals). RTI is significantly affected by a range of tangible and intangible effects. Flood victims trapped by flooding on roads account for more than half of the total death toll from floods in some cases (Diakakis *et al.,* 2020:4). This is further supported by the European Truck Accident Causation report, according to which severe weather conditions (such as severe precipitation causing flash flooding) account for 4.4% of all road accidents (Diakakis *et al.,* 2020:4). In addition to RTIs, other factors, such as mobility and routines, are adversely affected. Worker displacement occurs when flash floods occur, resulting in workers having to travel additional distances, spending more money on fuel, and spending more time in traffic to reach their jobs (Bhuiyan *et al.,* 2021). Yin *et al.* (2016) note that the majority of deaths resulting from flash floods occur as a result of people becoming trapped on flooded roads.

Pluvial flooding is a type of flooding caused by torrential rains that overwhelm an area's drainage capacity (Rözer *et al.,* 2021). Water accumulates on the surface as a result of intense rain exceeding the capacity of drainage systems and engulfing RTIs completely (Kundzewicz & Pińskwar, 2022:2). Unlike to coastal fluvial floods, they can occur anywhere (urban and rural areas) as a result of factors such as poor drainage, impervious surfaces like asphalt, and increased rainfall intensity exacerbated by climate change (Kundzewicz & Pińskwar, 2022:2). After excessive rainfall, these floods usually appear within minutes or hours (Naulin *et al.,* 2013; Yin *et al.,* 2016:138). A significant problem with RTIs susceptibility to pluvial floods. This is attributed to the conflict between accelerated urbanisation and inadequate urban infrastructure planning (Yin *et al.,* 2016:138-139). The majority of evidence indicates that pluvial flood disasters have a significant effect on RTI systems (He *et al.,* 2023:1; Pregnolato *et al.,* 2017:2). Due to pluvial flood disasters, the water flow accumulates and significantly reduces the capacity of road traffic. It is without a doubt that pluvial floods are among the most serious climate disasters in the world (He *et al.,* 2023:1; Bauer *et al.,* 2019:2).

Most of the world's regions are affected by fluvial flooding. In this type of flood, the river overflows or bursts its banks in response to prolonged periods of heavy rainfall (Acosta-Coll *et al.,* 2018:2). During continuous heavy rains, urban areas and river channels are prone to flooding (Bates *et al.,* 2021). The most prevalent weather-related disruption to transport infrastructure is fluvial flooding. Clearly, these incidents undermine RTI systems' effectiveness (Abdulla *et al.,* 2020:1). Most often, pluvial flooding and fluvial flooding are concurrent, resulting in greater effects than either flooding alone (Ashley *et al.,* 2005).

Van der Berg (2018:103) states that coastal towns are especially susceptible to flooding. When seawater invades coastal areas due to storm surges, high tides, sea level rise, tsunamis, or subsidence, coastal floods occur (Acosta-Coll *et al.,* 2018:1-2). This increases the susceptibility of the coastal area to floods. The ability of cities to remain connected during floods is largely dependent on roads and bridges (Lu *et al.,* 2015:3). Coastal flooding causes roads and bridges to fail, reducing RTI's network accessibility (Lu *et al.,* 2015:5). In light of the challenges associated with coastal flooding due to climate change, it is particularly imperative to prioritise RTIs in coastal areas. Water intrusion will exacerbate coastal flooding's impacts and affect more transportation facilities (Lu *et al.,* 2015:7). During extreme flooding, RTI systems are the primary means of rescuing or delivering aid to communities. This is when a region is faced with loss of mobility or essential goods. As sea levels rise and extreme weather events become more common in coastal areas, flooding can become a more significant threat to RTI (Duy *et al.,* 2019:28).

Climate change, excessive urbanisation, and the ever-growing interdependence of various sectors exert increasing strain on crucial infrastructure systems. There is, however, a growing concern about the high cost of failures in critical infrastructure systems, due to cascading failures that originate in one area and eventually affect other sectors that are dependent on it. Thus, engineers and policymakers are facing one of the most pressing challenges of the 21st century, which is to ensure the resilience of interdependent critical infrastructure systems (Abdulla *et al.,* 2020:1-2). In the road transportation sector, extreme weather conditions have an adverse effect due to their impacts. Therefore, various design strategies have been developed to minimise the effects of climate change on transport infrastructure (De Abreu *et al.,* 2022:8). The number of goods transported by roads has increased to approximately 70% in the last few years. The threat of extreme weather events (storms, heavy precipitation, and heat waves) has increased due to climate change. (Force, 2015:8). Transport infrastructure systems are supposed to be designed to withstand typical weather patterns. The RTI operations and their ability to withstand short, medium, and long-term extreme events can be adversely affected by climate change in several ways (i.e. flood damage). Evans *et al.,* (2022:11) recommend that infrastructure must perform reliably under normal circumstances and minimise failures during extreme weather conditions.

Various environmental and human factors are contributing to the increasing frequency of flood disasters worldwide. There are other factors that affect flood impacts, such as demographic density at specific region, as well as the quality of risk-averse urban planning to ensure resilience to flooding (Duy *et al.,* 2019:29). The frequency and intensity of natural hazards, in particular floods, are increasing (Musyoki *et al.,* 2016:3). It is evident that floods are common in South Africa, and climate change contributes to their intense occurrence (Chuene, 2021:24; Van Niekerk *et al.,* 2022:1-3). Floods have occurred in South Africa (SA) on many occasions. One of SA's most significant flood events happened in 1958. Other significant floods pointed out by Grobler (2001:13) include the Laingsburg flood of 1981, Natal flood of 1987, the Free State flood of 1988, Ladysmith flood of 1994, these are examples of SA well-known floods (Chuene, 2012:4; Dube *et al.,* 2022:460; Grab & Nash, 2024:13; Grobler, 2001:13; Kagoda, 2006:4-5). Munzhedzi *et al.* (2024:2) have indicated that the floods of 2011 and 2022 were declared as national disasters. In addition, several provinces were affected by floods every year between 2011 and 2022, causing serious infrastructure damage, displacement of people, and a considerable number of fatalities (FloodList, 2022; IFRC, 2023:8).

Whenever road transport systems are damaged, fail, or are disrupted, the effects may extend beyond the primary area of concern. A disruption in one area may have domino effects on other regions due to the interconnected nature of various transport systems. As a result, passengers and goods are typically unable to move due to service disruptions (Lykou *et al.,* 2017:5). Often extreme precipitation causes flash floods that damage infrastructure, for instance, extensive damage to streets, lanes, roads, and bridges, among others (Guze & Kołowrocki, 2017).

Despite their best efforts, regions, particularly in developing countries, are facing new challenges related to climate change (Dube *et al.,* 2022:453). Impacts of climate change, such as extreme weather events, cause infrastructure damage, economic disruption, and the displacement of individuals. A country's vitality is therefore affected as it depends on road transport infrastructure. In a study by Singh *et al.* (2018:238), the authors found that climate-induced road pavement deterioration may account for 30% to 80% of the damage to road infrastructure. For example, Australian roads deteriorate as a result of the impact of floods. It is estimated that approximately 4% to 36% of the cost of road damage and losses can be attributed to flooding. In another study conducted by Savonis *et al.* (2014:29), it was found that weather-induced costs for European countries were between 8 to 13 billion Euros per year, amounting to between 30% to 50% road damage. Singh *et al.* (2018:239) highlighted that weather related disaster events that are being attributed to climate change are increasing in frequency and will have a greater impact on the functioning of transport infrastructure. It is, therefore, clear that flooding has a long-lasting and detrimental effect on transportation systems.

2.3 IMPACTS OF FLOODS ON ROAD TRANSPORT INFRASTRUCTURE

The severity of extreme weather events is expected to increase due to climate change, if not already so (Len *et al.,* 2018:32). Diakakis *et al.* (2016:115) raised concerns about the performance of transport infrastructure based on these predictions and documented impacts of floods on infrastructure and humans. An infrastructure network (roads and bridges) that supports the transportation of goods and individuals is susceptible to adverse weather conditions and can be damaged by floods (Pregnolato *et al*., 2017:69). Ntakiyimana *et al.* (2022:3738) further indicated that in an economy that relies on transport for development, any changes in the road network could have a detrimental effect on the economy. In the event of a flood, a wide area could be affected for a considerable period; thus, causing disruptions in the transportation sector. When floods damage roads infrastructure, millions of people can be affected (Ntakiyimana *et al.,* 2022:3738). Inundation of the subgrade soil beneath the roadways can result in erosion of the entire road foundation (Fioklou & Alipour, 2019:1). This can lead to roads becoming unstable and more susceptible to further damage. Furthermore, flooding can cause bridge decks to dislocate, materials to loosen, and corrosion to penetrate (Fioklou & Alipour, 2019:1; Shang *et al.,* 2018:1). Thus, the bridge's structure may be damaged, increasing the likelihood of further hazards (i.e. collapse). Direct flood damage can result in extensive indirect losses and interruptions extending beyond the affected area in space and time. However, cost-effective innovative expenditures must be undertaken to rehabilitate and maintain RTI resulting from flood risk damage. To avoid the risk of potential losses, bridge infrastructure must be protected from flooding.

Floods have caused severe impacts on transportation networks in the past (Shahdani *et al.,* 2022:2). Significant disruptions, resulting in economic and social consequences can be associated with extreme weather events, including direct or indirect damage to the infrastructure and threats to human safety (Pregnolato *et al.,* 2017:68). Due to this, RTI must be resilient to withstand extreme weather events. However, few studies have been conducted on flooding in South African road transport infrastructure (Dube *et al*., 2022:455). Due to its location on the southern African continent, South Africa is susceptible to extreme weather events (Van Der Walt & Fitchett, 2022:71). Sea level rise and extreme weather conditions, including storms and hurricanes, affect the country's coastal areas. The road infrastructure is therefore at risk. Nonetheless, climate change influences extreme weather events (floods) through changes in meteorology. There is a correlation between the probability of damage occurring and the maximum flood height exceeding a certain level. This correlation is related to the distribution of coastal impacts. Climate change can also affect the distribution of damages as it alters weather patterns, thus changing the variability of erratic weather events (Guze & Kołowrocki, 2017).

Socio-economic activity is affected whenever RTI or other municipal utility services are disrupted. In accordance with Iloeje *et al.* (2015:105), floods have destroyed transport infrastructure, leaving cities disrupted. Leviäkangas and Michaelides (2014:283) emphasise the importance of assessing the impact of severe weather events on the transport sector because of the significant economic impacts and threats to human safety associated with these events. Pregnolato *et al.* (2016:3) argue that flood impacts must be understood to make informed decisions regarding limited financial resources. Pregnolato *et al.* (2017:78) supported the above point by mentioning that gaining a deeper understanding of flood damage to transportation systems is imperative so that investments can be prioritised. The existing approaches that estimate flood disruption assume that either a road has been blocked or is fully functional following a flood event (Pregnolato *et al*., 2017:69). In the aftermath of RTI disasters, financial resources and budgets are severely limited, which ultimately impedes economic development (ADPC, 2017).

Depending on the flood's magnitude and duration, each flood's impact has a different associated cost. Transport infrastructure is adversely affected in various ways, including direct (damage to physical infrastructure) and indirect effects (business interruption and increased emissions). Although indirect economic damage will likely occur in the future (USACE, 2009:1), flooding may have a more detrimental impact on society by reducing transport performance (Pregnolato *et al.,* 2017:69; Walsh *et al.,* 2012). Floods directly impact government finances by requiring emergency response expenses, and citizens bear the cost. These costs include health-related expenses (including treatment for injuries and rehabilitation) and property damage (such as damage to vehicles, equipment, buildings, etc.). Congestion problems affect not only private vehicles, but also transit operators, passengers, and freight vehicles. Moreover, businesses incur costs due to missed shipments, lost sales, and production delays (Chang *et al.,* 2011:19; He *et al.,* 2022:21). Whenever transportation capacity is reduced or roads are closed, these indirect costs occur. The cost of replacing damaged RTI after flood disasters often exceeds the institutions' (provincial roads department and local government roads) budgetary resources. Flood damage sometimes, if not often, causes funds for other development projects to be diverted into rebuilding RTI (ADPC, 2018:12).

As a result of flooding, traffic is often negatively affected by intangible effects: time loss, frustration, and a degraded environment. Direct damage may occur when an asset of interest (such as buildings, people, roads, etc.) is physically exposed to floodwaters. Pyatkova *et al.* (2018:41) report that indirect damages usually happen outside of the flooded area and develop over an extended period. Therefore, it is vital to invest in resilient infrastructure to mitigate flood damage and the effects of extreme weather events (Shahdani *et al.,* 2022:3; Tramblay *et al.,* 2020:7). When roads and bridges are damaged after flooding events, congestion and increased travel time are likely to occur. In addition, flooding may damage stations and tracks, disrupting public transportation networks, such as trains and buses. IPCC's Sixth Assessment Report, for example, indicates that heavy rain events have become increasingly frequent and intense over most land areas in recent decades. The continued warming of the planet is increasing the frequency and intensity of heavy rainfall events. In essence, so flooding will become increasingly frequent in the future (Grab & Nash, 2024:476). To protect the road network from natural hazards, road authorities need to understand the resilience of existing structures (Setunge *et al*., 2014:2).

The soil and vegetation may fail to absorb water due to heavy rains. Sometimes floods cause rivers to overflow beyond their banks into floodplains. Floods caused by lunar pull and earthquakes are also associated with tsunamis and coastal surges. Human-induced factors, such as urbanisation, have increased the vulnerability of rivers to flooding. A major cause of floods in some urban areas is inadequate management of drainage systems. In addition, many developing countries experience flooding due to poor town planning (Glago, 2021:30). Often, human development patterns, especially in floodplains, contribute to the extent of flood impacts (Pant *et al.,* 2018:22). Moreover, the effects of flood disasters can be felt not only on infrastructure and property but also on agricultural activities, historical and cultural sites. Road transport infrastructure's vulnerability to floods can be mitigated by minimising direct impacts through constructing flood-resistant bridges, raising roads, and constructing culverts. Traffic models can be used to estimate the magnitude of the disruption of transport service caused by floods (Shahdani *et al.,* 2022:4). Karamouz *et al.* (2019:145) indicate that recent and historical natural hazards have shown the necessity for building resilient infrastructure. A comparative analysis of historical data (flood damages) can be beneficial for constructing resilient RTI (Capacci *et al.,* 2022:35; Enriquez-de-Salamanca, 2019:4; Regmi & Hanaoka 2011:34).

More than 40 flood disasters have occurred in South Africa over the past 40 years. Over the course of this period, floods caused the country to suffer losses amounting to approximately R35 billion in direct losses, such as damage to infrastructure (Engelbrecht *et al.,* 2022). A severe weather event occurred in the Western Cape Province between September 23 and 26, 2023, which resulted in extensive flooding, death, and displacement. In at least seven different areas of the Western Cape, infrastructure was damaged, including electrical lines, shelters, roads, and water supply systems (Grab & Nash, 2024). The RTI system has been extensively disrupted by floods, complicating relief efforts and making it difficult to reach the affected areas (IFRC, 2023:3). For example, major highways such as the N1, R60, and R62 were closed as a result of flooding. The extensive impacts of the floods prompted a state of emergency in Western Cape Province. A similar situation occurred in Bela-Bela, Limpopo, in 2014 due to heavy rainfall. The dams overflowed, causing flooding in the town which caused extensive damage to properties and roads (Bopape *et al.,* 2025).

Moreover, in 2017, several coastal cities, for example Durban, were severely flooded due to torrential rains and hail, resulting in disruption of a major highway (the N2) and damage to vehicles, hospitals, factories, homes, and other infrastructure (Grab & Nash, 2024:489). There were also significant damages to bridges and roads (Singh *et al.,* 2022:2). There were flash floods across Johannesburg and Ekurhuleni from November 2016 until January 2017. A municipal state of disaster was declared in these areas. A significant amount of damage was caused to informal and formal settlements, as well as collapsed bridges, as a result of the flash floods. Further, in addition to disrupting municipal services, the flooding damaged roads and business properties (Van der Berg, 2018:111). Therefore, it is essential to take expedient steps in order to prevent future flood-related loss of livelihoods and damage to transport infrastructure.

The impacts of intense rainfall as a result of climate change on infrastructure services are evident in the increasing number of damages caused by floods. For example, these can be attributed to poor maintenance, increasing numbers of people living in floodplains, an inadequately planned infrastructure and drainage system, and developments along roads that increase runoff and degradation of catchment areas due to invasive plant species. Developing countries tend to react to, rather than proactively manage, flood damage to infrastructure. The literature provided by Njogu (2021:1-3) shows that preparations for, during, and after the flooding event are insufficient. Even so, a growing amount of attention is being paid to adaptation measures, primarily preventive measures aimed at minimising the adverse impacts of induced hazards and enhancing cross-sectoral resilience. This regime is not unfamiliar to the South African transport sector, which is one of the most important economic sectors in the country. Due to more frequent and intense extreme weather events, the infrastructure and operation networks are not immune to climate change impacts. Floods have been a major cause of global economic disruption and human death since the beginning of the twentieth century (Merz *et al.,* 2021:592). Consequently, Stamos *et al.* (2015:1) advocate for proactively addressing this issue of floods.

2.4 SOUTH AFRICAN EXISTING LEGISLATIONS AND POLICIES IN THE TRANSPORT SECTOR.

A resilient, safe, and efficient road transport infrastructure (RTI) system begins with intentional and integrated planning. Weilant, Strong, and Miller (2019:53) emphasise that resilience must be incorporated from the outset of transport system planning. This requires engineers, planners, and policymakers to assess future risks such as flooding and other climate-related events, particularly in the context of the road type and geographic exposure. However, in many developing countries, including South Africa, there remains a limited emphasis on resilience during the planning and development stages (Fay *et al.,* 2010:40). This omission has long-term implications, including increased infrastructure vulnerability, maintenance costs, and service disruptions. Njogu (2021:2) underscores that resilience can be enhanced through land-use planning, implementation of robust building codes and standards, and long-term infrastructure investments that reduce lifecycle costs while ensuring reliability and service adequacy.

The governance of RTI in South Africa is complex, involving multiple actors including national and provincial transport agencies, municipal departments, and private sector stakeholders. These actors set priorities and influence the policy landscape. However, there is ongoing debate over whether a dedicated Roads Policy is needed. Some argue that existing frameworks such as the Road Infrastructure Strategic Framework for South Africa (RISFSA) and the S'hamba Sonke Programme (SSP) are sufficient but suffer from poor implementation (DoT, 2017:15). Others caution against introducing new layers of regulation, arguing instead for more enabling and streamlined policy mechanisms.

South Africa has adopted several policy initiatives aimed at reforming and improving public transportation. One key development was the introduction of interim contracts (ICs) in 1997 by the Department of Transport (DoT) to bring existing subsidised operators under contract and transition toward more competitive service delivery. However, these ICs were not integrated within formal Integrated Transport Plans (ITPs) and often resulted in operators receiving near-perpetual operational rights, with limited accountability or transformation (Walters, 2013). To address structural inefficiencies, the National Land Transport Transition Act (2000) marked a turning point. It was the first legislation to define the distinct roles and responsibilities of different levels of government in transport governance. It also introduced competitive tendering as the preferred mechanism for public transport contracting, though negotiated contracts remained permissible under specific conditions (Walters, 2013:39; Wosiyana, 2005:1). These provisions were later reinforced under the National Land Transport Act of 2009, which advocated for the devolution of transport responsibilities to local and metro governments, seen as better positioned to respond to local mobility needs (Walters, 2013).

Despite a robust policy and legislative framework, implementation challenges persist. Coordination failures among national, provincial, and municipal authorities, lack of funding, and limited technical capacity remain major bottlenecks. Many municipalities, especially in rural areas, are underperforming or dysfunctional, requiring targeted coordination and support to fulfil their road delivery mandates (DoT, 2017:27). The sector also grapples with a complex web of intermodal and intramodal negotiations, which further complicate efficient service delivery and infrastructure development.

In summary, while South Africa's transport policy framework provides a comprehensive foundation for improving RTI and public transport systems, its success hinges on overcoming entrenched institutional and capacity constraints, ensuring adequate funding, and fostering effective multi-level coordination.

2.5 ADAPTATION STRATEGIES FOR FUTURE ROAD TRANSPORT INFRASTRUCTURE

In a disaster-affected area, the recovery speed remains extremely dependent on the condition of the RTI networks (Nipa *et al.,* 2022:111). Developing a strategic plan allows project coordination, which considers synergies between projects and balances competing interests among various sectors. It provides a mechanism for making investment decisions oriented towards national priorities instead of making such decisions piecemeal. The current context, in which uncertainty regarding some of the major drivers of infrastructure demand is probably at its highest, makes strategic planning especially valuable. A deeper use of scenario analysis may also benefit government planning and decision-making. This may substantially enhance the success of planning and decision-making at the local, regional, and national levels. Despite this, there has only been limited evidence of progress in this direction (Durrant, 2021:320).

A decisive factor in determining RTI stability is the selection of materials. Flooding and heavy rainfall determine the stability of a road (ADPC, 2018:14). Road design improvements, such as adding barriers and increasing drainage capacity, can reduce flooding risks. To reduce flood risks, roads should be designed to meet the annual flood probability. These design standards should withstand a flood with a 1/100 return period rather than a flood with a 1/50 return period. In this case, some roads were built before design standards were established, which suggest the need for retrospective changes, while new roads can be planned in a manner that alleviates risk by incorporating updated mitigation design specifications. Approximately 0.1% to 0.9% of global maintenance costs could be saved if the design standards are met. A key component of reducing damages will be upgrading design standards for surface flooding (ADPC, 2018:14; Koks *et al.,* 2019:3-8).

Road infrastructure assets can have a long lifespan, if effective assessment management is performed, particularly when the maintenance schedule is appropriate. For adequate incentives to promote effective RTI management, responsibilities must be clearly allocated, as well as financial transparency regarding asset performance. Infrastructure planning is a complex task, especially when dealing with multiple scenarios or interactions. Drazkiewicz *et al.* (2015:213-218) indicated that a greater participation of citizens in infrastructure planning is a key contextual factor in addressing complexity. Governments should increase their investments in consultations to make the process easier. By doing so, they are able to make difficult trade-offs, enable users and taxpayers to debate the subject matter, and in addition, most importantly, provide the basis for making decisions (Durrant, 2021:17). Compared with other sectors, RTI plans and programmes require considerable government investment. However, the deficiency of government officials' interference and a lack of public involvement affect significant investments. Thus, government planning and decision-making should maintain a multidisciplinary approach (Durrant, 2021:24). To be successful, this requires greater collaboration and coordination among sectors involved in road transport infrastructure.

Towards addressing climate change, South Africa's National Development Plan (Vision 2030) guides a comprehensive adaptation strategy. Various sectors of society are required to participate in Vision 2030. Taking part in the transition to a low carbon economy is the primary objective of the Department of Transport (State Action Plan) (DoT, 2016). Climate change mitigation, building a resilient road transport infrastructure, and taking advantage of all possible opportunities are primary objectives of this project. The adaptation to climate change programme complements policies aimed at reducing greenhouse gas emissions by enhancing the readiness and capacity of the transport industry to deal with the impacts of climate change at the local, regional and national levels, thereby contributing to a climate-resilient transport industry. The Department of Transport also recognises transport as a sector that needs to be adapted. Moreover, the transport sector is committed to a low carbon economy in 2050. This will reduce

80% of global greenhouse gas emissions. Several policies can be implemented as part of the program, which contributes to increased resilience. The strategy emphasises that early, planned adaptation action is more affordable than the cost of not adjusting (DoT, 2018:43-44).

Politics and technology continue to be significant barriers to adaptation in RTI. It is difficult for RTI to adapt to climate change due to a lack of adequate financial resources. Training, awareness, and capabilities are perceived as less significant and with less consensus across government spheres. It is important to address obstacles such as uncertainty and a lack of political action. As a result, adaptation has been regarded as a long-term problem. Due to the lack of political priority or the fact that adaptation is considered a longer-term endeavour, it does not encourage urgent short-term action (DoT, 2018:44). By reviewing and monitoring the adaptation measures taken in the RTI infrastructure governance, future policies can be improved in terms of efficiency and effectiveness. Furthermore, it will help facilitate a transparent public discussion regarding what additional actions may be required. A resilient transportation system requires the integration of adaptation and mitigation strategies related to climate change. A coordinated transportation policy can, therefore, bridge this policymaking gap (DoT, 2018:44-45).

2.6 CONCLUSION

Transportation systems are essential components of human society because they facilitate the connection of communities, increase individual activities, and improve the quality of life of individuals. The effects of floods may last for several days and can seriously damage an organisation's transport network. Many indirect and direct losses may be incurred due to damaged road transport systems, which impede mobility for individuals and risk safety. In the wake of these events, profound consequences, even death, may result in other sectors. In light of this, policymakers must incorporate disaster management techniques into their decision-making processes regarding the transport sector. This is a holistic problem rather than a design flaw of an isolated transport infrastructure element. To resolve this issue, a comprehensive approach is required.

The right to travel is often restricted, as is the right to move freely and conduct commerce, thus safety and livelihoods are threatened. With the increased frequency of extreme flood events, infrastructure networks must be more resilient to floods. To this end, various calamities, notably floods, have posed serious challenges to the South African road infrastructure and services. It is undeniable that floods are the most common natural hazards in South Africa and that they have the greatest impact on the environment.

CHAPTER 3: THEORETICAL CONCEPTUALISATION OF RESILIENCE IN RELATION TO ROAD TRANSPORT INFRASTRUCTURE

3.1 INTRODUCTION

The chapter provides a theoretical conceptualisation of resilience about road transport infrastructure. The term resilience was introduced in the ecological literature by ecologist C.S. Holling in 1973 (Park *et al.,* 2013:356). However, the concept was already being used in material science and psychology (De Weijer, 2013:2). With the passage of time, the concept has assumed various meanings as it has used in a variety of fields, including ecology, psychiatry, disaster risk management and psychology, to mention but a few. This study draws heavily from Freckleton *et al.* (2012:110), who defined resilience as the ability of transport networks to bounce back (return itself to a level of service equal to or greater than the pre-disruption level of service within a reasonable time frame) to its normal state after disruptive flood events. Over the years, the concept has gained prominence in road transport infrastructure (Bruneau *et al*., 2003:15, Little, 2003). As Renne *et al.* (2020:3) point out, the notion of resilience has become increasingly prevalent in the context of transportation systems. This is mainly because the resilience-thinking assures that the RTI will continue to operate despite disruptions or unforeseeable weather conditions (Leviäkangas & Aapaoja, 2015:83).

This chapter provides an in-depth review of existing literature on the concept of resilience, focusing on RTI resilience with particular emphasis on the R4 framework for resilience proposed by Tierney and Bruneau (2007:15). The R4 attributes and determinants of resilience are robustness, redundancy, resourcefulness, and rapidity (Tierney & Bruneau, 2007:15). The chapter also reflects on the different approaches used to measure the resilience of RTI and the different stressors that can affect its performance. Additionally, it outlines the most relevant strategies for enhancing the resilience of road transport infrastructure. The structure of this chapter is as follows: immediately following this introduction, the chapter discusses the conceptualisation of resilience in general and disaster resilience. A brief explanation of the principles of resilient infrastructure is provided. Thereafter the concept of resilience is explored within the context of road transport infrastructure, followed by an examination of the most appropriate strategies for resilient road transport infrastructure with a particular focus on the R4 framework. In conclusion, the chapter identifies the most suitable strategies to enhance the resilience of road transport infrastructure.

3.2 CONCEPTUALISATION OF RESILIENCE

The concept of resilience has gained increasing prominence in both scholarly and policy debates, particularly in the context of disaster risk reduction, climate change adaptation, and infrastructure development. While resilience is often described as a straightforward or intuitive idea, the ability to recover from adversity or maintain function under stress, it is, in fact, a complex, multifaceted concept that varies significantly across disciplines and contexts (Alcántara-Ayala *et al.,* 2022:404; Rahi, 2019:72). It encompasses analytical, descriptive, and causal frameworks, and has evolved through decades of theoretical development since the early ecological work of Holling in 1973 (Park *et al.,* 2013:356).

In engineering and infrastructure studies, resilience has been widely applied to assess and enhance the performance of systems, particularly in the face of external shocks such as floods, earthquakes, and other disruptions. This is especially relevant for road transport infrastructure (RTI), which serves as the backbone of national economies and is highly vulnerable to both acute and chronic hazards. In this context, the R4 framework developed by Tierney and Bruneau (2007), which identifies four key attributes of resilience: robustness, redundancy, resourcefulness, and rapidity, has been extensively employed to guide infrastructure resilience assessments and interventions. Due to its technical focus and applicability to physical systems, the R4 model has been adopted in this study as a suitable lens for understanding and evaluating RTI resilience.

Despite its growing popularity, resilience remains a contested and evolving concept. Scholars like Welsh (2014) and Weichselgartner and Kelman (2014) have highlighted that resilience has eclipsed earlier paradigms such as vulnerability and sustainability, partly because it better captures the dynamic, contingent, and systemic nature of risk and response. Resilience is not only about bouncing back from shocks but also about the capacity to adapt, reorganise, and even transform in the face of adversity (Manyena & Gordon, 2015:39). This quality is particularly critical for transport systems, which are often required to remain functional during crises and quickly return to normal operations thereafter.

In practical terms, the application of resilience in infrastructure planning must go beyond rhetoric to encompass design standards, land use planning, and redundancy measures that enhance the functionality of critical systems under stress (Labaka *et al.,* 2013:137). For instance, to build resilient RTI systems, it is essential to identify the environmental risks, understand the infrastructure's exposure and sensitivity, and ensure that systems are designed not only to withstand disturbances but to operate during and after such events. Tzavella (2021:4) argues for an integrated approach to infrastructure resilience, emphasising that robust built environments are essential for withstanding climate-related shocks like flooding.

The broader policy discourse on resilience, driven by agencies such as the UNDP, World Bank, and DFID, reflects a shift toward using resilience as a bridging concept between climate change adaptation, disaster risk reduction, and development (Brown, 2012). These actors recognise that resilience must be understood not only in technical or infrastructural terms, but also in terms of social, economic, ecological, and governance dimensions. This holistic understanding allows for better collaboration and coordination among institutions tasked with responding to disasters and building future-ready infrastructure.

Moreover, understanding the nuances between engineering resilience and ecological resilience is crucial for infrastructure planning. Engineering resilience focuses on the speed of recovery and efficiency of return to a pre-disaster state. It values predictability, constancy, and stability, making it a preferred framework for physical infrastructure like RTI. Ecological resilience, on the other hand, emphasises adaptability, transformation, and the ability to reorganise in response to stress, qualities that are equally important in dynamic and uncertain environments (Holling, 1973; Rahi, 2019:73). By combining these perspectives, a more comprehensive resilience framework can be established that informs both the design and governance of infrastructure systems.

The emphasis on reliability, redundancy, and flexibility has become central in resilience thinking for transport systems. Reliable RTI systems are those that can continue to operate under abnormal conditions and resume normal function quickly after disruptions. Redundancy ensures that there are backup components or routes to maintain service continuity. Flexibility allows the system to adjust and reallocate resources in real time (Leviäkangas & Aapaoja, 2015; Zhou *et al.,* 2019:4265). These features are not only technical requirements but also institutional ones, requiring cross-sector coordination, funding mechanisms, and political will to implement.

In the wake of frequent and intensifying disasters, many driven by climate change, resilience is increasingly seen as a proactive strategy rather than a reactive response. The resilience agenda developed between 2000 and 2010 (UN, 2021:9) stresses the need for infrastructure systems that can withstand and adapt to chronic and acute stresses, ensuring continuous provision of critical services such as transportation, water, and energy. The United Nations (2009:22) defines resilience as a system's ability to reduce the magnitude and duration of disruptions, reinforcing the importance of early planning, risk-informed investments, and adaptive governance.

Ultimately, achieving resilience in RTI systems requires a shift in mindset, from building systems for static efficiency to designing adaptive systems capable of learning and evolving. This includes designing infrastructure that is interconnected but not overly dependent, with the capacity for self-organisation in response to crises (Alcántara-Ayala *et al.,* 2022:33). As many scholars have argued, resilience is not merely about recovery, it is about building capacity to navigate and shape change, and in doing so, contribute to long-term sustainability, equity, and development (Alinovi *et al.,* 2010; Brown, 2015; Chandler, 2015).

Resilience, especially when framed through the R4 lens, offers a valuable approach to enhancing the performance, safety, and adaptability of road transport infrastructure systems. However, translating this conceptual richness into actionable strategies requires careful attention to design, policy alignment, institutional coordination, and socio-technical integration. It is through this multi-dimensional approach that resilience can move from theory to transformative practice in the transport sector.

3.3 DISASTER RESILIENCE

Disaster resilience is the capacity to anticipate, prepare for, respond to, recover from, and adapt to hazardous events while maintaining essential functions (Keating *et al.,* 2017:80; National Research Council, 2012:15). Within the context of road transport infrastructure (RTI), resilience is crucial not only for reducing disaster-related disruptions but also for supporting economic development, service delivery, and social well-being, especially in disaster-prone or vulnerable communities (Rinaldi *et al.,* 2001:15; Zhu *et al.,* 2017:147). RTI forms a foundational layer for mobility, trade, and emergency response; as such, its ability to withstand, adapt, and recover from external shocks defines the broader system's resilience.

The concept of resilience has steadily evolved, becoming a core analytical and practical framework across disciplines. Its interdisciplinary nature enables scholars and practitioners to examine dynamic interactions between systems and their environments, allowing for a more nuanced understanding of disruption and recovery. In transport systems, resilience refers to the ability of networks to respond to unexpected demand, manage disruptions, and maintain critical service levels despite constraints (Reeves *et al.,* 2019:10). This aligns with the broader notion that infrastructure must perform reliably under stress, not only by resisting shocks but by adapting and recovering rapidly (Reeves *et al.,* 2019:14).

Since the Hyogo Framework for Action in 2005, the concept of resilience has increasingly permeated the field of Disaster Risk Reduction (DRR). Terms like "sustainable resilient communities" have gained traction in both academic and policy discourses, signalling a shift in disaster management paradigms from reactive to proactive models (Darmi & Mujtahid, 2024). Resilience is now frequently discussed alongside or in place of related concepts such as vulnerability, with the former emphasising systems' and communities' capacity to cope and transform rather than merely absorb impact (McEntire *et al.,* 2002:270).

Bradely and Grainger (2004:455) argue that under severe constraints, actors often switch from performance-based to survival-oriented strategies. This has important implications for RTI resilience, rather than simply restoring roads to pre-disaster functionality, resilience planning must account for shifting priorities, changing travel patterns, and constrained resources. Investing in resilient infrastructure supports proactive adaptation, allowing transport systems to anticipate and absorb disruptions, particularly in socially and economically vulnerable areas. The resilience of RTI is closely tied to political, economic, and social contexts, underscoring the need for a comprehensive approach (Middleton & O'Keefe, 1998:615).

A meaningful shift toward resilience requires rethinking traditional risk equations. The standard formulation, risk = hazard × vulnerability can be enriched through a resilience lens. By reducing vulnerability and increasing adaptive capacity, resilience-based approaches empower communities to make informed, context-sensitive decisions. This shift allows for a more people-centred approach, where community participation and local knowledge are harnessed to build resilience from the ground up (Paton & Johnston, 2001:273). Unplanned urbanisation, poor land-use practices, and inadequate governance in many developing countries have heightened disaster risks. Resilience thinking highlights the need to address these underlying drivers of vulnerability through systems-oriented planning.

Technological advances, particularly in Information and Communication Technologies (ICTs), offer new tools for strengthening resilience. ICTs facilitate early warning, rapid communication, public engagement, and disaster response coordination. For example, in Türkiye, government, civil society, and private actors use ICTs to decentralise disaster risk management and build resilience through enhanced participation (Tarhan *et al.,* 2016:453). Digital tools enable citizens to co-produce resilience, making real-time decisions during crises and contributing to a more responsive and flexible disaster management system.

Understanding how systems respond to disruptions involves key resilience metrics such as resistance**,** recovery, and return time. Resistance refers to a system's immediate response to external shocks, while recovery entails the return to equilibrium or stable functioning (Hodgson *et al.,* 2015:504). In transport infrastructure, this might mean how quickly a damaged road segment is cleared or how effectively traffic reroutes during a flood. Return time reflects the period required for infrastructure to resume stable operations after a disturbance. Proximity to a tipping point, the threshold at which a system transitions into a different state, indicates a network's stability. RTIs near such tipping points are more susceptible to collapse and therefore require targeted interventions to strengthen their resilience.

Participatory governance is central to building such resilience. By disseminating information, engaging communities in planning processes, and recognising the criticality of specific infrastructure components, societies can better prepare for disasters and reduce their vulnerability. The resilience of infrastructure depends not just on technical characteristics, but on its social value and impact. In this regard, critical infrastructure resilience (CIR) strategies typically involve two primary approaches, protection and mitigation. Protection entails safeguarding infrastructure from collapse or systemic failure, while mitigation seeks to reduce disaster impacts and the risk of occurrence (Hodgson *et al.,* 2015:504–508). Both are essential for maintaining the continuity of services and ensuring public safety.

Importantly, the protective role of resilient RTI extends beyond physical assets. Resilient road networks support emergency response**,** medical evacuations, and supply chains during crises, making them vital lifelines for affected communities. Their robustness and flexibility determine the overall effectiveness of disaster response and recovery. Moreover, by proactively designing transport systems with redundancy and adaptability, planners can better prepare for future risks, whether natural, technological, or societal in nature.

Therefore, disaster resilience in RTI must be understood as a multi-dimensional, dynamic process that incorporates technical, social, and institutional elements. It is about more than returning to normal, it is about building better, adapting faster, and enabling systems to learn and evolve. As disasters grow in intensity and frequency, particularly under the influence of climate change and rapid urbanisation, embedding resilience in infrastructure planning and governance becomes not just desirable but necessary. Through strategic investments, community engagement, technology, and governance reforms, RTI can become not only a mode of connectivity, but a critical pillar of resilience.

3.4 TOWARDS RESILIENT INFRASTRUCTURE: PRINCIPLES AND PRACTICES FOR TRANSPORT SYSTEMS

Investing in infrastructure is both an economic imperative and a developmental necessity, particularly in regions facing the compounded risks of climate change, disasters, and aging physical assets. Infrastructure investment serves not only to replace obsolete systems but also to create resilient networks that are capable of withstanding shocks and adapting to emerging challenges. According to Palatse (2021), such investments can be driven through various mechanisms including asset conversion, public-private partnerships, and blended financing. However, the resilience of infrastructure cannot be understood or enhanced in isolation, it requires a systems-based approach that acknowledges the interdependence of infrastructure and services across planning, financing, design, operation, and eventual decommissioning.

A resilient infrastructure system is one that does more than simply resist collapse during a hazard event, it must also recover quickly, adapt to changing conditions, and ensure continuity of critical services. This perspective is embedded in global frameworks such as the Sustainable Development Goals (SDGs) and the Sendai Framework for Disaster Risk Reduction, which view resilient infrastructure as key to sustainable development. Jackson and Ferris (2013:153) and UNDRR (2022:16) emphasise that integrating resilience principles helps manage risk complexity and reduce cascading failures during disasters.

Key foundational elements of resilience, as noted by Scholl and Patin (2014:42), are redundancy and resourcefulness. Redundancy refers to the existence of alternative routes or systems, such as RTI with multiple access points (Alcántara-Ayala *et al.,* 2022:417). Resourcefulness involves the capacity to mobilise diverse assets, including human, technical, and financial resources, to achieve objectives (Bruneau *et al.,* 2003:15; Tierney & Bruneau, 2007:2). Together, these qualities determine how well infrastructure systems can adapt and continue functioning under stress.

UNDRR (2022) outlines six interrelated principles to guide the development and governance of resilient infrastructure systems throughout their lifecycle, from design and construction to operation and decommissioning. These principles are not just technical prescriptions, but normative guides aligned with broader resilience and sustainability goals.

1. Proactively Protected

A key tenet of infrastructure resilience is proactive hazard preparedness. Infrastructure systems must anticipate a wide spectrum of threats, both known and emerging including climate change, sea level rise, and industrial risks like nuclear pollution (UNDRR, 2022). Proactive protection entails incorporating emergency planning into design processes, elevating safety baselines, safeguarding critical infrastructure components, and ensuring robust maintenance regimes. This anticipatory approach significantly reduces vulnerabilities and potential impacts over the infrastructure's lifespan.

2. Environmentally Integrated

Infrastructure development, especially in the transport sector, often contributes to environmental degradation and increases exposure to hazards. For instance, deforestation resulting from RTI construction may intensify climate risks. An environmentally integrated approach seeks to harmonise infrastructure with the natural environment, using nature-based solutions such as green corridors and reforestation to mitigate impacts (Rich, 2014:35). This approach not only protects ecosystems but also leverages natural capital to enhance resilience.

3. Socially Engaged

Communities play a vital role in creating and sustaining infrastructure resilience. The socially engaged principle promotes participatory planning, where communities, local governments, and private stakeholders co-create knowledge and preparedness strategies. This inclusion fosters ownership, enhances public awareness, and ensures that infrastructure systems are responsive to the needs and behaviours of those they serve (UNDRR, 2022:44). As Trump *et al.* (2017:294) and Pelling (2012) argue, resilience is shaped as much by social and political dynamics as by engineering.

4. Shared Responsibility

The governance of resilient infrastructure must be collaborative. Sharing responsibilities among stakeholders, including public agencies, private companies, civil society, and technical institutions helps build trust and improves coordination. Common standards, data-sharing platforms, and clearly defined roles and responsibilities are essential components of this shared responsibility framework (UNDRR, 2022:49). Engaging diverse actors in resilience governance also expands the knowledge base and fosters legitimacy (Folke *et al.,* 2003:16; Colding *et al.,* 2020:3).

5. Continuous Learning and Systems Thinking

Given the dynamic nature of risks and socio-ecological systems, infrastructure resilience must be supported by continuous learning and adaptive management. This includes regular monitoring and evaluation, scenario modelling, and experimentation with new technologies and governance models (UNDRR, 2022:26). Co-learning among stakeholders allows for the refinement of resilience strategies based on real-world experiences, ensuring that infrastructure systems evolve in response to changing threats and user needs (Colding *et al.,* 2020:3).

6. Adaptive Transformation

Resilient infrastructure must not only bounce back from disruptions but also transform in response to long-term shifts, especially those driven by climate change. Adaptive transformation requires the integration of flexibility into infrastructure design, construction, and operation. For instance, RTI must be equipped to deal with extreme weather events such as floods through revised building codes, drainage systems, and emergency protocols. The goal is to enable infrastructure systems to perform reliably outside of normal operating conditions and to incorporate innovations such as early warning systems and low-carbon technologies over time (UNDRR, 2022:55).

While these principles are theoretically robust, implementing them is particularly challenging in resource-constrained contexts like South Africa. Barriers such as underinvestment, excess capacity, institutional fragmentation, and environmental degradation complicate the operationalisation of resilience. Infrastructure development must balance socio-economic priorities with environmental protection and disaster risk management, a task that requires political will, coherent policies, and sustained financing. Despite these challenges, South Africa's Ministry of Transport has adopted a forward-looking approach. Its climate change response strategy recognises the transport sector's dual role in contributing to and mitigating climate risks. Key measures include raising awareness, promoting energy-efficient policies, supporting low-carbon mobility, and developing climate-resilient infrastructure systems (DoT, 2018:6–7). This approach reflects a systemic understanding of resilience and aligns closely with the UNDRR principles.

Thus, building resilient infrastructure is not a one-time project but a continuous, adaptive process that requires integrated planning, inclusive governance, and ongoing learning. As demonstrated by the six UNDRR principles, proactively protected, environmentally integrated, socially engaged, shared responsibility, continuous learning, and adaptive transformation, infrastructure systems can be designed and managed to withstand disruptions and adapt to evolving conditions. In the context of transport infrastructure, these principles provide a comprehensive framework to guide investment, planning, and operational decisions in ways that reduce disaster risk and support sustainable development.

In South Africa and similar settings, the translation of these principles into practice must be accompanied by enabling policies, institutional reform, and innovative financing mechanisms. When applied holistically, these principles not only strengthen infrastructure resilience but also generate broader co-benefits for society, the economy, and the environment. As infrastructure systems become more central to climate adaptation and disaster risk reduction, embedding resilience into every stage of their lifecycle will be critical to achieving long-term sustainability and equitable development outcomes.

3.5 THE RESILIENCE OF ROAD TRANSPORT INFRASTRUCTURE

Infrastructure is the collection of logistical resources required to successfully run a country. Rather than only covering roads and buildings, it encompasses a wide range of facilities (Proag, 2015:27). It is without doubt that road transport infrastructure must involve both physical and operational elements to enable, sustain, or improve societal living conditions (Krieger *et al.,* 2020:16). Infrastructure must be designed more resiliently and constructed more sustainably. As part of building resilient road transport infrastructure, it is necessary to maintain and repair existing infrastructure facilities. Additionally, it is of critical importance to use appropriate design approaches considering vulnerabilities and criticalities (Krieger *et al.,* 2020:18). Resilience emphasises performance, reduction and recovery when confronted with inevitable disruptions. Sajoudi *et al.* (2007) stressed that when RTI is resilient, it must exhibit robustness, reliability, redundancy, and rapidity (See section 3.6). A well-designed road transport infrastructure can withstand interruptions and maintain their functions in the face of disaster fluctuations (Zhou *et al.,* 2018:1). As a result, organisations can cope with the ever-changing environment and respond to the unexpected changes.

Road transport infrastructure plays a significant role in the mobilisation of resources. If RTI is damaged, it can negatively affect the country's economy. Jelti *et al.* (2023:3) highlight that RTIs play a crucial role in sustaining society's standard of living and economic growth. Dong and Frangopol (2015:198) acknowledge that a country's socio-economic development can be adversely affected by the failure of RTI due to impacts of natural hazards. For this reason, the infrastructure on which transport relies must be resilient. These infrastructures must be designed, built, and maintained to take potential risks into account and withstand natural hazards without causing severe damage or disruptions to services (Carlson *et al*., 2012:13-17). RTIs are, however, not resilient, because they deviate from their equilibrium state in large-scale and small-scale disasters, such as earthquakes, floods, etc. (Zhao *et al.,* 2018:4). As opposed to serving as an end in itself, transportation serves as a means. Rather, it provides an essential conduit for facilitating economic activity, social interaction, facilitate trade, support development and access to essential services.

Transport infrastructure enables people to access economic, social, and environmental resources. When transport infrastructure functions properly, people and goods can be mobilised efficiently within and between communities (Weilant *et al.,* 2019:14). Conversely, when the transport infrastructure is strained, traditional definitions of resilience may exhibit contradictions and omissions. Ignoring these considerations can lead to an underappreciation of the critical role RTIs play in maintaining the stability and adaptability of infrastructure during disruptions (Weilant *et al.,* 2019:10). Based on Weilant *et al.*'s (2019:12) findings, resilience can be incorporated into long-term planning and decision-making through a revised transport planning process. Department of Transport (2014:9) pointed out that extreme weather events determine whether RTIs are resilient. Murray-Tuite (2006:1400) indicated that resilient road transport infrastructure could continue to operate during disasters, quickly regaining efficiency (rapidity) (Du *et al.*, 2022:105). However, as the magnitude has been taken into account RTI's resilience is determined by its properties and nature of the event (Weilant *et al.,* 2019).

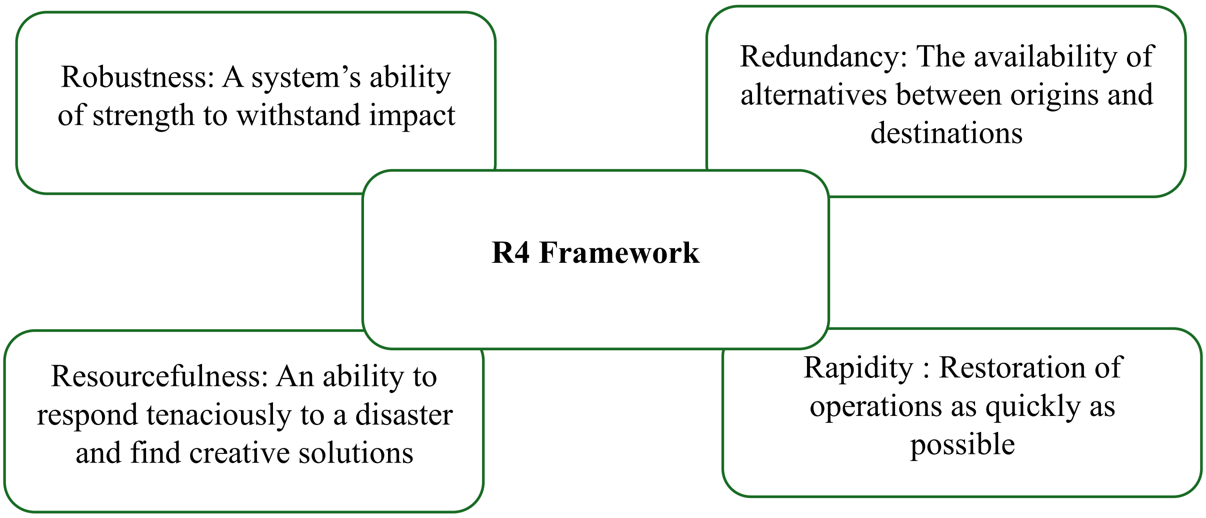
Disasters generally result in severe damages to transport infrastructure (Calvert & Snelder, 2018:130). When roads are damaged, emergency responses are affected (Valenzuela *et al.,* 2017:349-350), as several other infrastructures rely on roads for cross-cutting support. Access to assets that have been flooded, damaged, or require inspection at the source is subject to the functionality of the road network (Fekete, 2020:5). In some cases, flooded roads may alter evacuation routes and pose a severe hazard to emergency vehicles. In this regard, it is possible to enhance the resilience of road transport infrastructure by implementing robust failure detection systems to reduce the consequences of catastrophic disruptions (Berdica, 2002:126). Using such an approach can promote a more resilient and sustainable system of road transport infrastructure. In addition, economic costs associated with road infrastructure damage could be reduced. Furthermore, a challenging component of disaster risk management (DRM) is the identification and assessment of underlying risks in natural and built environments. The adverse impact of natural hazards on RTIs can take various forms, ranging from temporary road disruptions to widespread disasters that result in deaths and long-term economic difficulties. A crucial part of ensuring that goods and services remain accessible is to design bridges and roads to withstand flood hazards (UN, 2017:40).

Natural and man-made hazards continue to pose significant challenges to road transport infrastructure (Wang *et al.,* 2020:5). A single attack (natural hazard impact) on a node, link, or city can have significant consequences, but suitable topological structures and characteristics allow road transport infrastructure to be resilient to disasters. To achieve RTI resilience, the design attributes should be redundant, diverse, resourceful, efficient, autonomous, robust, flexible, and safe (Du *et al.*, 2022:105; Murray-Tuite, 2007:11). Redundancy and vulnerability are characteristics of the network; collaboration is an enabler of resilience, and efficiency and safety can be achieved (Murray-Tuite, 2007:11).

To ensure road transport infrastructure reliability, it is vital to consider resilience when designing RTIs. Several characteristics and properties contribute to the concept of resilient infrastructure. During hazard, Sajoudi (2007) refers to capacity as the ability of infrastructure to withstand external disturbances, similar to robustness. However, robustness refers to a component's inherent ability to resist damage, while capacity refers to a broader concept (Baker *et al.,* 2008:254; Sajoudi, 2007). Capacity also considers some strategies to cope with disturbances that exceed those predicted. Thus, redundancy and flexibility are crucial in case of disturbance or emergency to have alternative options. Having a reliable redundancy programme can lead to choices and sound decisions. In contrast, a flexible programme allows for the rearranging of infrastructures in the event of disasters (Sajoudi, 2007:5). Lastly, road infrastructure connects important geographical regions and provides physical access to destinations using various modes and alternate routes (Governors' Institute on Community Design, 2017:4). Basic services are also mobilised using transport infrastructure.

3.6 R4 FRAMEWORK FOR RESILIENCE

According to Bruneau *et al.* (2003:15), robustness, redundancy, resourcefulness, and rapidity (R4 framework), are the four characteristics used to describe resilience. Following Tierney and Bruneau's (2007:1) R4 framework, subsequent studies on resilience have extensively incorporated this framework. Applied to road transport infrastructure, the R4 framework can ensure that road transport infrastructure remains and continues to operate in case of disruptions. Zhou *et al.* (2019:4266) argue that system robustness and redundancy determine the extent of disruptions in RTIs. Robustness and redundancy determine the effectiveness (disaster-resilience) of RTIs. Restoring the functionality of road transport infrastructure during the disaster recovery phase depends on resourcefulness and rapidity. Snelder *et al.* (2012:832) contend that the R4 is critical for maintaining a road network's function to facilitate people's movement. The R4 framework can therefore be utilised for analysing the current condition of a network, such as in an RTI, or even in a situational analysis. When RTIs are resilient, the probability of failure is reduced, and thus, consequences of failure, such as death, injuries, physical damage, and negative economic and social effects, could be prevented (Tierney & Bruneau, 2007:4). Therefore, a strong correlation exists between the R4 (Figure 3.1) properties (Capacci *et al.,* 2022:26), which will be discussed in the sections below.



Source: Author

Figure 3.1: The R4 Framework

3.6.1 Robustness

Robustness refers to the ability to maintain functionality under conditions that deviate from normal state (Domaneschi et *al.,* 2019: 2196; Ge et *al.,* 2022:192; Snelder *et al.,* 2012:831; Tierney & Bruneau, 2007:4; Zhou *et al.,* 2018:5). Regarding transport infrastructure, robustness refers to the ability of an RTI to function despite hazard occurrence, thus limiting direct and indirect economic losses (He *et al.,* 2021:2). A robustness assessment of transportation infrastructure can be conducted both based on its topology and its intended use (He *et al.,* 2021:5). Robust systems perform well even when subjected to high pressure (Alcántara-Ayala *et al.,* 2022:415; Aparicio *et al.,* 2022:3; Ayala *et al.,* 2022:14). Thus, the state of a system under adverse conditions should be considered as a measure of its robustness.

A process called "hardening" or "resilience engineering" is used to enhance the robustness of RTI with more durable alternatives to withstand destructive events. The road infrastructure component will be able to ultimately withstand any disruptive events without displaying any visible adverse effects (Guo *et al.,* 2021:8; Gunderson, 2000:431; Xu & Kajikawa, 2018:242; Zhou *et al.,* 2018:4). Robustness, therefore, determines the remaining level of functionality under disruptions.

Robust road transport infrastructure retains its original properties whenever disasters occur. For example, road infrastructure robustness prevents disconnection by emphasising road connectivity and converting from a collapsed path to a redundant path, thus ensuring road resilience. Xu and Kajikawa (2018:239) highlight that transformability is the characteristic of this transition. Robustness aligns with engineering resilience, which states that an infrastructure can withstand disasters and recover from changes. The interchangeability of road infrastructure maintains the functionality of a robust system. In Scholl and Patin's (2014:33) view, organisations can return to normal operations sooner if road infrastructure maintains its robustness during disasters.

Alternatively, robustness is a source of reliability and resilience (Aparicio *et al.,* 2022:5). For example, findings from a case study conducted by Duan and Lu (2014:22) on six city road networks worldwide demonstrated that topological structure plays a more significant role in the robustness of a city road network than geographical features and inherent characteristics. The level of diversity in the central distribution of the road network is particularly significant. Due to the similarity in their topological structures, road networks subjected to disasters tend to perform similarly; however, they differ by degree due to different model dimensions. In addition to describing the performance of a city road network, robustness also analyses and provides early warning of traffic incidents. An improved understanding of RTI robustness can enhance existing networks by considering road robustness planning and traffic guidance (Duan & Lu, 2014:25).

In Duan and Lu's (2014:22) paper, Derrible and Kennedy argued that the availability of alternative routes determines the robustness of a network. Thus, Duan and Lu (2014:22) evaluated the robustness of road networks by measuring the number of cycles in the system (i.e. loops). Clustered road networks generally perform better than other linear road networks due to the availability of alternative routes. In previous studies, structural complexity has been found to significantly influence the efficiency of road robustness (Iyer *et al.,* 2013:25; Yin *et al.,* 2009:470). Using a simplified national road network in north Sweden, Jenelius & Mattson (2020:13) provided a practical framework for evaluating its robustness. The robustness of the network was assessed by observing structural changes after removing randomly selected or intentionally selected roads. Depending on the structure of a road network, the robustness can vary greatly (Duan & Lu, 2014:23).

A RTI's robustness and resilience are measures of its ability to respond to disruptions. To ensure that road transport systems remain functional and dependable despite disasters, such systems must be both robust and resilient (Iyer *et al.,* 2013:21; Mattsson & Jenelius, 2015:19). The ability of a system to rebalance its demand and supply when it has reached an imbalanced state is the measure of its robustness (Zhou *et al.,* 2019: 4266). Therefore, a reliable RTI is defined as one that can provide the level of service required during disasters. As a result of disturbances, both robustness and resilience are measured. While disasters can happen, a robust road transport infrastructure can continue to operate.

3.6.2 Redundancy

According to Bruneau *et al.* (2003:15) and Alcántara-Ayala *et al.* (2022:417), redundancy refers to the availability of alternative routes. Redundancy not only provides travellers with alternative transport routes (Tierney & Bruneau, 2007:2), but it also increases the resilience of transport infrastructure in the event of disasters (Guo *et al.,* 2021:9; Jansuwan *et al.,* 2018; Xu *et al.,* 2021:3). In the transport sector, redundancy is defined as the availability of multiple routes to an original destination (Argyroudis, 2021:2; Domaneschi *et al.,* 2019:2192; El Rashidy, 2014:82). Road transport infrastructure redundancy thus occurs when functional requirements are met during a disruption. A further aspect of redundancy in transport infrastructure that Berdica (2002:117) discusses is its ability to operate without interruption in the event of disturbance. In this way, the availability of alternative routes ensures mobility and distribution of services. Alcántara-Ayala *et al.* (2022:417) and Kerner and Thomas (2014:678) advocate for redundancy to avoid disruptions caused by unforeseen events. Despite hazards or disasters, options should be made available (alternative roads). Thus, the ability to achieve desired goals or functions through various options constitutes redundancy.

To accelerate the recovery of disrupted transport infrastructure, resilience is an integral part of the National Transportation Recovery Strategy of the United States (USDOT, 2009:9). Redundancy has received little attention in the transport sector despite its significant contribution to resiliency assessments (Croope & McNeil, 2011:3). Several disciplines have discussed the relationship between redundancy and resilience (Cabinet Office (UK), 2011; Sajoudi, 2007:5; Xu & Kajikawa, 2018:244). For example, to enhance RTI resilience, redundancy is often deemed a "tool" in engineering during unexpected events or disturbances. Besides redundancy being defined as an option for alternative routes, Yazdani and Jeffrey (2012:53), on the other hand, consider redundancy as a topological phenomenon of transport infrastructure resilience. Likewise, Tsuji *et al.* (2002) pointed out that redundancy is necessary to ensure adequate capacity in a local failure. An analysis by Randles *et al.* (2011:294) suggests that redundancy may reduce the vulnerability of complex systems. According to Anderson *et al.* (2011:28), RTI redundancy is a good indicator of resilience.

Redundancy also enhances recovery strategies to make road transport infrastructure more resilient to disruptions. Redundancy is a vital component of an emergency response and recovery plan according to the Federal Highway Administration (Zhang & Chen, 2024:10). The most effective method to improve road network resilience is to add redundancy to the existing road transport infrastructure to increase alternative means of coping with disasters. One can increase redundancy by introducing a certain amount of spare capacity into RTI (Goodwin, 1992:211). In the event of disaster disturbance, the transport sector will be able to function continually. According to Snelder *et al.* (2012:835), there are two types of redundancy: active and passive. Active redundancy refers to the availability of alternative routes, while passive redundancy refers to a backup option that is only used in case of interruptions. Additionally, measures that maintain alternative capacity under normal conditions (such as road pricing or speed adjustment) must be taken to create network redundancy (Snelder *et al*., 2012:835).

Lastly, resilience has several interrelated properties. If a system continues to meet sufficient functional requirements even after experiencing a partial disruption, it is deemed redundant. As with resourcefulness, it is a property that depends upon the complex interrelationships between structures within structures and between networks within communities. Due to this, redundancy and resourcefulness are also often viewed as two sides of the same coin: redundant systems that had not previously existed can be activated when resources are readily available, but redundant systems can also serve as alternatives when uncertainty is present (Capacci *et al.,* 2022:26). Redundancy plays an important role when there is a breakdown in the transport network. During the recovery phase, resourcefulness and rapidity determine the ability to restore functionality (Zhou *et al.,* 2019:4266).

3.6.3 Resourcefulness

According to MacKinnon and Derickson (2013:263), resourcefulness has steadily complemented sustainability in the globalisation of resilience. Resourcefulness ability is defined as the ability to identify resources, set priorities, and attain objectives using a variety of materials, such as property, technology, information, etc. (Alcántara Ayala *et al*., 2022:413; Bruneau *et al.,* 2003:15; Tierney & Bruneau, 2007:2). Factors that contribute to resourcefulness are availability of resources and skill development. Technical and local knowledge are regarded as important skills that complement resourcefulness (Verlinghieri, 2020:366). Zona *et al.* (2020) added that materials, organisational capacity, social capital, and financial investments are all factors that contribute to resourcefulness. Factors of resourcefulness are considered key components of disaster preparedness (Zona *et al.,* 2020:6). Using existing resources efficiently to address existing problems is a crucial characteristic of resourcefulness in the transport sector (Argyroudis, 2021:2). As a result of resourcefulness, transport infrastructure management can be effective and, thereby, efficiently responsive to disasters (Chester *et al.,* 2021:3).

To enhance resourcefulness, investing in innovative technology and improving existing infrastructure is necessary (Calvert & Snelder, 2018:135). A resourceful system also minimises the impacts of disaster by providing materials and services during an emergency (Alcántara-Ayala *et al.,* 2022:13). Thus, a set of resources is required to manage disaster as it unfolds. Moreover, effective decision-making is based on the availability of financial materials and human resources (Capacci *et al.,* 2022:24-26). A resourceful system must also be capable of preventing future hazards through the preparation of adequate emergency plans and recovery policies. Achieving resourcefulness involves a fair distribution and accessibility of resources. The scope of resourcefulness includes social, natural, economic, and political factors. It can, therefore, be viewed as a complement to capabilities theory (Verlinghieri, 2020:367).

Based on the above discussion, it would consequently be apt to argue that an infrastructure's ability to cope and recover is influenced by its resourcefulness. Similarly, a resourceful infrastructure can immediately utilise internal and external resources to achieve resilience. In the event of unforeseen circumstances, a flexible and resourceful infrastructure can adjust regardless of the circumstances. Resilient systems must be resourceful when resources, such as human, financial, technological, etc, are limited. In such circumstances, it is imperative that fewer resources are allocated and utilised effectively. In addition, alternative pathways for using resources are identified and pursued to build resilience. Moreover, to be resourceful, RTIs should be able to procure the required materials without disrupting service provision in any devastating way. Thus, a resourceful and resilient RTI ensures that resources are utilised effectively (Alcántara Ayala *et al*., 2022:413; Kerner & Thomas, 2014).

3.6.4 Rapidity

Sohouenou *et al.* (2019:3) refer to rapidity as the ability of a system to quickly recover from failures. Rapidity enhances infrastructure resilience during disaster recovery and response (Tierney & Bruneau, 2007:3; Zhu *et al.,* 2017:150). The degree of rapidity in the transport sector is determined by the nature of the damage and the availability of resources following a significant event (Argyroudis, 2021:2; Mitoulis *et al.,* 2021). As per Argyroudis (2021), restoration and reinstatement functions can be used to estimate the value of RTI rehabilitation (Argyroudis, 2021:16). A rapid process in this context is characterised by improved robustness, redundancy, and resourcefulness (Tierney & Bruneau, 2007:15). Achieving rapidity objectives allows losses to be contained, functionality to be restored, and future disruptions to be limited. Thus, the measure of how rapidly a system can restore itself to normal operational level can be used to evaluate recovery capabilities (Kong & Simonovic, 2018:378). A redundant and resourceful infrastructure enables Rapidity. Norris *et al.* (2008:134) and Scholl and Patin (2014:42) emphasise the importance of redundant systems and resourcefulness as antecedents to robustness and Rapidity.

Rapid response is paramount in enhancing infrastructure resilience during disaster and recovery phases (Zhu *et al.,* 2017:18). Wan *et al.* (2018:492), identified that redundancy, robustness, rapidity, and resourcefulness are four keys of resilience characteristics of road transport infrastructure. Regarding disaster recovery and mitigation, the first two Rs (robustness and redundancy) are primarily concerned with preparation (network design, and mode options) for disasters. The latter two Rs (rapidity and resourcefulness) are related to the entities that implement and operate the transport system (Xu *et al.,* 2018). Therefore, rapidity determines the ability to restore functionality.

The ability of a system to anticipate disruptions that result from disasters, for instance, contributes to its adaptive capabilities (Francis & Bekera, 2014:94). People, processes, and organisations are also essential factors in determining the resilience of infrastructure systems (Zhu *et al.,* 2017:150). For the network to be functional again, it is necessary to develop a recovery strategy and identify the associated repair activities before the final agenda. Using the recovery time interval as an approximate measure of rapidity (Capacci *et al.,* 2022:26) is the most straightforward way to measure residual functionality. The mobilisation of goods and services relies on the functionality of road transport infrastructure. Thus, if RTI is affected by disaster, rapidity (i.e. quick response) must be prioritised. Zhou *et* al. (2018:5) highlight two types of rapidity, i.e. accessibility and repair, which characterise resilient RTI. For example, a road serves as a key infrastructure for accessing assets that have been flooded or damaged and offers mobility for onsite inspection and road maintenance (Fekete, 2020:3). Therefore, RTIs serve as the backbone for emergency response.

3.7 STRATEGIES TO ENHANCE THE RESILIENCE OF ROAD TRANSPORT INFRASTRUCTURE

Many studies have examined the efficacy of resilience strategies in conjunction with resilience measures (Zhou *et al.,* 2018:5). As with resilience, a variety of emphasis is placed on its components and attributes. In this regard, there is no universally accepted approach to managing or enhancing resilience. When generic approaches are available (Leviäkangas & Aapaoja, 2015:3), some tools are found to be applied across systems and subsystems. It is promulgated in the Constitution of the Republic of South Africa that various levels of government have legislative responsibilities concerning airports, roads, traffic management, and public transportation (DoT, 2020-2025). Each level of government is responsible for legislating and implementing a particular function of transportation. The Department of Transport oversees state and local public entities that carry out transport functions on a national level. Various public entities have different delivery mandates. Research, development of legislation, and delegation of responsibility to government agencies are all things that the Department can do in this area (DoT, 2020-2025), establishing guidelines and standards, regulating implementation, and monitoring progress.

Following the Department of Transport (2022:127), policies in the transportation industry must consider the needs of society, transport users, and the economy, needs which transportation must support, when formulating policies. As a catalyst for development or as a means of correcting spatial distortions, the transport industry plays a leading role in many different ways. Per the "avoid shift-improve" paradigm, transport policies should aim to reduce distances and minimise unnecessary motorised travel (Government Gazette, 2022). With increased motorisation, there is anticipation to shift towards safer, more efficient, and environmentally friendly modes of transportation, as well as smarter, cleaner, and more efficient technologies and practices in transportation infrastructure and management. In all policy decisions relating to transportation, the environmental, social, governance, and economic implications will be considered (Government Gazette, 2022).

Developing resilient road transport infrastructure networks begins with measuring their resilience. This is the first and most crucial step. Hosseini *et al.* (2016:50) summarised the state-of-the-art methods for measuring system resilience and identified qualitative and quantitative approaches for achieving this. The fact that these methods all concentrate on one type of transportation system only, although they possess several advantages, makes them all fall short (Wang *et al.,* 2020:2). There is no numerical description of the resilience of a system in the qualitative assessment approach. In this type of assessment, experts evaluate qualitative aspects of resilience or formulate theories to suggest best practices to enhance resilience. To optimise the resilience of a system, quantitative methods use structural-based modelling, as described by Hosseini *et al.* (2016:50) and Wang *et al.* (2010). Xu *et al.* (2022:4) have demonstrated that quantitative indexes can effectively identify road vulnerability.

Transportation can be made more resilient to climate change by increasing its capacity to embrace it. Through implementation of governance models to facilitate the resilience measures in road transport systems. As well as build technical expertise in resilient transport and provide knowledge products and exchange opportunities to enable the mainstreaming of resilient transport globally through the collaboration of disaster management and transportation experts. As part of the programme, assessments are developed, technical knowledge is built, and support is provided to implement resilient transportation projects. Developing a comprehensive geospatial data infrastructure for road asset management to improve road maintenance and operation efficiency and effectiveness. By doing so, transport sectors can determine which roads are most prone to natural hazards. This enables them to take preventative measures using early warning systems and risk management strategies (Nipa *et al.,* 2022:111).

Risk reduction and vulnerability are often not prioritised when road networks are designed, exposing them to extreme weather events. The concepts of adaptability and resilience have become increasingly prominent in research as the focus shifts from reducing vulnerability to improving the resilience of road networks. In recent years, more attention has been paid to the ability of roads to withstand flooding. Despite being recognised, these hazards are often not addressed until after their occurrence (Xu *et al.,* 2022:17). As a result, this study examined the resilience of South Africa's road infrastructure to floods through the lens of resilience theory. Mitigation, preparedness, response, and recovery are the four phases of disaster risk management. Enhancing one or more stages of disaster recovery in a transportation system can lead to a more resilient system. An important aspect of mitigation strategies is to revamp the transportation network to be more resilient to alterations, especially the most vulnerable parts. While disasters are not always preventable, or retrofitting is too costly, being prepared at the pre-disaster stage will be advantageous during recovery and response. In the aftermath of a disaster, temporary measures are often taken, such as counter-flows to support disruptions in metro networks. As a result of the actions above, disaster impacts can be mitigated, and subsequent failures can be avoided. According to Zhou *et al.* (2018:2), restoring the original state can be achieved by eliminating response and performing recovery actions. Furthermore, the recovery plan must consider the original infrastructure and condition before the disaster to ensure success.

Ganin *et al.* (2017:5) have noted that resilient infrastructure systems can respond adaptively to threats and adapt in response to stress. A liquefaction-induced lateral spread of embankments and landslides renders roads impassable. A network's resilience is determined by its damage and continued access, as well as the outage (when the network is in a state of failure). Because of safety, disruption, loss of emergency service access and the need to restore lifelines, several factors may influence roadways' tolerable level of resilience. Having transportation networks in place during and after significant hazard events, such as flooding, is essential to a community's response and recovery efforts. In the event of significant natural hazards, transport networks should be capable of maintaining functionality (Bhamra, 2015:125). A resilient road transport infrastructure is essential to maintaining a sustainable built environment. A climate-resilient road transport infrastructure considers projected future climate effects, the inherent characteristics of transportation and socio-economic and socio-political considerations. By understanding these external, internal, and contextual dimensions of resilience, infrastructure administrators can develop adaptation projects suitable for specific hazards and systems. A failure to make these adaptations will result in widespread challenges posed by climate change effects such as intensive rains and floods to threaten the long-term existence of transportation infrastructure systems (Martello & Whittle, 2023:82).

3.7.1 The role of technology and innovation in enhancing resilience and public-private partnerships in funding and implementing resilience measures

Through the use of emerging and digital technologies, critical infrastructure can be assessed and supported in order to improve its climate resilience. The implementation of multidisciplinary roadmaps, along with the use of computational technology, communication technology, tools, and monitoring systems, is essential in this pursuit. Although these emerging technologies are promising, they remain underutilised due to a lack of consensus, integrated approaches and legislation that supports their implementation (Argyroudis *et al.,* 2022:1-3).

Innovative technology enables resilience evaluations to be conducted more efficiently, rapidly, and accurately, thus enabling better decision-making before, during, and after hazards. With near real-time agent-based modelling that incorporates both impacted infrastructure systems and interconnected infrastructure systems in the event of a flood, the use of innovative technology improves access to a destination during a flood (Battegazzorre *et al.,* 2021:3-5), thereby simulating realistic scenarios involving disaster-affected transport infrastructure (networks). In resilience analytics, there are three fundamental components: descriptive, predictive, and prescriptive models that are used to leverage resilience (Linkov & Trump, 2019). A visualisation of key infrastructure performance through innovative technology can assist in determining the impact of connectivity on decision-making, which ultimately facilitates determination of priorities (Argyroudis *et al.,* 2024:3-5).

Defining roles and responsibilities in public-private partnerships ensures effective accountability. Collaboration between both the government and private critical infrastructure operators is a useful approach to enhancing resilience. While it is the government's responsibility to safeguard critical infrastructure and citizens from disasters, they also involve private infrastructure owners. Due to the essential nature of the services and products offered by private sector operators, they are also responsible for ensuring the resilience of these infrastructures. In order to enhance the resilience of critical infrastructure, the government is usually responsible for leading the initiative with the support of private entities. Ampratwum *et al.* (2022:1) emphasise the importance of assigning responsibilities to each stakeholder involved in RTI implementation. Stakeholders such as governments and private infrastructure operators must cooperate to ensure road transport infrastructure's resilience. Ampratwum *et al.* (2022:1-2) argue that resilient infrastructure requires cooperation between the government and the private sector.

3.8 CONCLUSION

To provide a clear understanding of resilience, this chapter reviewed the concept from the perspective of different disciplines of study, as well as from the perspective of transport literature, to provide a thorough understanding. Furthermore, the study discussed the facets and aspects of resilience. A review of the literature presented in this chapter shows that resilience is not a universal concept as definitions vary from discipline to discipline. For several reasons, academic disciplines and sectors have differed in their interpretations and definitions of resilience. In modern societies, threats pose an enormous challenge, which makes resilience even more valuable regardless of the field of study. Although it acknowledges the difficulty in establishing the basis for the question, this study propounds that the answer depends on contexts such as those of groups, individuals, communities, and environmental factors. In some cases, all of these contexts must be taken into consideration in research. Moreover, the chapter evaluated recent methods for ascertaining road infrastructure resilience. Relatively few studies have analysed the resilience of road transport networks. Transportation systems must be designed for resilience from a systems perspective. Resilience cannot be built solely by direct transportation infrastructure; human relationships and collaborative efforts play an important role. Finally, the complexity of the issue must be unravelled by academics.

By examining how transportation systems are affected by various disturbances, ranging from daily fluctuations to rare disasters, some concepts have been applied to investigate how their performance is impaired. The concept of resilience, among others, has gained considerable traction in recent years. Moreover, extreme weather events threaten road transport infrastructure and are likely to become more severe over time. As a result of the loss of transport facilities and road network infrastructure, disaster management may be compromised, and evacuation may be delayed. Moreover, disasters provide opportunities for changing systems and addressing undesirable circumstances.

CHAPTER 4. THE RESILIENCE OF ROAD TRANSPORT INFRASTRUCTURE TO FLOODS IN SOUTH AFRICA: EMPIRICAL FINDINGS

4.1 INTRODUCTION

The main purpose of this study was to evaluate the resilience of South Africa's road transport infrastructure (RTI) to floods. This chapter analyses and discusses the main empirical findings of the study. The third and fourth objectives of the study are addressed in this chapter. Objective 3 focused on assessing the participants' perspectives on road transport infrastructure resilience**,** existing flood resilience measures and response strategies within the South African road transport sector. Objective 4 evaluated South Africa's RTI resilience using the R4 (robust, redundancy, resourcefulness, rapidity) resilience framework. The chapter builds on preceding chapters synthesising the literature on resilience, specifically the impacts of floods on road transport infrastructure (Chapter 2) and road transport infrastructure resilience (Chapter 3). Chapter 3 focused on the theoretical conceptualisation of resilience about RTI, emphasising the R4 framework for resilience. Additionally, it discussed the different approaches used in measuring the resilience of RTI and the factors that affect their performance. The two chapters form the basis of the analysis and discussion of the findings presented in this chapter. This chapter is structured as follows: firstly, the introduction, a summary of the research methods applied, presentation of the findings with the main focus on the participants' view on South African road resilience to floods, understanding of robustness, redundancy, rapidity and resourcefulness in RTI climate-change-adaptation approach to road construction in South Africa.

4.2 A SUMMARY OF THE RESEARCH METHODS APPLIED IN THE STUDY

This section summarises the research methods used in the study, including the research design, sampling strategy, data collection techniques, and data analysis procedures. A more detailed account of the research methodology is provided in Section 1.4 of Chapter 1. The study adopted a mixed-methods research design to obtain a comprehensive understanding of participants' perspectives. As Morse (2010:484) notes, mixed-methods research integrates both meaning and measurement, enhancing the depth and breadth of inquiry. This approach combined quantitative and qualitative methods, based on the recognition that neither alone would be sufficient to fully explore the complexity of the research problem. The mixed-methods design was selected because of its complementary strengths (Tashakkori & Creswell, 2007:5) with the quantitative component offering statistical precision and the ability to generalise findings (Creswell, 2015), while the qualitative component provided deeper insights into human behaviour and contextual factors.

Specifically, an exploratory mixed-methods design was employed in this study. The qualitative data were collected and analysed first, and the findings informed the development of instruments for collecting quantitative data (Brannen, 2009:8-12; Creswell, 2009:197; Creswell, 2015). Qualitative data was collected through face-to-face interviews with the key participants. Meanwhile, quantitative data was collected through an online survey. Given that all participants in both the face-to-face interviews and online surveys were professionals involved in the road transport infrastructure sector, non-probability sampling techniques, specifically purposive and snowball sampling were employed to ensure the selection of individuals with relevant expertise, experience, and contextual knowledge. The sampling process began with purposive sampling to identify key informants, followed by snowball sampling to reach additional participants through referrals. This approach facilitated the identification of key systems and their interdependencies, contributing to a deeper understanding of road transport infrastructure resilience in real-world settings.

The study captured diverse perspectives from participants with varying levels of knowledge and experience. These included officials from the South African National Roads Agency Limited (SANRAL), the Department of Roads and Transport, the Council for Scientific and Industrial Research (CSIR), Leo Consulting, AG Traffic and Transportation Engineering Consultancy, and the South African Road Federation (SARF). A total of 14 participants took part in face-to-face interviews, while 16 individuals completed the online survey, despite it being distributed to over 30 potential respondents. Notably, five participants who were interviewed also completed the survey. In total, 25 unique individuals contributed to the study. The quantitative survey was administered to the broader sample to assess whether the themes and findings from the qualitative phase could be generalised to a wider context.

The collected qualitative data has been organised and presented using thematic analysis (Chapter 1, section 1.4.5). Using thematic analysis (TA) makes it possible to identify, analyse, and interpret patterns of meaning within qualitative data (Clarke & Braun, 2017:297). By performing a TA on a collection of interviews, the study was able to identify the common threads systematically. Thus, focusing on implicit and explicit ideas within the data, thematic analysis goes beyond counting explicit words or phrases (Guest *et al*., 2012:9). One of the distinctive features of TA is its flexibility. This is not only in terms of its theoretical flexibility but also in its approach to data collection, sample size composition, and meaning generation strategy. TA allowed the researcher to identify patterns in data related to participants lived experiences, opinions, beliefs, and behaviours (Clarke & Braun, 2017:297). Furthermore, graphs and tables were used in descriptive statistics to present quantitative findings (Kaur *et al.,* 2018:62; Sharma, 2019:4). Both closed-ended and open-ended questions utilising Likert scales were used to collect quantitative data (Annexure C). This study phase utilised descriptive statistics to determine the relative prevalence and importance of each dimension (Creswell & Clark, 2011). Table 4.1 below presents statistical information on the respondent profile from face-to-face interviews and online surveys.

Table 4.1: Participants' codes

Name of institution	Position	Code
South African National Roads Agency Limited (SANRAL)	Engineer 1	Eng 1
	Engineer 2	Eng 2
	Engineer 3	Eng 3
	Engineer 4	Eng 4
	Network Planning Manager	NetpM 1
	Project Manager	ProjM 1
	Project Manager	ProjM 2
	Project Manager	ProjM 3
	Project Manager	ProjM 4
	Environmental Personnel	Envi 1
	Environmental Personnel	Envi 2
	Bridge Technician Specialist	BriTS 1
	Project Manager	ProjM 5
AG Traffic and Engineering Consultancy Transportation	Managing Director	MD 1
	Engineer	Eng 5
South African Road Federation (SARF)	CEO	ActC 1
	Stakeholder Manager	StakeM 1
	Researcher	Res 1
Department of Roads and Transport	Engineer	Eng 6
	Engineer	Eng 7
	Environmental Personnel	Envi 3
	Road Disaster Manager	Rdm 1
	Engineer	Eng 8
Leo Consulting	Engineer	Eng 9
The Council for Scientific and Industrial Research (CSIR)	Senior Researcher	SenR 1

Source: Author's construct

4.3 PRESENTATION OF FINDINGS AND ANALYSIS

This chapter presents the findings derived from semi-structured face-to-face interviews and online questionnaire surveys conducted with senior officials from national and provincial road agencies. The qualitative data were transcribed verbatim, carefully reviewed, and systematically coded to identify recurring themes and patterns. These findings are organised thematically to provide a coherent and in-depth understanding of the perspectives and experiences of participants. The chapter is structured around the R4 resilience framework, Robustness, Redundancy, Resourcefulness, and Rapidity which serves as the central analytical lens for interpreting the data. The use of this framework enables a focused analysis of institutional, technical, and operational dimensions of resilience in road transport infrastructure (RTI). Each main theme corresponds to one of the four resilience components, while the associated subsections represent sub-themes that emerged during the analysis (see Table 4.2 for a summary).

This thematic structure allows for a nuanced exploration of both the challenges and opportunities identified by participants, shedding light on the internal dynamics of road agency operations and their implications for developing a resilient transport infrastructure system. Through this approach, the chapter builds a comprehensive narrative of how resilience is understood, prioritised, and implemented across different institutional levels.

Table 4.2: Themes/concepts and sub-themes/sub-concepts that emerged from the study

THEMES/CONCEPTS	SUB-THEMES
Understanding resilience in road transport infrastructure	Participants' view on South African road transport infrastructure's resilience to floods
	Integrating resilience to infrastructure design, maintenance, and management
Road Robustness	Understanding robustness in road transport infrastructure
	Techniques to improve road drainage and flood prevention
Road Redundancy	Understanding redundancy in road transport infrastructure
	Planning alternatives in case of emergencies
Road Rapidity	Understanding rapidity in road transport infrastructure
	Challenges that arise when implementing road rapidity
Road Resourcefulness	Understanding resourcefulness in the transport sector
	Pointers on selecting roads and bridges for maintenance
Adapting road construction to withstand climate change impacts	Negative impacts of floods on the transport system
	Measures that can be taken to reduce the risk of road damage
	Climate-change-adaptation approach to road construction in South Africa

Source: Author

4.3.1 Participants' profile

As mentioned in the previous sections, a total of twenty-five participants took part in this study. These comprised nine engineers, three environmental professionals, five project managers, one road disaster manager, one CEO, one bridge technician, one laboratory technician, one managing director, one network planning manager, one researcher, and one stakeholder manager. The participants' experience levels were varied: 32% had 11-20 years of experience, 32% had 5-10 years, and 20% had less than five years of experience. Additionally, 4% reported having 30-39 years of experience, 8% had 21-29 years of experience, and another 4% had more than 40 years of experience. Participants held a wide range of academic qualifications, from undergraduate degrees to doctoral levels. The study captured the participants' perspectives based on their varied professional experiences and expertise, reflecting a broad array of roles, with engineers, managers, and environmental specialists being particularly prominent.

4.3.2 Understanding resilience in road transport infrastructure

The findings in this theme are presented under two sub-themes, as discussed below.

4.3.2.1 Participants' view on the resilience of South African RTI to floods

The face-to-face interviews revealed that participants (n=40%) demonstrated a reasonable understanding of road transport infrastructure (RTI) resilience. Their responses generally align with the fundamental principles of resilience, particularly in terms of preparedness for disasters**,** engineering standards**,** and climate adaptation. Several (n=36%) participants linked resilience to infrastructure safety, disaster preparedness, and security, reinforcing a multi-faceted perspective. A noteworthy insight comes from ProjM 1, who uniquely associated road resilience with the United Nations Sustainable Development Goals (SDGs), particularly Goal 9 (Industry, Innovation, and Infrastructure). The participant stated that "*road resilience is having to do with the United Nations Sustainable Development Goals*" (ProjM 1). This demonstrates an awareness of global policy frameworks, though it is striking that only one respondent made this connection. This suggests a gap in awareness among other participants regarding global resilience policies and frameworks guiding infrastructure development.

Despite a generally sound grasp of resilience, several misconceptions and inconsistencies emerged. Some participants argued that South African roads are resilient because they are built according to international engineering standards. However, ProjM 5's example—that "*roads crossing mountains follow engineering standards*"— focused more on design principles than resilience. This highlights a common misconception because meeting engineering standards does not automatically equate to resilience if maintenance, climate change adaptation, and long-term sustainability are not adequately considered. Furthermore, some interviewees suggested that resilience is naturally embedded in infrastructure due to standardised construction practices. However, the KZN flood damage in 2022 directly contradicts this assumption (IFRC, 2023:2-3). The discord between perceived resilience and real-world failures suggests that some participants overestimate the current state of infrastructure resilience in South Africa**.**

However, some participants (n=32%) had differing views, indicating that some roads and bridges are not resilient. In this regard a specific reference was made to the KZN roads heavily affected by floods in 2022. This was supported by other participants who said that, in general, the country's RTI is inadequate to withstand flooding. Also, ProjM (1) said that *"since South Africa is still a developing country, its infrastructure is not resilient enough to withstand the effects of climate change".* Furthermore, the respondent stated that as South Africa is still in the process of achieving SDGs, it is unlikely to meet these targets by 2030 because there is still much to do. Despite some differences in explanations, the participants showed a clear understanding of road resilience. In most cases, resilience was explained as the infrastructure's ability to withstand and adapt to external pressures, such as floods and accidents.

There was convergence between qualitative findings and quantitative results. As it can be seen in Figure 4.1 below, over 43% (31.25% agreed, and 12.50% strongly agreed) of participants believed that South African roads were resilient to floods. In contrast, over 31% (25% disagreed and 6.25 strongly disagreed) of participants were disputed that South African road transport infrastructure is resilient to floods.

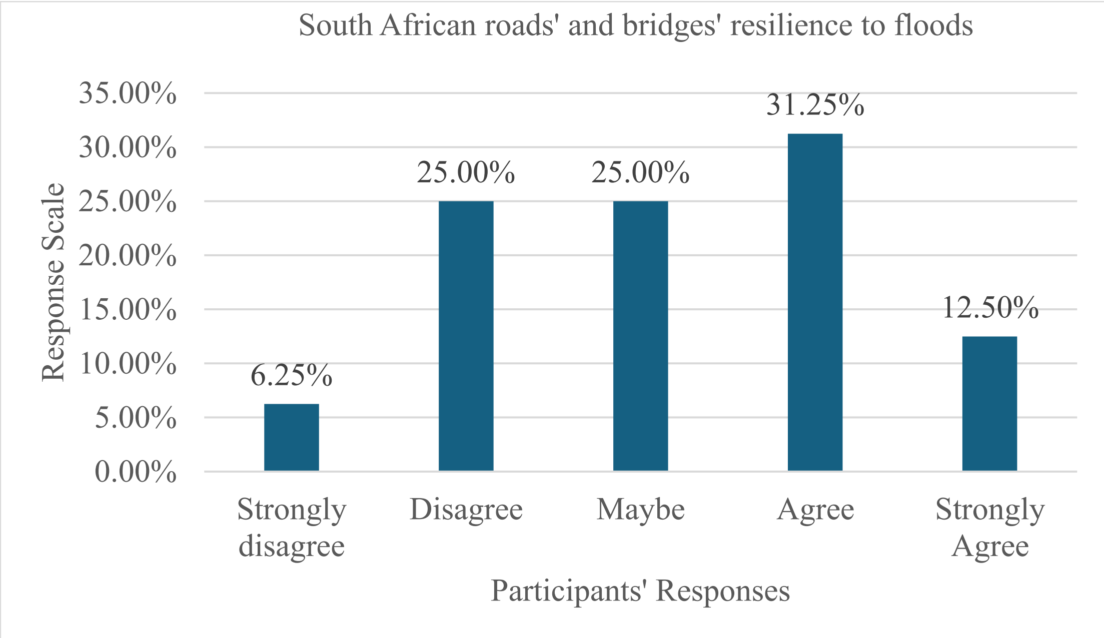


Figure 4.1: Participants' perspectives on RTI resilience to floods (Source: Data from interviews, 2024)

Remarkably, 25% of the participants were unsure if the South African road transport infrastructure was resilient. Statistical results indicated that the difference between those who believed the road transport infrastructure was resilient to floods and those who do not, was marginal, 43.75% versus 31.25%, respectively.

Overall, both qualitative findings and quantitative results showed that participants generally understood the concept of resilience in relation to road transport infrastructure but had varying interpretations, with gaps in knowledge about institutional, policy, and socio-economic dimensions. For example, above 43% of the participants indicated that South African roads and bridges are resilient to floods. This contrast mirrors broader debates in resilience literature, where some scholars emphasise technical and engineering-based resilience, while others focus on institutional, financial, and adaptive capacities. Their responses differ due to different departments they work under. This lack of consensus is well noted by Herrman *et al.* (2011:259) who state that there is no consensus on the operational definition of resilience. Importantly, some participants overestimated the resilience of South African RTI, possibly due to a focus on engineering design rather than real-world performance. This necessitates further education and awareness on how resilience extends beyond engineering to governance, climate adaptation, and long-term sustainability. It also points to a broader scholarly challenge of the need to provide a universal definition of resilience (Walsh-Dilley & Wolford, 2015:174; Weichselgartner & Kelman, 2015:251).

4.3.2.2 Integrating resilience into infrastructure design, maintenance, and management

During face-to-face interviews, participants provided varied perspectives on the integration of resilience into road transport infrastructure (RTI) design, maintenance, and management. A significant majority of the participants (48%) emphasised that roads should be designed to meet daily needs (transporting people between points A and B) and to be improved by utilising innovative technology such as early warning systems, to enhance resilience. Such perspectives highlight an understanding of rapidity within the R4 framework, as timely communication of potential disruptions can improve responsiveness and preparedness.

Further, participants indicated that the current materials used in road infrastructure construction are not sustainable as they contribute to increasing greenhouse gases. Therefore, there is a need for change in current practices to achieve resilience. Given this, some participants mentioned that there is a need to follow green building principles and the use of nanotechnology. Also, the process of using waste produced by human beings to reuse it as road building material and reusing asphalt. Participants further stated that enhancing resilience to extreme weather events requires improvement of road design. To be precise, one key respondent alluded that "*It is challenging to meet resilience standards because of the high associated cost and unstable weather patterns, however all designs are intended to cater for extreme weather conditions, but we fall short"* (Eng 8).

Moreover, SenR 1 indicated that RTI resilience could be improved through research. In the same manner, the participants pointed out that when designing the RTI, hydrologists assist in determining the flood history of a particular area. Furthermore, some participants indicated that it depends on the intended use and the level of the RTI design. For example, SANRAL has Class 1 and Class 2 roads. Class 1 roads have return periods of 100 - 200 years (overtopping) and Class 2 roads have return periods of 50 - 100 years (overtopping). There have, however, been some transfers to class 3 roads (maintenance of certain provincial roads has been assigned to SANRAL). Their classification determines return period for roads; other factors may also influence return periods, including their cost, their risk of failure.

In addition, (n=16%) highlighted the impact of unregulated development near roads, which exacerbates flooding by diverting storm water into drainage systems, causing blockages and failures. Thus, the DRAINAGE MANUAL must be consulted, and all RTI must be maintained following their maintenance systems (SANRAL, 2013). The drainage manual is used in South Africa as a guide when building roads and bridges, and one of the participants stated that *"the manual serves as the bible for storm water management"* (ProjM 1).

Climate change emerged as a significant factor influencing future infrastructure resilience. One participant (Eng 3) stressed the need for a tailored strategy to address rising temperatures and extreme weather conditions. This illustrates the need to develop a tailored strategy based on climate change, rising temperatures, and how much quantification should be implemented, meaning that these adaptation strategies should be incorporated into standard practice to achieve climate resilient RTI in the future. As part of a climate change policy developed in 2018 (Climate Change Bill), the South African government set five-year sectoral emission targets (SETs) for each sector that emits greenhouse gases every five years (Zheng *et al.*, 2019:1127). One of the participants asserted that this historical information would assist in determining or predicting future weather conditions. It will then be possible to determine the adaptation strategies required to construct a resilient road transport infrastructure. Therefore, to design and plan proper resilient road transport infrastructure, it is necessary to consider information on historical climate hazards.

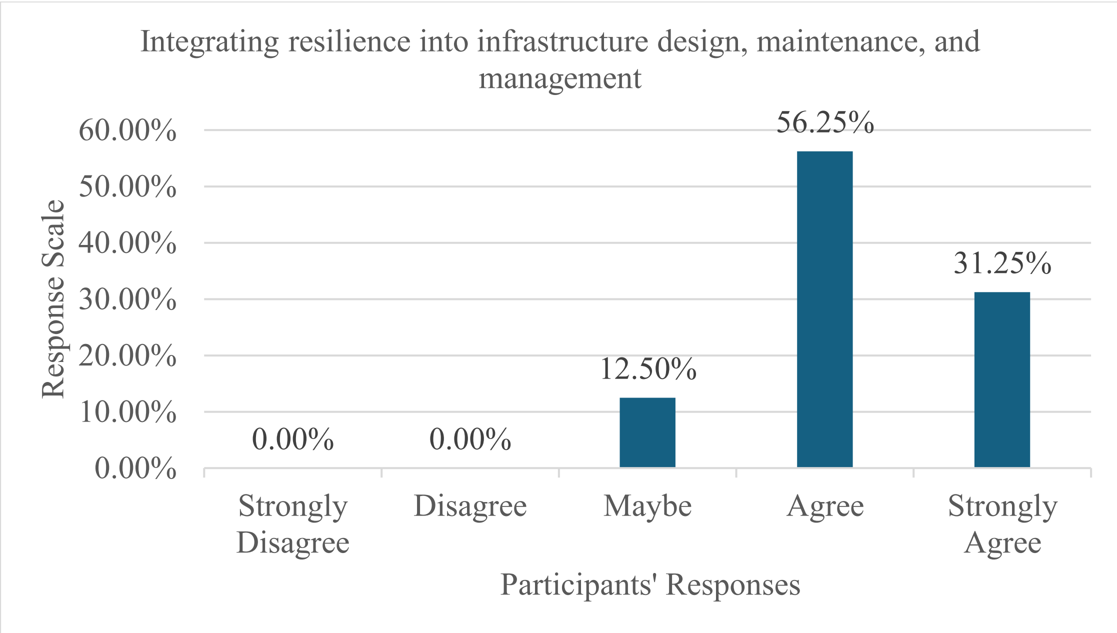


Figure 4.2: Integrating resilience into infrastructure design, maintenance, and management (Source: Data from interviews, 2024)

The responses from the online survey demonstrated that a combination of those who agreed and strongly agreed amounted to 87.5% in favour of improving road designs to enhance resilience against extreme weather conditions. However, 12.5% of participants remained undecided. It is clear from the above analysis that most participants supported the development of RTI designs capable of withstanding extreme weather conditions.

The face-to-face interviews and the online survey findings show a strong convergence. In line with qualitative findings, the online survey results showed that participants have a comprehensive understanding of the importance of integrating resilient infrastructure in the transport sector. Moreover, they recognise that resilient infrastructure has the potential to offer a variety of benefits within the transport sector. These findings correspond with Zhou *et al.* (2019:4262), who indicated that a well-designed transport system is capable of withstanding interruptions from day to day and maintaining their functions in the face of such fluctuations.

4.3.3 Road robustness

The first key element of the R4 (Road Robustness) is presented in this section. As it pertains to transport infrastructure, robustness refers to an RTI's ability to function despite hazards occurring, to limit direct and indirect economic loss (He *et al.,* 2021:2). The findings in this element are presented under two sub-themes, as discussed below.

4.3.3.1 Understanding robustness in road transport infrastructure

During the face-to-face interviews, participants (n=40%) indicated that durable materials are incorporated by engineers to design robust RTI. According to the participants, a robust road can handle the traffic it was designed to accommodate. For example, participants emphasised that roads are a major mode of transportation in SA (overloaded trucks exerts pressure on the roads). Indicated further was the need for effective compliance (road engineering standards) by parties involved in awarding RTI contracts. Several decades of research, empirical data, and lessons learned from failures have been incorporated into these standards. In this way, the robustness of roads and bridges is determined by predefined performance, safety, and resilience criteria. By adhering to road engineering standards, road robustness may be ensured. In addition, Rdm 1 raised the issue of political interference and funding obstacles in RTI construction, which leads to insufficient performance by hindering the construction of more robust RTI. It was further indicated that traffic load (overloaded trucks), intensive rain and flooding could erode the road base and cause potholes. The participants also underscored the importance of giving engineers more authority without external interference (i.e. political interference with RTI construction). There is an apparent desire for politicians to be involved in the award of RTI contracts. Construction of robust RTI is more costly, which is exacerbated by an already over-burdened economy.

One of the most important considerations is to ensure that roads contribute to economic development. Participants stated that to ensure economic growth, movement of goods should not be interrupted, which leads to the need for robust roads. According to Eng 10, "*in order to ensure safety, all roads are designed with different speed zones, which is why there are different speed limits on each" (achieving robustness).* It is evident that speed is influenced by a variety of factors, including road design, speed limits and their enforcement, traffic control, signs and markings, etc. This, in turn, influences road safety (Hauer, 2009:10). For example, the N3 was mentioned as part of RTI implementing robust design elements.

Participants indicated that N3 projects enhanced robustness through the Sustainable Road Forum Tool (SURF) which measures elements of road sustainability. In the context of the N3 (pilot project), a collaborative effort was made between the Department of Transport, the engineering industries, the CSIR, and SANRAL. The project used less materials (water, asphalt, cement, to name a few) to construct RTI, which is the key to long-term sustainability. In addition, the ring road in Limpopo Polokwane and the N12 are also noteworthy for their robust design (Eng, 9). For example, the materials used in the construction of these roads contribute to their robustness. Several participants further indicated that robustness can be achieved depending on the function and the type of road. Under the design recommendations (robust) from the South African road drainage manual, the thicker the design is, the stronger the layers. In addition, more participants indicated that they rely on guidelines, standards, and practices developed based on prior research. Lastly, the participants indicated that all roads are designed with safety elements. This is done through conducting safety audits pre-construction; such can be witnessed from different speed limits on various types of roads signs. In return, motorists are alerted through warning signs, which limit accidents. These are some of the factors considered when designing road transport infrastructures to be robust.

Robust transport systems should retain their original properties and continue functioning during and after hazardous events like floods. Accordingly, the current practices are insufficient to achieve robustness within road transport infrastructures, and the process is weak. This is so because not every RTI in the country is robust. For example, SANRAL's techniques are consistent with the latest research and best international practices, as discussed in section 3.6.1. As a result, road infrastructure organisations ought to ideally learn from SANRAL's measures which they undertake to ensure robustness. In addition, legal measures should be implemented to ensure consistency in providing road transport infrastructure. Lastly, there is also a need to address the political interference in contract awarding that undermines RTI's robustness objectives.

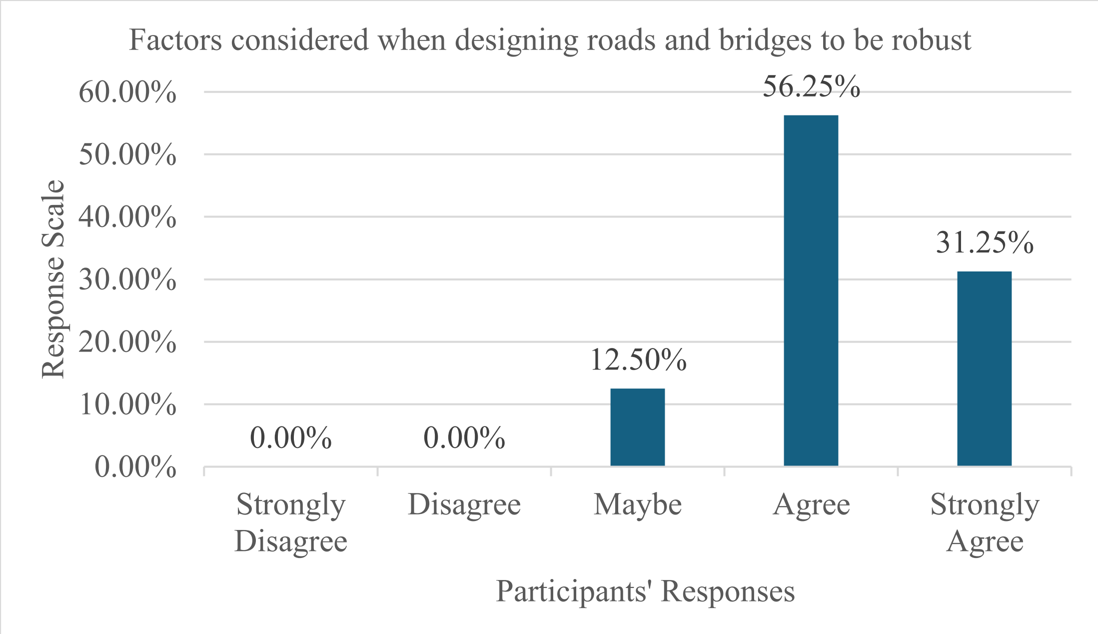


Figure 4.3: Factors considered when designing roads to be robust (Source: Data from interviews, 2024)

Most aspects of the responses provided from the online survey were consistent with those provided in face-to-face interviews. However, there is a small variation in factors considered when designing RTIs to be robust. In support of this, the survey indicated that the difference between factors considered when designing RTIs to be robust and those not considered (designed with safety element such as warning signs, research, pre-construction safety audits) is relatively small at 81,2% versus 18,7% respectively. As represented in Figure 4.3, 87,5% indicated that all roads are designed with safety element (warning signs), being able to warn motorist, research, to name a few. Also, to ensure safety, authorities are required to conduct pre-construction safety audits, except for a few varied responses.

4.3.3.2 Techniques to improve road drainage and flood prevention

Project managers emphasised the significance of conducting research to achieve an effective road drainage system. While engineers also stressed the importance of surveying the area, to determine the level of the storm water drainage. Moreover, SenR (1) further elaborated that research reports can assist in determining specifics of the inlet and outlet pipes to prevent RTI floods. Sandbanks are used to improve road drainage and prevent floods as a temporary measure. Thus, road robustness contributes to road safety.

Moreover, geological specialists determine the underlying geology which relates to road stability, which assists engineers in constructing with suitable materials. This facilitates the decision-making process involved in enhancing road project robustness. Likewise, ProjM (4) indicated that engineers must identify the source (topographical survey to understand the terrain) and quantify them to ensure sustainability. Performing hydrological studies inform the type of material available in the area, and whether they are suitable for road construction. For instance, it was indicated that SANRAL has a laboratory that tests all RTI construction materials before they are approved. In addition, engineers prepare traffic impact assessments (TIA) and import sound material. This assessment provides information concerning how much traffic will normally traverse the road and E 80s (load exerted by the road) load. An analysis of this kind is useful for determining a road's capacity for handling the expected traffic volume, as well as its structural integrity over the long term.

Participants further indicated that maintenance should be prioritised to ensure robustness of a busy road. Each road must be maintained. By doing so, it will remain in good condition and sustain robustness. Nevertheless, some engineers indicated that maintenance on a busy road can be challenging. As a solution, traffic may be diverted, or a single lane may be used while the other lane is being maintained. For this to happen, some participants revealed that engineers assess the contractor's proposed traffic accommodation plan, focusing on the workload distribution method, to determine its suitability for approval. Following the engineer's review and incorporating their feedback, the board will consider and approve the plan depending on its feasibility. The interviewees indicated that transport robustness refers to assessing the road's ability to withstand hazards. As Chapter 3: section 3.6.1 indicated, robust systems perform well when subjected to high stress.

4.3.4 Road redundancy

This section addresses the second key element of R4 (Road Redundancy). According to Argyroudis (2021:2), redundancy in transportation infrastructure refers to the availability of multiple routes to an original destination (Domaneschi *et al.,* 2019:2192; El Rashidy, 2014:82). The findings in this element are presented under two sub-themes as discussed below.

4.3.4.1 Understanding redundancy in road transport infrastructure

The participants' conceptualisations clarified road redundancy or what they considered in terms of road redundancy. While some participants (n=48%) highlighted that alternative roads exist but are not constructed for alternative purposes (an existing road becomes an alternative in case of an emergency). For instance, according to Envi (1), *"Limpopo has N1 and R101, whereas KZN has N3 and R102, and Johannesburg has N1 and N3 which form a ring road around the city".* It is, however, not always possible to construct an alternative road because some areas may not be suitable for such construction. For example, the findings indicate that it is difficult to construct alternative roads in the Western Cape due to the terrain between the sea and mountains. Due to its lack of alternatives, such a road is a priority if it is destroyed or damaged by floods. Hence, road redundancy would assist in diverting traffic during an accident or road maintenance in the case of Western Cape.

Eng (4) further pointed out that national roads have alternative routes, although some may be time-consuming and not meet national road standards. Funding is the major challenge in road redundancy. Eng (6) substantiated that it is extremely expensive to build RTIs for redundancy, thus it is impossible to build alternative routes purposefully. In addition, the study revealed that a challenge to redundancy is to expropriate land to construct alternative routes, for example, when a planned route development goes through residential areas. Also, whenever there is a route development in a residential area, there is a need to benchmark an alternative place for residence of that particular area. Furthermore, the location planned for RTI development might be a flat area. According to ProjM (5), flat areas are unsuitable for road construction (such roads are easily flooded). Prior to the development of the RTI, a thorough evaluation of the potential benefits and risks associated with this undertaking is conducted. Such considerations assist in avoiding the construction of white elephant roads (roads that will stay idle for many years). Constructing a road is an extremely expensive undertaking, thus traffic impact assessments are required to make informed decisions.

In Eng (6)' opinion, although alternative roads exist, they are not built for redundancy but for other purposes; this is so due to the cost associated with RTI construction. Similarly, the findings revealed that possibility of land acquisition being required for the construction of a new road for alternative purposes exists, which would be expensive and would lead to controversy, since some people and communities may not wish to sell their property. In addition, there will be construction costs associated with building a new route, as well as maintenance costs and environmental impact assessments. Hence, no road is built as an alternative but instead any road within the vicinity of the damaged or affected road becomes an alternative when necessary. Motorists in Limpopo, for instance, opted to use another road instead of R523 between Musina and Masisi, due to flood damage (redundancy justified) (Rdm, 1). A single lane was used during road widening in Port St Johns since a suitable alternative route was unavailable (Eng, 1). No road is constructed as an alternative to another, but whenever one is constructed, the old one serves as an alternative when necessary. In addition, participants indicated that alternative routes offer benefits such as easier access to affected populations during disasters, reduced travel times, and improved traffic at peak times. Considering the high cost of building new roads for alternative purposes, this study suggests that retrofitting existing roads to accommodate increased traffic and tunnelling or overpassing existing roads can increase road redundancy and reduce the requirement for additional land by increasing road redundancy.

As explained by ActC (1) the study's conceptualisation of road transport infrastructure redundancy (Chapter 3: section 3.6.2) involves designing a system that provides backup. In this case, the study's findings of road redundancy are similar to the explanations provided by Alcántara-Ayala *et al.* (2022:417), Domaneschi *et al.* (2019: 2192) and Argyroudis (2021:2). Since road redundancy is a vital component of any emergency response and recovery planning, innovative funding mechanisms should be implemented to ease the process. Among the leading indicators of a network's resilience is its redundancy, as stated by Anderson *et al.* (2011:26).

4.3.4.2 Planning alternatives in case of emergencies

Figure 4.4 indicates that those who agreed and strongly agreed to consider alternative roads during an emergency amounted to 25% and 43.75%, respectively (see figure 4.4). Therefore, 68.8% participants indicated that they always consider road redundancy in case of emergencies, whereas 18.75% indicated that they might consider it and 12.50% disagreed with the usefulness of alternative roads.

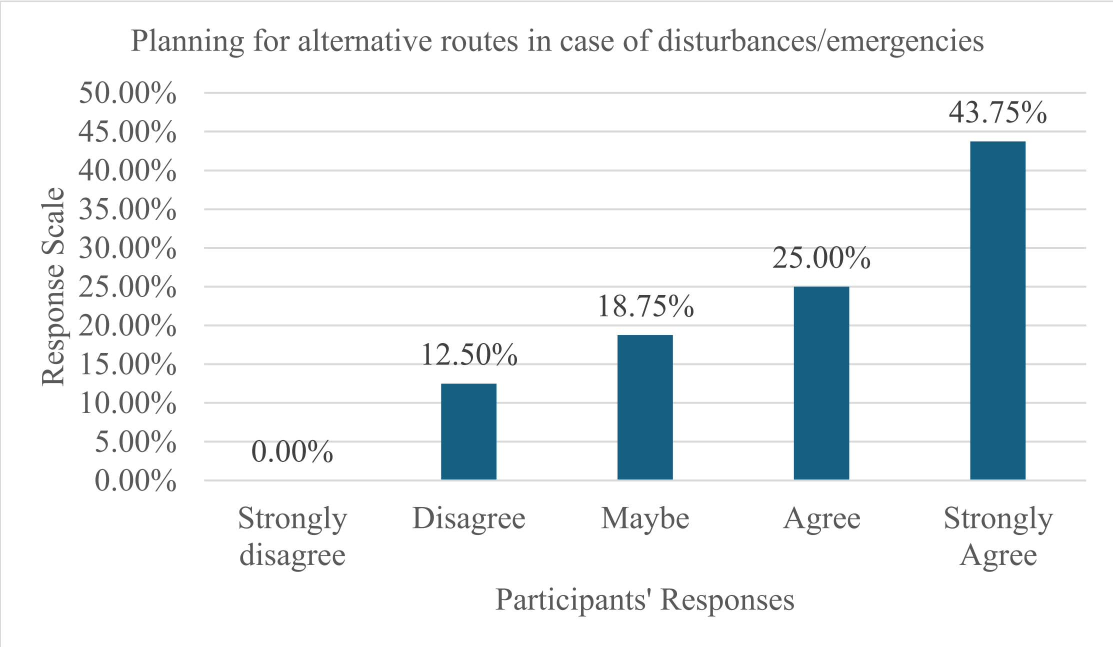


Figure 4.4: Planning for alternatives in case of emergencies (Source: Data from interviews, 2024)

The online survey results indicated that the difference between those aware of road redundancy and non-considerers of road redundancy is relatively immoderate 68.75% versus 31.25%. Thus, most participants understood the importance of road redundancy in increasing accessibility when an emergency occurs. Although road redundancy is relatively prevalent, a considerable number of individuals may not fully appreciate its significance. In emergency situations, road redundancy often serves as the only viable means of reaching certain destinations. The empirical findings reveal a lack of clear consensus across both the qualitative and quantitative data.

4.3.5 Road rapidity

The third key element of R4 (Road Rapidity) is addressed in this section. Following a significant event, rapidity in the transportation sector depends on the nature of the damage and the available resources (Argyroudis, 2021:2; Mitoulis *et al.,* 2021). The findings of the element are as follows: the first finding relates to the understanding of rapidity in road transport infrastructure, followed by the challenges that arise when implementing road rapidity.

4.3.5.1 Understanding rapidity in road transport infrastructure

In the face-to-face interviews (n=52%), participants described "road rapidity" as the speed at which a response is initiated to repair a damaged RTI. The participants emphasised that there is a statute (state of national disaster) permitting emergency projects to be undertaken to achieve road rapidity (ProjM, 3). This decree is implemented when the government declares a state of disaster in a certain area, depending on the extent of the damage sustained. Similarly, Rdm (1) elaborated that in the case of Modimmolle and Lephalale in Limpopo, for example, the issue of flooding caused a road and bridge to be washed away. Despite the evident need, the road authorities failed to allocate any funding. However, there was coordination between the government and a mining company, which provided funds to construct a temporary bridge within a month of the incident. The process of constructing a bridge took three months to complete, leading to an achievement of rapidity (Rdm, 1). The participants noted that the bridge was only designed to accommodate one vehicle at a time. Eight years after the incident, a large size bridge was constructed. The finding concurs with Argyroudis (2021:2) and Mitoulis *et al.* (2021) who state that the nature of the damage and availability of resources determine the degree of rapidity in the transport industry. Road transport institutions differ in their ability to achieve rapidity. For example, according to Eng (9) the Limpopo Road Agency had limited funds to repair a road damaged by floods in 2014. SANRAL, however, managed to fix the same road within five years of taking over. Additionally, SANRAL took 35 days to complete a section of the N2 that was washed away near the Bot River Bridge in the Western Cape (Eng, 7). Thus, SANRAL's rapid response accords with Bruneau *et al.* (2003:737) contention that a rapid process is characterised by improved robustness, redundancy, and resourcefulness.

A permanent solution for a damaged RTI may be available within two to three years or six months (NetpM, 1). Participant further emphasised that the appropriate solution is contingent upon the severity of the flood damage. Bridges take longer period to repair, whereas road repairs take less time. According to Rdm 1 *"we take time to provide solutions which results due to lack of funding and the number of people acquainted in terms of the process to rebuild."* Sometimes, the individuals responsible for handling disaster funds have insufficient knowledge of disasters. On the other hand, sometimes funds intended for flood response are diverted for other purposes. Thus, no funds would be available when flood incidents occur.

4.3.5.2 Challenges that arise when implementing road rapidity

Implementing the *rapidity* element of the R4 framework in road infrastructure projects presents several complex challenges. As highlighted by ProjM 1, these include the negative consequences of limited financial resources, delays in procurement processes, and civil unrest from communities demanding employment opportunities in construction projects. A particular concern is that local communities may lack the necessary skills for available roles, leading to tensions and project delays. Overcoming issues related to road rapidity is not straightforward. ProjM (3) suggested that greater community engagement and the reprioritisation of project plans could help accelerate implementation efforts. Additional concerns were raised by Eng (9), who pointed to procurement-related issues such as overspending and irregular expenditure. Furthermore, time- and resource-intensive activities, such as the removal of silt and debris beneath bridges, managing powerful hydrological forces capable of altering river courses, and forging partnerships between landowners and environmental authorities, further complicate rapid response efforts. ProjM (1) emphasised the need for competent personnel, sound financial management, and the development of reliable systems to support the rapidity dimension of road infrastructure resilience.

Moreover, Rdm (1) indicated that SANRAL is known for producing high-quality roads; however, political interference may impact their performance. ProjM (4) corroborated this view, stating, *"A fundamental problem in government lies in hiring incompetent personnel for strategic positions, corrupt officials, and limited state capacity"*, the participant further recommended appointing professional engineers to leadership positions, free from political agendas.

The South African Road Standard, established in 1996, mandated the reconstruction and maintenance of road infrastructure (Department of Transport, 1996). However, according to several participants, limited progress has been made in aligning current practices with this standard, largely due to shortcomings in decision-making. A recurring concern was that the existing road infrastructure is inadequate to accommodate the growing volume of heavy trucks, many of which should ideally be replaced by rail transport to preserve road longevity. Yet, the current limitations of the rail network have necessitated continued reliance on road freight, contributing to increased congestion, accelerated road deterioration, and heightened environmental impacts. Participants widely agreed that expanding rail infrastructure could serve as a long-term solution by facilitating a shift to a more sustainable and efficient freight system that reduces emissions and road wear while strengthening national logistics capacity. There was also a strong call to reduce truck overload and improve freight regulation. In comparative terms, some participants argued that South Africa lags significantly behind countries such as China and several European nations in the development of advanced freight and public transport systems. Echoing these sentiments, Eng (3) observed that "*it is more than about who heads what*; *it is about investing in proper infrastructures and retraining people on accountability"*.

These findings highlights that South Africa's road freight challenges are symptomatic of broader governance and planning deficiencies, not merely technical shortfalls. Truck overloading and freight regulation issues must be addressed alongside strategic investments in rail infrastructure, policy coherence across transport modes, and skills development. Comparisons to more advanced systems reveal untapped opportunities for reform, while participant insights reinforce the need for a shift in institutional mindset, from reactive, short-term fixes to proactive, integrated and accountable transport governance.

Furthermore, funding was regarded as an issue by the majority of participants. Conversely, some participants noted that there is a lack of enthusiasm among the responsible officials in the transport sector, coupled with political interference, which negatively affects the efficiency of rapidity (road reliability). Based on this observation, only one institution (SANRAL) aligns with Zhu *et al.* (2017:150) who assert that enhancing infrastructure resilience during disaster recovery requires a timely response. Making informed decisions reduce failure, risks and optimise resource utilisation. Having passionate individuals in leadership positions is a necessity, and there should be minimal interference from the political arena.

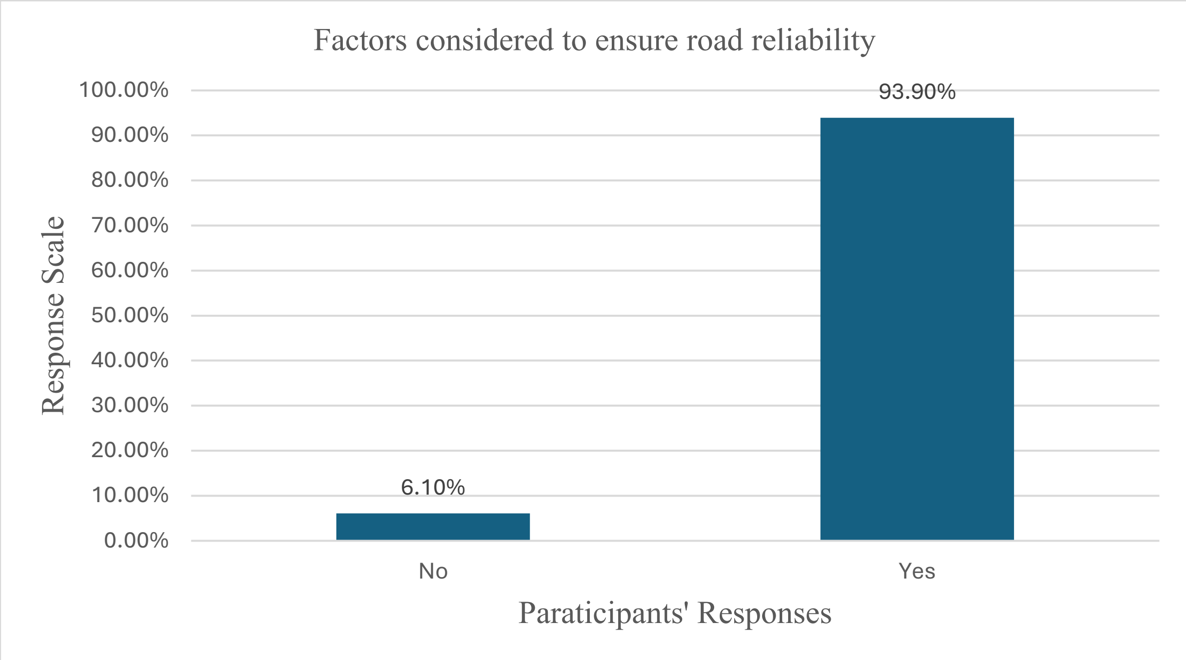


Figure 4.5: Participants' views on factors that ensure road reliability (Source: Data from interviews, 2024)

As illustrated in Figure 4.5 from the online survey, an overwhelming majority of participants (93.9%) expressed strong support for key measures to enhance road rapidity systems, specifically the appointment of competent individuals, prevention of fund misuse, and assurance of system reliability. Only 6.1% of respondents did not endorse these measures. This survey findings closely aligned with the insights gathered from the face-to-face interviews, reinforcing the general consensus. However, a small number of interview participants did not prioritise the identified factors as critical for ensuring road system reliability, indicating some divergence in perspectives.

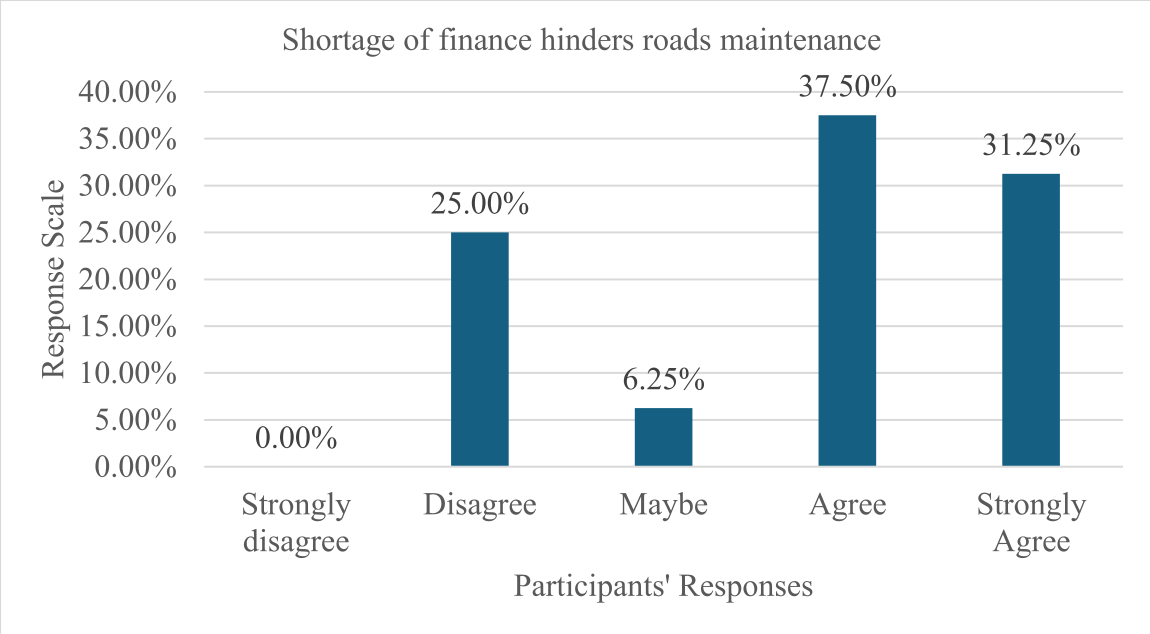


Figure 4.6: Participants' reflection on shortage of finance as hindrance in achieving road rapidity (Source: Data from interviews, 2024)

Figure 4.6 above reveals that more than two thirds (68.75%) of the participants agreed that finance plays a critical role in achieving road rapidity. This underscores the perception that financial constraints are a major barrier to the timely completion of activities related to both road redundancy and rapidity. However, 25% of respondents disagreed with this view, while 6.25% remained uncertain. Supporting this finding, the online survey results revealed a moderate difference (31.4%) between participants who emphasised the importance of ensuring system reliability and those who identified finance as a primary challenge. This suggests that while financial limitations are widely acknowledged, perspectives vary on the extent to which they impede progress.

4.3.6 Road resourcefulness

In the context of road transport infrastructure (RTI), resourcefulness refers to the system's capacity to effectively identify, mobilise, and manage a variety of resources, such as personnel, technology, information, and materials in order to respond to disruptions and maintain operational functionality (Tierney & Bruneau, 2007:15). This ability enables RTI to adapt to challenges, prioritise critical actions, and optimise available assets for rapid recovery and sustained performance.

The findings related to road resourcefulness are presented below under two sub-themes.

4.3.6.1 Understanding resourcefulness in the transport sector

Participants' definition of RTI resourcefulness revolved within an economic context, emphasising that roads are crucial for fostering economic growth. The responses from the face-to-face interviews (n=88%) demonstrated a clear understanding of resourcefulness within the transport industry. Therefore, if resources are limited in the transport sector, it would hinder the distribution of goods. For example, when roads are damaged and not rehabilitated, this could interfere with logistics. It is obvious that transport resourcefulness takes into account necessary factors, such as labour and operational costs. ProjM 1 further noted that the presence of maintenance systems for RTI is an integral aspect of the resourcefulness of transport institutions. However, they also highlighted that despite the existence of such systems, challenges persist in the implementation process. Participants highlighted that implementation obstacles arise from the diversion of maintenance funds. Hence, there are poor quality and unmaintained roads.

Eng (8) noted that although a national-level team under the Department of Transport is responsible for overseeing road maintenance, tangible results have yet to materialise. Funding remains a persistent challenge across institutions at municipal, provincial, and national levels, as resources are often redirected to other sectors such as health and education. Participants highlighted uncertainty as to whether implementation failures stem primarily from funding shortages or negligence; however, it is clear that inadequate funding consistently undermines maintenance efforts. This concern was echoed by Rdm 1, who questioned the effective use of available funds, stating, *"Despite insufficient funding, the question still remains: are the funds received for road maintenance used properly? One would say not exactly."* Supporting this perspective, ProjM (5) remarked confidently that *"most of the poor infrastructure can be attributed to negligence or lack of passion, lack of funding, and political interference."* Consequently, even minimal flash floods can severely damage road transport infrastructure (RTI) if it is not properly maintained, constructed according to engineering standards, and designed with resilience in mind. This vulnerability is further exacerbated by the construction of roads in low-lying areas. Several participants also acknowledged that their departments operate with minimal funding and limited personnel, further hindering effective maintenance and resilience-building.

Road transport infrastructure (RTI) can benefit significantly from innovation and technology, particularly through the reuse of waste materials using nanotechnology. Technological advancements now make it possible to process and integrate these materials more efficiently. For instance, the use of microcapsules embedded in asphalt enables roads to self-heal by autonomously sealing cracks, thereby extending the infrastructure's lifespan and reducing maintenance costs.

However, for such innovations to be effectively implemented and sustained, it is imperative to ensure transparency in project management. This includes the efficient allocation of resources and mitigation of corruption risks through tools such as centrally managed digital ledgers, which can track funding flows and the use of materials in real time. Equally important is the engagement of local communities through participatory research and planning processes. In this context, "local communities" refer to those directly or indirectly affected by the development and maintenance of RTI, such as residents living near road construction sites, local labourers who could be employed in infrastructure projects, small-scale businesses dependent on the road network, and community-based organisations (CBOs) advocating for equitable development. These stakeholders should be involved from the outset to ensure that their needs, insights, and concerns are meaningfully integrated into decision-making. Their participation not only fosters local ownership but also enhances accountability, ensures more socially responsive designs, and improves the long-term sustainability and functionality of the infrastructure.

4.3.6.2 Pointers on selecting roads and bridges for maintenance

The majority of face-to-face participants (n=14) emphasised that all road transport infrastructure (RTI) should undergo periodic inspections every five to ten years, depending on the classification and condition of the asset. This aligns with national policy provisions outlined in the South African Road Infrastructure Strategic Framework (RISFSA) and the Road Infrastructure Maintenance Guidelines issued by the Department of Transport, both of which underscore the critical role of routine, periodic, and preventative maintenance in ensuring the long-term sustainability and resilience of road networks. These frameworks mandate that infrastructure be regularly assessed to identify structural deficiencies, environmental wear, or risks arising from increased traffic loads and climate-induced hazards.

Standard operating procedures (SOPs) further stipulate that municipal and provincial road authorities must implement comprehensive asset management systems, which include scheduled condition assessments. Specifically, low-volume or rural roads are to be inspected at least once every ten years, while high-volume national and regional roads should be assessed every three to five years due to their strategic economic and social significance. However, despite these well-established policy and procedural guidelines, participants widely reported that inspections are often irregular, delayed, or entirely absent. The causes identified include chronic funding shortages**,** capacity constraints, and institutional fragmentation, which hinder effective implementation. This results in infrastructure deterioration going undetected until severe, often costly damage necessitates emergency repairs a far less efficient approach than planned, preventative maintenance.

As Eng (2) observed, road maintenance is further challenged by limited access to machinery and inadequate financial resources. While some participants noted that maintenance plans are developed for individual roads and bridges using a cycle management approach, the emergence of potholes and surface cracks (such as hairline or linear fissures) often signals lapses in timely maintenance. MD (1) additionally highlighted the potential of virtual assessments and remote sensing technologies for enabling annual road condition monitoring, which could strengthen existing systems and support more proactive infrastructure management.

In a similar vein, ProjM 2 noted that the neglect of community involvement often results in project disruptions, including strikes and resistance from local stakeholders whose interests were not considered during the planning phase. This highlights the importance of inclusive planning and early stakeholder engagement. SenR (1) emphasised the need to conduct a situational analysis prior to construction, as it enables more informed decision-making and helps tailor interventions to the specific socio-economic and environmental context of the area. Regarding funding and implementation structures, it was noted that SANRAL (South African National Roads Agency Limited) generates revenue through toll collections, while private sector actors, such as consulting and construction firms, are remunerated by government entities including the Department of Transport, SANRAL, and provincial governments for their services. This ties directly into the broader theme of resourcefulness, a core dimension of disaster preparedness and infrastructure resilience. As Zona *et al.* (2020:6) argue, the availability and strategic use of resources are central to effective disaster preparedness. Moreover, Argyroudis (2021:2) underscores that resourcefulness in the transportation sector involves not only leveraging existing resources but also developing innovative solutions to persistent infrastructure challenges.

4.3.7 Adapting road construction to withstand climate change impacts

As climate change continues to intensify extreme weather events and environmental stressors, the resilience of road transport infrastructure is increasingly under threat. This theme explores how road construction practices are evolving or need to evolve to address these challenges. Drawing from participant insights, the findings are organised into three sub-themes that examine current adaptation strategies, institutional and technical barriers, and the role of innovation and policy alignment in enhancing climate-resilient road infrastructure

4.3.7.1 Negative impacts of floods on the transport system

The findings reveal that much of South Africa's road transport infrastructure (RTI) is experiencing accelerated deterioration, primarily due to recurring flood damage. According to Eng (2), existing infrastructure is increasingly unable to withstand the impacts of extreme weather events. StakeM (1) attributed this vulnerability to a combination of factors, including negligence, lack of technical capacity, unregulated land use changes, and the increasing frequency and intensity of rainfall, largely driven by climate change. A key concern raised by Rdm (1) is that several RTI components have exceeded their intended design lifespan, typically around 20 years without the necessary structural upgrades or reinforcements. Although routine maintenance has been attempted in some areas, many of these systems now require complete overhauls. Their current state renders them highly susceptible to collapse or failure under stress from climate-related events.

Envi 3 reinforced these concerns by highlighting the growing severity of floods, which are inflicting widespread damage across regions. The inability of existing RTI to absorb or deflect such hydrological shocks indicates a systemic lack of adaptive capacity in infrastructure planning and design. Eng 5 added that repeated instances of road and bridge failures during heavy rainfall further illustrate this fragility. In such cases, the responsibility for rehabilitation typically falls on the government, often through emergency responses rather than proactive adaptation. Quantitative data from Figure 4.7 supports these qualitative insights: 68.60% of participants agreed that floods negatively affect the road transport system, while 25% were uncertain, and only 6.20% disagreed. This consensus underscores a shared recognition of the urgent need to adapt road construction and maintenance practices to withstand the evolving impacts of climate change.

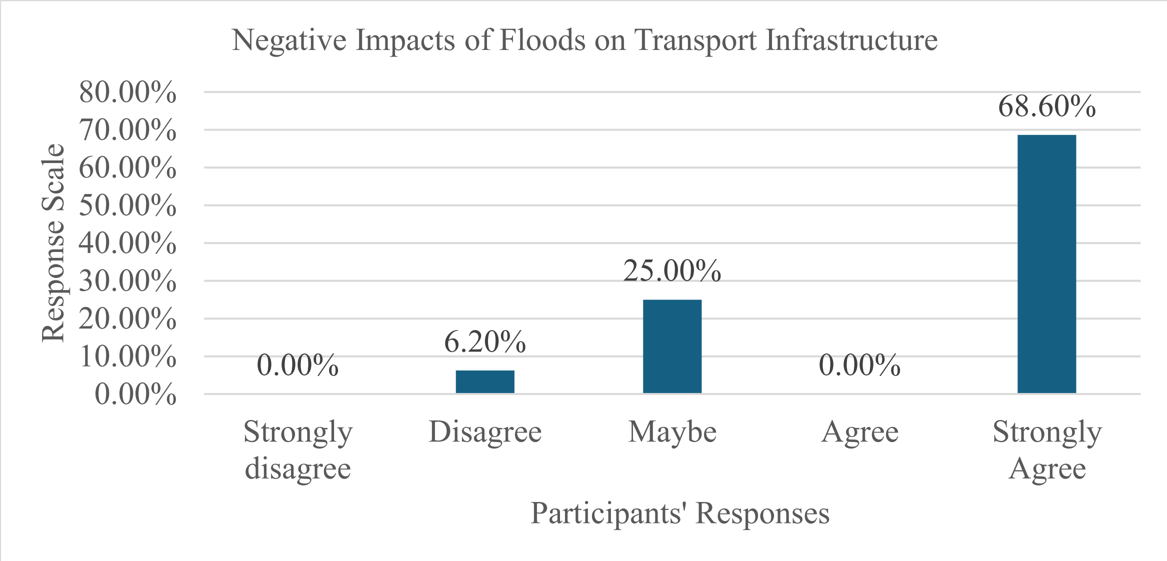


Figure 4.7: Participants' views on the negative impacts of floods on the transport system (Source: Data from interviews, 2024)

Figure 4.7 illustrates that a significant majority, 68.60% of participants, strongly agree that floods have a detrimental impact on the transportation system. This quantitative finding aligns closely with qualitative insights from face-to-face interviews, where participants elaborated extensively on the damaging effects of flooding on road transport infrastructure (RTI). Several interviewees reported that much of the country's existing infrastructure is rapidly deteriorating due to recurring flood damage, with some structures having exceeded their design lifespan without appropriate upgrades or climate-resilient adaptations.

The convergence between the online survey results and face-to-face interviews reinforces the credibility and consistency of this finding. While a small number of participants expressed uncertainty or disagreement about the extent of flood impacts, these outliers were minimal and did not significantly alter the overall pattern. The consensus across both data sources highlights a shared recognition of the urgent need to adapt RTI to withstand the increasing frequency and severity of flood events, which are closely associated with climate change and shifting environmental conditions.

4.3.7.2 Measures that can be taken to reduce the risk of road damage

Face-to-face participants (n=73%) emphasised the importance of implementing robust measures to mitigate the risk of road flooding. A key strategy highlighted was the construction of resilient infrastructure, including properly engineered drainage systems and structural reinforcements capable of withstanding extreme weather events. ProjM (1) stressed that adhering to engineering standards and guidelines during both the design and maintenance phases is critical for reducing flood-related vulnerabilities. Furthermore, participants underscored the need for clear accountability within the transport sector, particularly in assigning roles and responsibilities for infrastructure oversight and disaster preparedness.

Importantly, participants linked these design and governance considerations to broader sustainable development objectives, particularly Sustainable Development Goal (SDG) 9, which advocates for building resilient infrastructure, promoting inclusive and sustainable industrialisation, and fostering innovation. As one participant noted, cost-effective designs should not only reflect engineering excellence but also align with environmental sustainability principles and long-term development goals. Embedding SDG-aligned thinking into road infrastructure planning ensures that today's investments contribute not only to short-term functionality but also to intergenerational equity and climate resilience (Denoncourt, 2020:200). In this way, climate-resilient road design becomes both a technical and moral imperative in advancing sustainable development.

Participants overwhelmingly emphasised that proactive flood prevention is significantly more cost-effective and socially beneficial than post-disaster reconstruction. By mitigating flood damage before it occurs, road authorities can help protect livelihoods, as many communities rely heavily on functional transport networks for access to work, health services, education, and markets. Participants further stressed that mobility disruptions compromise not only safety but also have cascading economic repercussions, including delayed goods movement, lost productivity, and infrastructure repair costs.

Eng (5) highlighted the interconnected nature of climate impacts, noting that in flood-prone areas such as KwaZulu-Natal (KZN), the destruction of roads, homes, and even loss of life during heavy rains has forced some residents to consider relocation. As stated, *"Because during heavy rains, roads are damaged, houses are destroyed, and people are killed, which negatively affects the economy and livelihood. Further flood damage leads to increased insurance prices; in turn, this has led to some individuals needing to relocate."* This statement reflects the cascading social, economic, and spatial consequences of inadequate climate resilience in the transport sector. It also affirms that RTI is a foundational component of national resilience, underpinning economic stability and social well-being. These insights align with global evidence. For example, Ntakiyimana *et al.* (2022:3738) underscore that attempts to cross flooded roads remain one of the leading causes of flood-related fatalities, reinforcing the need for climate-adaptive design and planning.

Given these compounding risks, participants agreed that current approaches to climate change adaptation in the road sector are insufficient. The scale and intensity of climate hazards, particularly floods and prolonged heavy rainfall, demand a fundamental revision of planning frameworks and engineering practices. As noted in Chapter 2, section 2.5, strategic RTI planning must be central to building a safe, efficient, and resilient network, with engineers, planners, and policymakers embedding resilience considerations from the outset. Doing so allows investment decisions to be made in alignment with national priorities rather than as fragmented, reactive responses. Ultimately, strengthening climate adaptation in RTI is not only a technical requirement but a strategic necessity for sustainable development.

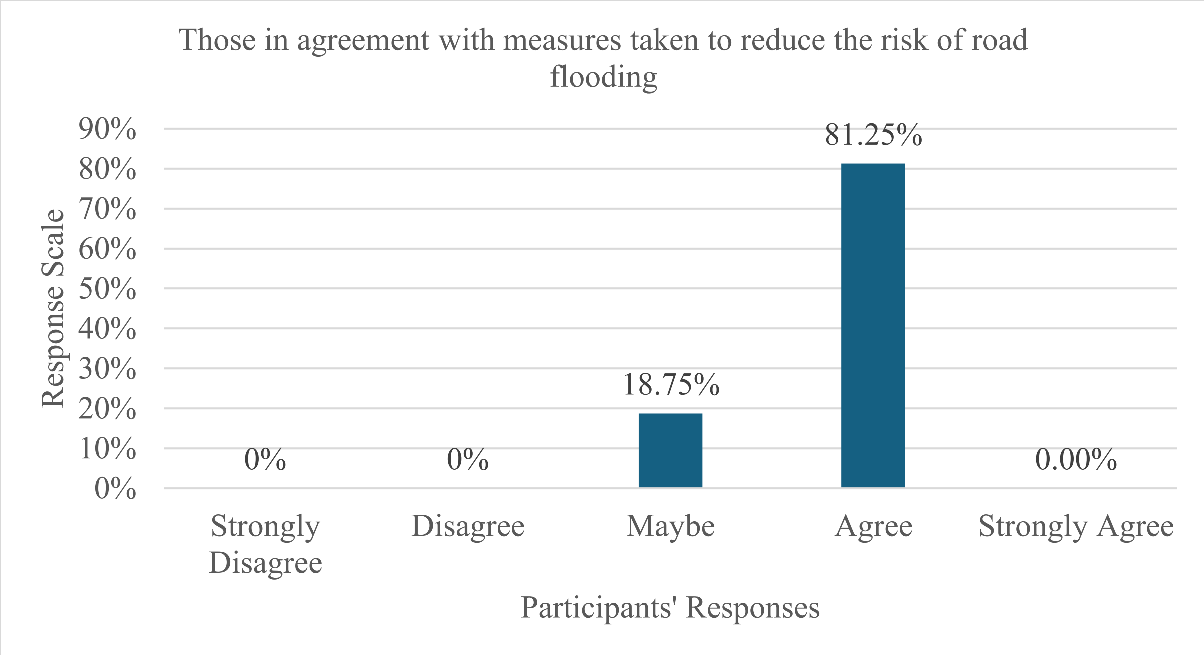


Figure 4.8: Means to reduce the risk of flooding (Source: Data from interviews, 2024)

From Figure 4.8 above, 81.25% agreed that it is important to align with SDGs, in addition to establishing proper systems to improve road infrastructure resilience, while 18.75% were undecided. These responses will help in decision-making regarding the elimination of road damage due to floods. Therefore, governments should invest in such measures to ensure citizens' safety and economic growth. Res 1 further emphasised that extreme weather conditions raise concerns about social factors such as accessibility and movement that may contribute to vulnerability. Thus, measures should be taken to minimise the risk of damage to roads to prevent vulnerability and hazards.

4.3.7.3 Climate-change-adaptation approach to road construction in South Africa

Face-to-face interviews (n=81%) indicated that the RTI must modify the current construction standard to adapt to climate change by, for example, updating the current catchment particularly in flood-prone areas and also ensuring the resilience of infrastructure through innovation and technology. Eng (6) highlighted the challenges faced by the transport sector and acknowledged that *"most of the infrastructures were built in the early 70s or 80s"*. Due to the current state of global warming, adapting or changing existing road infrastructure is complex and expensive, therefore, retrofitting existing roads to increase their resilience is intricate (Saleh & Hashemian, 2022:15). Envi 1 further alluded to the need for proper town planning to limit congested development around roads. For instance, Envi 1 stated that *"majority of informal settlements are built in roads' vicinity, waterways and wetlands. As a result, domestic waste leads to clogs in roads drainage systems."* A further suggestion made by participants is that there is a ''need to employ a variety of interventions by revisiting the road drainage guideline and updating the flood guidance''.

Rdm (1) emphasised the importance of utilising Indigenous Knowledge (IK) to adapt to climate change. This issue (floods impact) would likely not exist if local knowledge and signage were properly understood and adhered to, as flood damage to RTI is not a unique or uncommon problem. The participants further elaborated that soil types vary, depending on the location where construction occurs; thus, it is necessary to understand the dynamics of the area. Moreover, Eng 6 have noted the need to maintain the catchment areas to prevent flooding, especially in low-lying areas. Innovative solutions will yield resilience and sustainability by producing designs that are compatible with the site in which the construction will be undertaken.

In addition, ProjM (2) expressed the need for improved drainage and landscape (e.g. wetlands) around roads to reduce heavy water currents. In this regard, Envi (1) stressed that there are many factors which contribute to the degradation of roads, for example quality issues, procurement issues, among others, and that paying attention to these challenges could reduce heavy flow impacts. Mobilising the use of nanotechnology is beneficial for climate change adaptation. ProjM (1) highlighted that nanotechnology acts as a sponge that helps absorb liquid. In essence, the sponge-like substance handles the storm water by preventing large quantity discharge to the environment which may cause environmental damage.

4.4 DISCUSSION OF THE MAIN FINDINGS

The results indicate substantial convergence between face-to-face interviews and the online survey findings. In most cases, the responses provided by the participants in face-to-face interviews were consistent with those provided in the online surveys, with few exceptional varied responses. Moreover, the empirical findings revealed that only road redundancy is fully functional, whereas road rapidity, robustness, and resourcefulness are unsatisfactory. In addition, the finding pointed out that road rapidity and redundancy depend on the availability of resources. Thus, resourcefulness plays a significant role in achieving RTI resilience.

A comprehensive analysis of participants' perceptions regarding the resilience of South African RTI to floods was discussed in the first theme. The empirical findings delineated road transport resilience as the infrastructure's capacity to endure and adapt to external pressures, such as floods and accidents. This definition aligns with the perspectives presented by Freckleton *et al*. (2012:110) in Chapter 3, Section 3.1, who defined resilience as the ability of road transport infrastructure to bounce back (i.e. return itself to a level of service equal to or greater than the pre-disruption level of service within a reasonable time frame) to its normal state after disruptive flood events. The analysis further revealed that national roads in South Africa are designed in line with international standards and are built to withstand worst-case scenarios. However, some participants noted that achieving desired resilience standards is challenging due to the high costs associated with the implementation process (i.e. road upgrading, RTI planning, road construction) and the inability to control nature or weather patterns.

Regarding South Africa's RTI resilience, responses varied somewhat between participants from face-to-face interviews and those from the online surveys. Some participants expressed confidence in the infrastructure's resilience to floods, while others disagreed with this assertion. This divergence was reflected in the online survey results, where 43.25% of participants believed that South African RTI is resilient to floods, 31.25% disagreed, and 25% remained uncertain. Their responses differ due to different departments they work under, i.e. if not familiar with floods. Moreover, most face-to-face participants emphasised that resilience could be effectively integrated into the design and maintenance of road transport infrastructure. This view was further corroborated by 87.5% of online survey participants, with 12.5% remaining undecided. This part of the findings aligns with Weilant *et al*.'s (2019:12) findings, who assert that resilience can be incorporated into long-term planning and decision-making through a revised transport planning process.

The second theme focused on the robustness of RTIs, and factors considered when designing such infrastructures to ensure robustness (Chapter 4; Section 4.3.3.1). Participants defined a robust RTI as one that can effectively accommodate the traffic for which it was originally designed to accommodate. Findings from face-to-face interviews revealed that most participants believed engineers design RTIs using durable materials to ensure their robustness for two reasons. Firstly, as mentioned above, the durable material are observed mostly from the national roads as they can accommodate abnormal vehicles. For instance, SANRAL applied the Sustainable Road Forum Tool, research etc. Secondly, the national roads are prioritised because they contribute to economic growth. The study also revealed the non-compliance with road engineering standards. The respondent highlighted that even though the individual bid for tender have all the necessary documentation, without proper experience they can still be awarded the tender due to political interference. Additionally, the lack of functional and reliable rail systems, which places increased pressure on roads (i.e. overloaded trucks), further undermines road robustness in South Africa. Thus, achieving robustness in RTI development is challenging due to political interference and insufficient funding. These findings align with Alers's (2022:245) study, which highlighted that an accountable, transparent, and responsive governance system is needed to meet society's needs within the transport sector. To improve robustness, participants recommended empowering engineers and minimising external interference in the design and implementation of transport infrastructure projects. It can be concluded from the empirical findings that current practices are inadequate for achieving robustness in road transport infrastructure, and the overall process remains weak and needs to be revised.

The third theme concentrated on road transport infrastructure's redundancy (Chapter 4: Section 4.3.4). There was a clear consensus both in qualitative and quantitative findings. The majority of face-to-face participants (n=12) highlighted that alternative roads exist, but they were not constructed for alternative purposes, such that an existing road becomes an alternative in case of an emergency. The participants substantiated that it is extremely expensive to build RTIs, thus it is impossible to build routes for alternative purposes. These findings align with Snelder *et a*l. (2012:835) who voiced that measures such as road pricing should be considered to implement road network redundancy. Additionally, participants revealed that some routes do not have alternative routes, and they emphasised that such roads should be prioritised if disasters affect them. The findings further revealed that every national road has an alternative route. However, such alternative roads may be time-consuming and not constructed according to national road standards. Moreover, this study discovered that most participants understand the importance of redundancy. This can be observed from the online surveys, whereby 68.80% of participants indicated the significance of road redundancy in emergencies. These empirical findings coincide with Tierney & Bruneau, (2007) who found that redundancy not only provides travellers with alternative transport routes, but it also increases the resilience of transport infrastructure in the event of disasters (Guo et al., 2021:9; Jansuwan *et al.,* 2018; Xu *et al.,* 2021:3).

The fourth theme was directed on road transport infrastructure rapidity and challenges encountered during rapidity implementation process (Chapter 4: Section 4.3.5). The participants revealed that rapid response depends on the type of the damaged infrastructure and the institution (national, provincial or municipality) responsible for the infrastructure management. For instance, SANRAL, an institution responsible for national roads prioritise rapidity. Whereas organisations responsible for regional or provincial roads are struggling to achieve rapidity. From these findings, it can be drawn that national roads are prioritised due to their contribution to the country's economy and thus are equipped with resources to implement rapidity effectively. However, in some cases, rapid implementation is challenging for various reasons. Firstly, participants highlighted the issue of limited funds. Some participants, for instance, observed the diversion of funds intended for flood response to other purposes. Secondly, participants revealed that delays in procurement process from strategic positions were another obstacle to rapidity implementation. This can be further noted from a tremendous response from the online survey where most participants supported having competent individuals, and the avoidance of the misuse of funds to ensure the reliability of road rapidity systems. Moreover, achieving rapidity is highly dependent on the availability of finances especially allocated for such purpose. These findings align with Argyroudis (2021:2) who states that the degree of rapidity in the transport industry is determined by the nature of damage and the availability of resources following a significant event. In this regard, rapid response to RTI damage is influenced by resourcefulness in the transport sector.

The fifth theme concerned itself with the resourcefulness of the transport sector to achieve RTI resilience (4.3.6). A key component of this sub-concept is ensuring a reliable RTI resilience by investing in road transport infrastructure. In light of these findings, it is evident that human, financial and equipment (machinery) resources are of paramount importance in the transport sector. However, as mentioned above, funding is a major challenge for maintaining RTI resilience. The study also found a maintenance plan for every RTI built, but a problem with the implementation procedure, which needs to be attended to. Overall, the findings of this study are consistent with those of Zona *et al.* (2020:6) with a few exceptions (since not all institutions that deal with road transport are indicated to have enough resources to address road-related issues). For example, Zona *et al.* (2020) found out that during disaster events, communities/countries with more resources are more resilient. And the ability to be resourceful is considered one of the most important components of disaster resilience.

The final theme identified in this study related to climate change adaptation approaches to road construction in South Africa. The empirical findings revealed that lessons learned from past road construction experiences in South Africa should be applied to the current road construction projects. Understanding the dynamics of the area where construction is to take place and providing designs compatible with the site are important components for better road transport infrastructure. In addition, nanotechnology has the potential to absorb storm water and prevent it from flowing into and causing harm to the environment, thus minimising road transport infrastructure damage by floods. Measures should be taken to minimise the risk of road damage caused by extreme weather conditions, which raises concerns about the social factors that make people more vulnerable to such situations. Aside from aligning with sustainable development goals, there is a need to develop procedures for managing road infrastructure, research, development, and auditing of road contract acquisition. South African road transport infrastructure is vulnerable to extreme weather conditions, with some roads exceeding their design durability, others need adequate maintenance, and some are overused due to demographic changes. These findings align with Mokoena *et al.* (2019:3), who indicate that transport infrastructure design and maintenance must consider climate change. Compared to roads, bridges are less susceptible to damage. The study provided a systematic analysis of how floods negatively impact the RTI, and the importance of maintaining the resilience of the road transport infrastructure cannot be overstated.

4.5 CONCLUSION

An overview of the study is presented in this chapter based on the views of a selected sample of participants, as well as the study's findings and analysis. The study's main objective was to evaluate the resilience of South Africa's road transport infrastructure to floods, using the R4 resilience framework, whose elements include robustness, redundancy, resourcefulness, and rapidity. This evaluation was made by assessing the perspectives of participants regarding road infrastructure resilience and evaluating South Africa's road transport infrastructure or RTI. The analysis provided a clear point that extreme weather events indeed have an impact on road transport infrastructure. Moreover, only national roads are doing better than those under provincial and municipal control. The limitation of the study was the amount of time for data collection and the availability of the participants, which affected the number of participants. As participants came from different provinces, the researcher was compelled to conduct online surveys with those from afar because they could not be included in the semi-structured face-to-face interviews.

Due to the limited number of participants from all provinces, it will not be easy to generalise the findings to the entire country. Even so, the study still provides a detailed examination of the state of the country's road transport infrastructure in terms of resilience. As such, this chapter contributes to the broader field of infrastructure resilience by illustrating the need for improved policy formulation processes and advocating for concrete changes within the South African transport industry. Lastly, the study also recommends an amendment of the constitution to give SANRAL a greater authority to maintain more road infrastructure. A discussion of the analysis process and the methods used to select suitable participants were also included. The themes were developed following research findings derived from data collection. Overall, six themes were identified, some of which included sub-themes. Likewise, the data collection evidence supports the conclusions drawn from the data.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS OF THE STUDY

5.1 INTRODUCTION

The previous chapter analysed and presented empirical research findings on South African road infrastructure's flood resilience. As outlined in the previous chapter, several empirically supported reasons exist for the resilience of road transport infrastructure. Besides providing empirical insights into flood impacts on road transport infrastructure, the chapter also analysed related issues. The objectives of this chapter are to summarise, assess, and formulate conclusions and recommendations regarding the level of achievement of each objective. In this chapter, recommendations are presented to address the study's primary objective: to evaluate the resilience of South Africa's road transport infrastructure to floods. A summary of each chapter in this study and how they contribute to the main theme is listed below. Before presenting the overall conclusion, the study's recommendations are briefly summarised.

5.2 OVERVIEW OF THE CHAPTERS

Each chapter of this study has been designed to ensure that all the study's objectives are met. In Chapter 1, an overview of the study was provided. Furthermore, conceptualisation of the problem statement and the objectives to be addressed were presented. Specifically, this study evaluated the resilience of South African road infrastructure to floods. A comprehensive assessment of the officials' perspectives on road infrastructure resilience in South Africa and evaluation of South Africa's road infrastructure resilience based on the R4 resilience framework (namely, robustness, redundancy, resourcefulness, and rapidity) was used to achieve the research objectives. Throughout the chapter, the main theoretical pillars behind the study were described. Detailed explanations of the study's methodology can be found in Chapter 1. In conclusion, this chapter presents the outline of the dissertation chapters to give an overview of its structure.

A theoretical conceptualisation of floods and their impacts on road transport infrastructure was presented in Chapter 2. A major emphasis of this chapter was to examine the impact of floods on South Africa's road transport infrastructure since the country has been experiencing devastating floods caused by heavy precipitation, which affected several major cities recently. A discussion of the study's first objective can be found in Chapter 2.

As part of Chapter 3, an in-depth review of the existing literature on resilience was provided, with a particular focus on the R4 framework for resilience in the context of road transport infrastructure. While also examining the different sources of constraints that adversely affect RTI performance, this chapter also identified the most relevant strategies for enhancing the resilience of RTI networks and outlined the most effective approaches. Additionally, disaster resilience and the concept of resilience in the context of road transport infrastructure were discussed, as are various methods for assessing the resilience of road transport networks and constraints that negatively impact their efficiency. Further, appropriate strategies for road resilience transport were discussed with a particular emphasis on R4 framework for resilience (Tierney & Bruneau, 2007:15). Using the literature review from Chapter 3 as a basis for the theoretical framework used in Chapter 4, the R4 framework is introduced as a measure of the resilience of road transport infrastructure. As part of R4 framework, several factors were considered, including not just physical infrastructure, but also socio-economic, and environmental factors. In this way, the transport system was evaluated for its ability to cope with shocks and stresses, and to recover quickly.

Detailed empirical findings, as well as the process of analysis, were presented in Chapter 4, which provided a brief explanation of the methodology in conjunction with Chapter 1. Based on the research objectives outlined in Chapter 1, the findings in Chapter 4 were discussed. A series of themes was used in Chapter 4 to organise the findings related to the information gathered in the study so that officials' perspectives on road infrastructure resilience in South Africa could be determined and South Africa's road infrastructure resilience evaluated through the R4 (robustness, redundancy, resourcefulness and rapidity) resilience framework. The study revealed that of the three spheres of government involved in managing road transport infrastructure within the country, only the national government, as represented by SANRAL, performed far better. Also, climate change's impact was found to be growing, thereby necessitating the need for resilient road transport infrastructure. Moreover, only road redundancy is fully functional, whereas road rapidity, robustness, and resourcefulness were considered unsatisfactory. Furthermore, the findings pointed out that road rapidity and redundancy depend on resource availability. Thus, resourcefulness was found to play a significant role in achieving RTI resilience. Based on the findings of Chapter 4, recommendations are now presented here in Chapter 5. In addition, a comprehensive and collaborative approach is required to implement the framework.

The purpose of Chapter 5 is to draw overall conclusions and summarise main recommendations of the study. These recommendations are informed by the findings presented and discussed in sections 4.3 and 4.4 of Chapter 4 respectively. In the following section, each research objective is discussed in detail.

5.3 ACHIEVEMENT OF RESEARCH OBJECTIVES

During this study, the focus was on evaluating the resilience of South African road infrastructure to floods. This approach allowed the study to achieve its main objective by addressing four objectives. To accomplish this goal, it was necessary to achieve the objectives as outlined in Chapter 1, such as (a) to provide a theoretical conceptualisation of resilience of, and floods and their impacts on road transport infrastructure, (b) to assess the participants' perspectives on road transport infrastructure resilience, existing flood resilience measures and response strategies within the South African road transport sector, (c) to evaluate South Africa's road infrastructure resilience using the R4 (robustness, redundancy, resourcefulness and rapidity) resilience framework, (d) to propose strategies and policy recommendations for enhancing the resilience of road transport infrastructure, ensuring long-term sustainability and improved disaster preparedness, and ultimately (e) to draw conclusions and recommendations on the resilience of South African road transport infrastructure.

The results indicated that substantial convergence exists between the face-to-face interviews and the online survey findings. In most cases, the responses provided by participants in face-to-face interviews were consistent with those provided in the online surveys, with only a few points where they differed slightly.

In fulfilling the study's objectives, the amount of time for data collection and the availability of participants affected the number of participants. Because participants came from different provinces, the researcher needed to conduct online surveys with those in distant provinces who were consequently inaccessible in person. Since this particular group of participants could not be interviewed face-to-face, online surveys were conducted instead. Given the limited number of participants from all provinces, it is difficult to generalise the findings of the study across the country. Nevertheless, the study still provides an in-depth analysis of how resilient the country's road transport infrastructure is. Achieving the study's main objective was based on the completion of the objectives, each complementing the other for the study to be successful. As part of the study's objective, the chapters were arranged chronologically and linked with context to ensure they formed a coherent whole. The study's main objective was subsequently achieved by addressing the individual objectives through the review of literature, as outlined in Chapters 2 and 3, and conducting empirical analysis, whose results were discussed in Chapter 4. Each of the study's objectives is discussed in the following section to achieve the study's overall purpose.

5.3.1 Objective 1: To provide a theoretical conceptualisation of resilience of RTI to the effects of floods.

The first objective of this study was addressed in Chapters Two and Three, which together examined the relationship between flood hazards and the resilience of road transport infrastructure (RTI). Against the backdrop of increasingly frequent and severe weather events, the resilience of transportation systems has emerged as a critical area of concern. Chapter Two reviewed the growing body of literature highlighting the vulnerability of road networks to climate-induced hazards, particularly floods, which are the most recurrent and damaging natural disasters in South Africa. This review underscored the escalating risks that extreme rainfall and flooding pose to transport infrastructure and reinforced the imperative to embed resilience into infrastructure planning and management.

Building on this context, Chapter Three provided the conceptual and theoretical foundation necessary for understanding resilience in the transport sector. It introduced the R4 framework developed by Tierney and Bruneau (2007), which conceptualises resilience through four core dimensions: robustness, redundancy, resourcefulness, and rapidity. This framework served as the analytical anchor of the study, enabling a structured and multidimensional assessment of how road infrastructure systems can withstand, adapt to, and recover from flood-related disruptions. The R4 framework allowed the study to move beyond purely engineering-based interpretations of resilience, framing it instead as a complex interplay between physical design, institutional capacity, and adaptive governance. The chapter also engaged with various methodological approaches for measuring infrastructure resilience and identified a range of stressors, especially those linked to climate variability, that undermine the performance of road networks. Moreover, it outlined key strategies for enhancing RTI resilience, emphasising not only technical interventions such as improved drainage and structural reinforcements, but also the need for institutional reforms that support integrated planning, risk-informed investment, and cross-sectoral coordination. Through this analytical lens, the study offered a comprehensive understanding of RTI resilience, situating it within the broader challenge of adapting infrastructure systems to an increasingly uncertain climate future.

5.3.2 Objective 2: To assess the participants' perspectives on road transport infrastructure resilience, existing flood resilience measures and response strategies within the South African road transport sector

The second objective of this study was addressed in Chapter 4 by presenting empirical findings derived from interviews with transportation officials across different stakeholders. The empirical evidence revealed a strong alignment between the participants' perceptions and the analytical lens offered by the R4 framework (robustness, redundancy, resourcefulness, and rapidity). By applying this framework, the study was able to assess the extent to which resilience principles are integrated or absent across the different tiers of governance. While many of the insights confirmed theoretical arguments advanced in Chapter Two and elaborated in Chapter Three, some discrepancies emerged. Notably, several respondents cited political interference as a significant constraint to effective infrastructure planning and delivery, an issue also reflected in the literature, thereby validating this exception.

The findings suggest that strengthening resilience requires more than just technical interventions; it calls for institutional reform that empowers transport agencies, particularly at sub-national levels, to operate with greater autonomy, transparency, and strategic coherence. Accordingly, policies and practices must be reformed to ensure that governance structures support rather than hinder the development of resilient road transport infrastructure.

5.3.3 Objective 3: To evaluate the resilience of South Africa's road transport infrastructure using the R4 (robustness, redundancy, resourcefulness and rapidity) resilience framework

The third objective of this study was addressed in Chapter Four, which examined the resilience of South Africa's road transport infrastructure (RTI) through the lens of the R4 framework, comprising robustness, redundancy, resourcefulness, and rapidity. The application of this framework in the South African context remains relatively new, and the findings revealed uneven levels of familiarity and conceptual clarity among the participants. While redundancy and resourcefulness were broadly understood, the concepts of robustness and rapidity required explanation during interviews, underscoring a significant gap in conceptual alignment that may impede the framework's practical implementation.

The study also uncovered a range of structural and institutional barriers that could constrain the operationalisation of the R4 framework. Participants identified persistent governance challenges, including political interference, lack of transparency and accountability in infrastructure project delivery, the appointment of underqualified personnel to leadership positions, and an overarching absence of political commitment to long-term resilience objectives. These systemic issues were perceived as critical impediments, with respondents emphasising that no resilience framework, regardless of its technical soundness can succeed in such an environment without concurrent institutional reform. A noteworthy insight from the interviews was the increasing interest in technological innovation, particularly the use of nanotechnology, to improve the durability and adaptive capacity of road infrastructure. This highlights the need to couple governance improvements with technological advancements as part of a broader and more integrated resilience-building strategy.

Despite its limited application to date, the R4 framework was generally viewed by participants as a robust and accessible model capable of capturing the complex and interdependent dimensions of infrastructure resilience. However, its successful adoption and institutionalisation will depend heavily on sustained investments in capacity-building, the cultivation of political will, and the establishment of transparent, accountable governance mechanisms. In this way, the R4 framework offers a valuable foundation for resilience planning, but its transformative potential will only be realised through comprehensive reform efforts across the institutional and operational landscape of South Africa's road transport sector.

5.3.4 Objective 4: To propose strategies and policy recommendations for enhancing the resilience of road transport infrastructure, ensuring long-term sustainability and improved disaster preparedness

To address these deficiencies, several key recommendations were proposed. First, the empowerment of the South African National Roads Agency Limited (SANRAL) to take on a broader mandate beyond national roads was identified as a critical step toward improving uniformity in infrastructure standards and maintenance practices. Second, resilience considerations must be systematically integrated into the design, operation, and maintenance of road infrastructure to address the escalating impacts of climate change. Third, adequate financial and human resources must be made available across all RTI institutions to address regional disparities in performance and preparedness, particularly in the context of increasing flood risks. Lastly, the acceleration and reform of procurement processes through policy adjustments were identified as necessary to improve infrastructure delivery timelines and enhance the overall effectiveness of resilience-building measures.

Furthermore, when compared with the six internationally recognised principles for resilient infrastructure, discussed in Chapter Two, it is evident that their implementation in South Africa remains partial and fragmented. These principles emphasise the importance of capacity-building, cross-sector collaboration, and knowledge-sharing among stakeholders involved in infrastructure development and maintenance. The study's use of the R4 framework provided a structured and systematic lens through which to interpret these gaps, offering a clear pathway for how resilience can be operationalised more effectively.

In summary, the proposed strategies emphasise the need for a holistic approach that combines technical, institutional, and governance reforms. Without simultaneous attention to capacity development, resource allocation, and policy coherence, efforts to improve RTI resilience are unlikely to yield lasting or scalable outcomes.

5.4 CONTRIBUTION OF THE STUDY

This study makes a significant and timely contribution to the discourse on disaster resilience and infrastructure planning by providing a focused analysis of South Africa’s road transport infrastructure (RTI) through the lens of the R4 resilience framework, comprising robustness, redundancy, resourcefulness, and rapidity. It advances existing literature by examining how resilience principles are understood, operationalised, and challenged in a context marked by increasing climate-related disruptions, particularly flooding. South African road authorities hold a constitutional mandate to plan, design, construct, and maintain road networks while ensuring the safety, efficiency, and sustainability of transport systems (COTO, 2012). Within this institutional context, the study reveals a high level of awareness among stakeholders regarding the growing threat of flood-related hazards to RTI. Participants consistently identified floods as a pressing risk, underscoring the urgency of integrating resilience into all stages of infrastructure development and governance.

The study’s empirical findings highlight a critical gap in the implementation of resilience principles. While road redundancy, defined as the availability of alternative routes is relatively functional, the other three R4 components, robustness, rapidity, and resourcefulness remain underdeveloped. These weaknesses are attributed to systemic barriers, including inadequate investment, lack of skilled leadership, institutional opacity, political interference, and insufficient adaptation planning. Particularly important is the finding that rapidity and redundancy are deeply contingent on resource availability, positioning resourcefulness as a foundational enabler of resilience in the South African RTI context.

A unique insight from this study is the recognition of SANRAL’s potential as a transformative actor in strengthening national resilience. Participants advocated for empowering the agency with expanded jurisdiction, adequate financial and human capital, and greater autonomy to lead resilience-building initiatives across all levels of the road network, not just national roads. Additionally, the study draws attention to the importance of incorporating evolving climate adaptation strategies and technological innovations into RTI planning and operations.

Ultimately, the study offers a novel application of the R4 framework to the South African transport infrastructure sector and provides actionable knowledge that bridges the gap between theory and practice. It informs policymaking by outlining key institutional and governance reforms necessary for advancing resilience. Furthermore, it establishes an empirical foundation for future research, particularly in contexts of climate vulnerability and infrastructure inequality, and calls for more integrated, adaptive, and forward-looking approaches to infrastructure development in the Global South.

5.5 LIMITATIONS OF THE STUDY

Despite the valuable insights generated, this study was subject to several limitations that should be acknowledged. One of the primary constraints was the time available for data collection, which influenced the number and diversity of participants who could be engaged. Logistical challenges, particularly the geographic dispersion of relevant stakeholders across South Africa, further complicated the process. While efforts were made to include a broad range of perspectives, some participants, especially those located in remote or distant provinces could not be interviewed in person. Instead, their input was gathered through online surveys, which, while effective in reaching geographically dispersed respondents, limited opportunities for deeper qualitative engagement that face-to-face interviews typically allow. Furthermore, the limited representation of participants across all nine provinces restricts the generalisability of the findings. While the study offers critical insights into the state of resilience within South Africa’s road transport infrastructure, particularly concerning flood-related vulnerabilities, it cannot claim to capture the full national picture. Variations in infrastructure quality, governance capacity, and climate vulnerability across provinces suggest that experiences and levels of resilience may differ significantly from one region to another.

These limitations highlight the need for future studies to expand the sample size and ensure broader geographic and institutional representation. Extending the duration of fieldwork would also allow for a more in-depth exploration of the contextual and systemic factors influencing resilience. Despite these constraints, the study provides a valuable foundation for understanding the application of the R4 resilience framework within the South African context and sets the stage for more comprehensive investigations moving forward.

5.6 RECOMMENDATIONS OF THE STUDY

In light of the escalating impacts of climate change and increasing frequency of extreme weather events, this study’s findings underscore the urgent need for a more resilient and adaptive road transport infrastructure (RTI) system in South Africa. Beyond environmental concerns, the data revealed that institutional and governance-related challenges, such as political interference, lack of transparency, and the appointment of underqualified personnel to senior roles, significantly undermine the capacity of RTI institutions to respond to disasters effectively. These systemic issues must be urgently addressed to strengthen resilience at both operational and strategic levels.

The study also found that while road redundancy, understood as the availability of alternative routes is relatively well developed, the other three components of the R4 resilience framework, robustness, resourcefulness, and rapidity are insufficiently implemented. This imbalance threatens the overall integrity and functionality of the transport network during and after disruptive events. As Zhou et al. (2019) note, robustness and redundancy are critical in determining the extent of disruption experienced by RTIs, while resourcefulness and rapidity are central to effective recovery efforts. Similarly, Snelder et al. (2012) emphasise that the R4 framework is not only useful for post-disaster response but also provides a structured method for evaluating the resilience and operational sustainability of transport systems under stress.

The integration of resilience thinking into RTI planning and management is therefore not optional but essential. The use of advanced technologies, such as nanotechnology in road design should be prioritised, alongside broader institutional reforms and strategic investments. As Tierney and Bruneau (2007) argue, building a resilient infrastructure system significantly lowers the risk of catastrophic failure, reducing the potential for injury, loss of life, and economic disruption. This conclusion is supported by Capacci et al. (2022), who find a strong interdependence between the elements of the R4 framework, highlighting the need for a holistic approach.

Drawing on these empirical findings and the insights from the literature, the following recommendations are proposed to enhance the resilience of South Africa's road transport infrastructure:

- **Accelerating procurement process through policy changes to improve the rapidity of road transport infrastructure (RTI) development**

To improve the rapidity of road transport infrastructure (RTI) development, this study recommends accelerating procurement processes through targeted policy reforms. Currently, significant infrastructure progress is often delayed unless a national disaster is declared, with further setbacks caused by weak institutional accountability, limited financial resources, and lack of commitment among officials. To overcome these barriers, the capacity of provincial and municipal institutions must be strengthened, and a culture of responsibility, engagement, and urgency fostered among RTI managers. Moreover, resistance to change, often driven by political interference and institutional inertia, can be mitigated through collaboration with stakeholders, preparation of staff for reform, and the use of public-private partnerships. Aligning policy implementation with available resources will enable faster execution of infrastructure projects, narrowing the gap between problem identification and solution delivery. These reforms are vital for creating a more resilient, adaptive, and responsive RTI system.

- **Ensuring the availability of adequate human and financial resources for all road transport infrastructure (RTI) institutions to address disparities and improve sector performance**

To address disparities and enhance the performance of road transport infrastructure (RTI) institutions, it is essential to ensure the availability of adequate human and financial resources across all levels. While one institution demonstrated sufficient capacity and tangible outputs, most reported persistent funding shortages, compounded by negligence, lack of commitment, and hidden agendas among some staff. The study recommends the adoption of a budget policy that prioritises both net and adjusted gross investments, tailored to South Africa's socio-political and economic context. This would promote consistent, equitable resource allocation. In parallel, leadership must demonstrate accountability, integrity, and dedication to fostering a results-driven, resourceful institutional culture. Strengthening resource availability and leadership effectiveness will significantly improve RTI delivery, resilience, and long-term sustainability nationwide.

- **Integrating resilience into the design, maintenance, and management of road transport infrastructure to address the growing impacts of climate change**

To address the growing impacts of climate change, it is essential to embed resilience into the design, maintenance, and management of road transport infrastructure. Recurrent flood damage, such as that experienced in KwaZulu-Natal, demonstrates the high cost of reactive approaches and the urgent need for climate-adaptive planning. This study recommends that road authorities prioritise proactive strategies that integrate resilience from the outset. Key tools include the R4 Resilience Strategy and the Resilience Management Framework (RMF), which help identify, assess, and manage risks across interconnected infrastructure systems. By systematically incorporating risk classification, variable evaluation, and interdependency analysis, RTI systems can be designed to better withstand extreme weather. This will result in more durable, cost-effective, and disaster-resilient infrastructure capable of supporting sustainable development under changing climatic conditions.

- **Promote ethical leadership and prioritise sustainable investments in road transport infrastructure**

The study highlights the pivotal role of South Africa's road transport network in ensuring access to essential services and supporting national economic development, particularly in the context of a limited rail system. However, a key concern emerging from the findings is the detrimental impact of unethical leadership practices, particularly political interference in procurement processes, which has compromised the quality, sustainability, and climate resilience of infrastructure projects. Tender processes often favour politically connected contractors over technically qualified service providers, resulting in poorly constructed roads that do not meet engineering standards and are highly vulnerable to climate-induced disasters such as flooding.

To address these challenges, the study recommends a shift toward ethical leadership that prioritises integrity, accountability, and professionalism in infrastructure governance. Procurement decisions must be guided by merit, technical competence, and a commitment to public service rather than political patronage. Engineers and technical experts should be empowered to enforce standards that align with resilience and sustainability goals. Additionally, consistent and equitable investment in infrastructure maintenance and the revitalisation of public transport systems is essential. Ethical leadership is critical to restoring public trust, promoting long-term infrastructure resilience, and ensuring that development serves both current and future generations.

- **Empower SANRAL to maintain and manage a greater portion of South Africa's road transport infrastructure and not only national roads**

Transport infrastructure is essential for South Africa's economic growth and social development, yet the fragmentation of maintenance responsibilities across national, provincial, and municipal levels has resulted in inconsistencies in road quality and safety. The study finds that the South African National Roads Agency (SANRAL) consistently outperforms provincial and local authorities in managing and maintaining road transport infrastructure (RTI), particularly in terms of adherence to standards, maintenance efficiency, and technical competence. However, SANRAL's current mandate limits its authority to national roads, with responsibility for urban and rural roads often falling to under-resourced local entities. To address this disparity, the study recommends expanding SANRAL's mandate through constitutional or legislative reform, allowing it to maintain and manage a broader share of the national RTI. This would ensure uniform maintenance standards, reduce political interference, and enhance the overall performance and resilience of the road network.

Furthermore, adherence to technical standards, such as those outlined in the drainage manual should be enforced across all road authorities. Enabling SANRAL to assist the National Department of Transport on the regulatory and oversight role, supported by sufficient resources, would strengthen coordination, ensure compliance, and result in a more sustainable and reliable road transport system nationwide.

5.7 RECOMMENDATIONS FOR FUTURE RESEARCH

Although the study successfully achieved its objectives, several areas remain open for further exploration that could significantly enrich the academic discourse and inform practice. Future research in the field of road transport infrastructure resilience would benefit from a more interdisciplinary approach that bridges engineering and the social sciences. Such collaboration is essential for developing solutions that are both technically robust and socially acceptable. Integrating shared frameworks, fostering co-creation processes, and promoting institutional learning can enhance innovation and responsiveness in infrastructure planning and management. To advance knowledge and practice in this area, the following recommendations for future research are proposed:

- **Examine RTI resilience to floods**: Conduct province-, district-, or municipality-specific studies to evaluate the resilience of road transport infrastructure (RTI) to floods.
- **Assess economic impact**: Investigate the economic consequences of floods on the road transport infrastructure industry.
- **Incorporate disaster planning**: Explore whether disaster planning and climate change adaptation are integrated into the design and planning of the country's road transport infrastructure.
- **Evaluate maintenance processes**: Provide an in-depth analysis of provincial and municipal road transport infrastructure maintenance processes.
- **Experiment with resilient materials and technologies**: Focus on small-scale studies to test new materials and innovative technologies for enhancing road transport infrastructure's resilience. Develop strategies to minimise the impact of extreme weather events, such as using durable and resilient materials in construction.

5.8 CONCLUSION

This study has underscored the growing urgency of enhancing the resilience of South Africa's road transport infrastructure to floods, given the increasing frequency and intensity of climate-related hazards. Drawing on both a thorough literature review and rich empirical data, the research highlights the crucial role of proactive planning, sound engineering, and institutional capacity in developing flood-resilient infrastructure. The findings reveal that while national roads managed by agencies like SANRAL often meet acceptable standards, many provincial and municipal roads suffer from poor construction quality, making them especially vulnerable during flood events. This disparity poses significant risks to mobility, economic stability, and public safety.

The study concludes that constructing resilient road infrastructure requires more than technical fixes, it demands strong policy frameworks, ethical leadership, long-term investment, and local capacity building. A key insight from the research is the importance of integrating resilience into the entire infrastructure lifecycle, from planning and design to maintenance and governance. Moreover, the study calls for greater policy attention to infrastructure resilience at sub-national levels, where vulnerability is often highest and institutional capacity weakest. By addressing its research objectives systematically, the study has not only fulfilled its primary aim but also laid a foundation for future work. It contributes to the growing body of knowledge on climate-resilient transport infrastructure in the Global South and offers a practical basis for policy reform and institutional change in South Africa's road sector. Moving forward, future research should build on this work by exploring flood resilience at provincial, district, and municipal levels, focusing on context-specific solutions and implementation challenges. In doing so, scholars and policymakers alike can drive more equitable, efficient, and climate-resilient infrastructure development across the country.

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ANNEXURE A: LETTER OF CONSENT

African Centre for Disaster Studies

Unit for Environmental Science and Management

School for Geo- and Spatial Sciences

Faculty of Natural Sciences

North-West University

Private Bag X6001

Potchefstroom

Northwest Province

2520 South Africa

29 February 2024

To Whom It May Concern

INTRODUCTORY LETTER FOR DATA COLLECTION: O. SITHOLE

Oscar Sithole, student Number 32263910, is registered for the Programme: Master of Science in Environmental Science with Disaster Risk Science at the North-West University. The title of his Dissertation is: ***"The Resilience of South African Road Infrastructure to Floods."*** The study has been approved by the Faculty of Natural and Agricultural Sciences Ethics Committee (FNASREC) with the ethics number N W U -0 1 3 0 3 - 2 3 - A 9.

As part of the empirical evidence for his study, the student is expected to collect data for the research study, and this is anticipated to take place from March 2024. Data will be collected from institutions and participants that operate at national level who are involved in road transport infrastructure both at policy and operational level. This includes, but not limited to, Department of Roads and Transport, State Owned Agencies and Road Construction Companies.

The North-West University is therefore requesting you to grant the student a permission to conduct the study. Take note that data collection will not infringe of participants' right as their participation will be **voluntary** and **confidential** and will be based on **informed consent**. The findings of the study will be used solely for the purpose of the study even though some articles might be published in national and international peer reviewed journals.

Kind regards

Livhuwani Nemakonde (PhD)

Associate Professor & Geography Subject Group Head

School of Geo- and Spatial Science

Unit for Environmental Science and Management

Northwest University

Potchefstroom Campus

Tel: +27 (0)18 299 1671

E mail: livhu.nemakonde@nwu.ac.za

Website: http://www.acds.co.za

http://www.nwu.ac.za

ANNEXURE B: RESEARCH PERMIT

SANRAL

BUILDING SOUTH AFRICA THROUGH BETTER ROADS

Reference:	Research Consent/OSithole	Fax Number:	+27 (0) 12 844 8200
Date:	26 March 2024	Direct Line:	**+27 (0) 21 957 4600**
Email:	harperh@nra.co.za	Website:	www.nra.co.za

Oscar Sithole
Northwest University (NWU)
sitholeoj@gmail.com

RE: REQUEST FOR PERMISSION TO CONDUCT RESEARCH FOR A MASTER OF SCIENCE DEGREE

I, Adolph Tomes, Business Operations Executive (Acting) of The South African National Roads Agency SOC Limited **(SANRAL)**, grant permission to Mr. Oscar Sithole to collect data at SANRAL for his Master of Science qualification research project, titled, "**The Resilience of South African Road Infrastructure to Floods".**

I grant this permission as the authorized person to do so in the South African National Roads Agency SOC Limited and am aware of the following:

1. The study is conducted as a researcher at the Northwest University (NWU) and remains the property of the Northwest University (NWU).
2. You may not use the name of the South African Roads Agency SOC Limited in your research project and instead use generic language describing the entity as a large state-owned entity under the authority of the Ministry of Transport.
3. All data and information collected will be solely for the purposes of research and will be in the possession of the researcher only.
4. Feedback of the research will be provided to me (SANRAL) and,
5. The research may be published in the public domain under the supervision of the academic supervisor, within the ethical boundaries of good research and without bringing the South African National Roads Agency SOC Limited into disrepute.
6. Permission will be granted subject to SANRAL having sign-off of the report before you submit. The relevant subject-matter expert and/or delegated authority in the area where the research is conducted will vet the final draft before submission and make recommendations or adjustments if need be.

I wish you everything of the best in your research studies.

ATomes

Findings must be shared with the relevant business unit.

A Tomes: Business Operations Executive (Acting)

Head Office 48 Tambotie Avenue, Val de Grace, Pretoria, 0184 | PO Box 415, Pretoria, South Africa, 0001 | Telephone +27 (0) 12 844 8000 Fax +27 (0) 12 844 8200

Email info@sanral.co.za | Visit us at www.sanral.co.za

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ANNEXURE C: ETHICS APPROVAL LETTER OF STUDY

NWU®
NORTH-WEST UNIVERSITY
NOORDWES-UNIVERSITEIT
YUNIBESITI YA BOKONE-BOPHIRIMA

Private Bag X1290, Potchefstroom
South Africa 2520

Tel: 018 299-1111/2222
Fax: 018 299-4910
Web: http://www.nwu.ac.za

Senate Committee for Research Ethics
Tel: 016 910 3446
Email: Feziwe.Mseleni@nwu.ac.za

ETHICS APPROVAL LETTER OF STUDY

Based on approval by the **Faculty of Natural and Agricultural Sciences Ethics Committee (FNAS-REC)**, the Faculty of Natural and Agricultural Sciences Ethics Committee hereby **approves** your study as indicated below. This implies that the North-West University Senate Committee for Research Ethics (NWU-SCRE) grants its permission that, provided the special conditions specified below are met and pending any other authorisation that may be necessary, the study may be initiated, using the ethics number below.

Study title: The resilience of South African road infrastructure to floods
Study Leader/Supervisor: Prof LD Nemakonde
Student: O Sithole

Ethics number:	N	W	U	-	0	1	3	0	3	-	2	3	-	A	9
	Institution				Study Number						Year			Status	

Status: S = Submission; R = Re-Submission; P = Provisional Authorisation; A = Authorisation

Application type: Single **Risk Category:** **Minimal**

Commencement date: 25/05/2023
Expiry date: 25/08/2024

Approval of the study is initially provided for a year, after which continuation of the study is dependent on receipt and review of the annual (or as otherwise stipulated) monitoring report and the concomitant issuing of a letter of continuation.

Special in process conditions of the research for approval (if applicable):

- The following documentation are archived by FNASREC and should be complete and kept up to date:
  - Research proposal
  - Signed approval from the scientific committee indicating the proposed risk category
- All researchers involved in the study should submit signed NWU code of conduct statements annually.
- All researchers of low risk studies should submit proof of relevant ethics training every two years.
- All researchers that take part in activities that pose a safety and security threat to the researchers or the environment should submit a risk assessment form annually.
- All research involving human interaction should follow best ethical practise and keep documents as proof. This includes informed consent, questionnaires, incorporation of risk-benefit, and responsible data management.
- Any research at governmental or private institutions, permission must still be obtained from relevant authorities and provided to the FNASREC. Ethics approval is required BEFORE approval can be obtained from these authorities.

Special conditions:
The best practices with regards to interviews should be implemented, including proper negotiation of access to participants; representative sampling; documented informed consent that includes the important elements; alignment of information collected with research questions; anonymization of collected information, ensuring the integrity and security of all data collected. If personal information is collected as part of the study, it will change the risk level of the project.
General conditions:
While this ethics approval is subject to all declarations, undertakings and agreements incorporated and signed in the application form, the following general terms and conditions will apply:

- *The study leader/supervisor (principle investigator)/researcher must report in the prescribed format to the FNASREC:*
    - *annually (or as otherwise requested) on the monitoring of the study, whereby a letter of continuation will be provided, and upon completion of the study; and*
    - *without any delay in case of any adverse event or incident (or any matter that interrupts sound ethical principles) during the course of the study.*
- *The approval applies strictly to the proposal as stipulated in the application form. Should any amendments to the proposal be deemed necessary during the course of the study, the study leader/researcher must apply for approval of these amendments at the FNASREC, prior to implementation. Should there be any deviations from the study proposal without the necessary approval of such amendments, the ethics approval is immediately and automatically forfeited.*
- *Annually a number of studies may be randomly selected for an external audit.*
- *The date of approval indicates the first date that the study may be started.*
- *In the interest of ethical responsibility, the NWU-SCRE and FNASREC reserves the right to:*
    - *request access to any information or data at any time during the course or after completion of the study;*
    - *to ask further questions, seek additional information, require further modification or monitor the conduct of your research or the informed consent process;*
    - *withdraw or postpone approval if:*
        - *any unethical principles or practices of the study are revealed or suspected;*
        - *it becomes apparent that any relevant information was withheld from the FNASREC or that information has been false or misrepresented;*
        - *submission of the annual (or otherwise stipulated) monitoring report, the required amendments, or reporting of adverse events or incidents was not done in a timely manner and accurately; and / or*
        - *new institutional rules, national legislation or international conventions deem it.*
- *FNAS-REC can be contacted for further information or any report templates via Roelof.Burger@nwu.ac.za 018 299 4269*

The FNASREC would like to remain at your service as scientist and researcher, and wishes you well with your study. Please do not hesitate to contact the FNASREC or the NWU-SCRE for any further enquiries or requests for assistance.

Yours sincerely,

Prof Roelof Burger
Chairperson Faculty of Natural and Agricultural Sciences Ethics Committee (FNASREC)

ANNEXURE D: FACE TO FACE INTERVIEW QUESTIONS

Topic: The resilience of South African Roads Infrastructure to floods.

Biographical information of participant/ participants

- Gender
- Age
- Institution where the participants work.
- Position in the institution.
- Types of work they do/ Responsibilities.
- Number of years in the service

1. **What is your understanding of resilience in road transport infrastructure?**
    - How resilient is or are South African roads and bridges to floods.
    - How can resilience be integrated into infrastructure design, maintenance, and management.
    - How can road design be improved to enhance resilience to extreme weather events?
2. **Robustness**
    - What is your understanding of robustness in road transport infrastructure?
    - What factors are considered when designing roads for them to be robust?
    - Can you provide an example of a road project that has successfully implemented robust design elements?
    - What techniques would you employ to improve road drainage and prevent flooding during heavy rainfall?
    - How does road robustness contribute to road safety (A competent candidate should be able to discuss how robust roads can contribute to reduced accidents, improved visibility, and better detection of hazards).
    - Can you walk me through the decision-making process involved in selecting materials or construction methods for a road project to enhance its robustness?
    - How would you prioritise maintenance activities on a busy road to ensure its robustness?
3. **Redundancy**
    - What is your understanding of redundancy in road transport infrastructure?
    - Why is road redundancy an important consideration?

- Do you plan for alternative routes in case of disturbances/emergences?
- In your experience, what are the main challenges faced in trying to complete activities related to road redundancy.
- Can you discuss any specific case studies where road redundancy has played a crucial role in mitigating disruptions or accidents?
- Can you describe the methods used to analyse and determine the optimal road redundancy design for a particular area?

4. Rapidity

- What is your understanding of rapidity in road transport infrastructure?
- Describe a recent project or initiative related to road rapidity in which you were involved.
- What are the potential challenges that can arise when implementing road rapidity initiatives?
- What challenges have you faced in your previous roles related to road rapidity? How did you overcome them?
- How do you ensure the reliability of road rapidity systems, considering factors such as network redundancy, system maintenance etc.
- What are your thoughts on the future of transportation infrastructure design?

5. Resourcefulness

- Does your institution have resources (financial and human) for maintaining road infrastructure?
- What are the obstacles that hinder roads maintenance?
- What are the pointers to indicate that the road needs to be maintained?
- How does your organisation mobilise resources required to achieve set goals?
- Explain how resourcefulness encompasses the ability to adapt to unexpected situations on the road.
- Can you give an example of a time when you encountered a difficult situation on the road and how you overcame it?

6. How can the construction of roads in SA be adapted to conform to the changes in climate?

- What measures can be taken to reduce the risks of road damage due to extreme weather conditions/events?
- How can existing road infrastructure be retrofitted to increase road resilience?
- What are the strategies employed by government agencies and other stakeholders to address climate change-related challenges in road construction in South Africa?
- What are the lessons learned from past experiences with road construction in South Africa that can be applied in adapting to changing climate conditions?
- What innovative design and construction techniques can be implemented to enhance road durability, resilience, and sustainability in the face of climate change?
- How vulnerable is the South African road transport infrastructure to extreme weather events?
- What measures should be undertaken to reduce the risk of road flooding.
- What are the negative consequences of floods on a transport system?
- How can different intervention measures enhance the initial resilience of a system?

ANNEXTURE E: ONLINE SURVEY QUESTIONNAIRE

Gender	Age	Position in the institution	Number of years in the service

- **South African roads and bridges are resilient to floods.**

Strongly Agree	Agree	Maybe	Disagree	Strongly Disagree
1	2	3	4	5

- **South African road transport infrastructure is vulnerable to extreme weather events.**

Strongly Agree	Agree	Maybe	Disagree	Strongly Disagree
1	2	3	4	5

- **Resilience can be integrated into infrastructure design, maintenance, and management.**

Strongly Agree	Agree	Maybe	Disagree	Strongly Disagree

- **Road design can be improved to enhance resilience to extreme weather events.**

Strongly Agree	Agree	Maybe	Disagree	Strongly Disagree

- **On a scale of 1-5 please rate the following: These are some of the factors that are considered when designing roads and bridges to be robust (1=Highly important and 5= least important)**

Developed guidelines and standards for roads and bridges	
The change of intensities of extreme weather events	
Research	
Consider road users	
Catchment management, materials used for example an un-sufficed road cannot withstand pressure of like longer compared to a sufficed road.	

- **Rate the following on a scale of 1-5: Robustness contributes to road safety (1=Highly likely and 5=least likely)**

Highly likely	Likely	Maybe	Not likely	Less likely
1	2	3	4	5

- **By using one lane or diverging traffic one would prioritise maintenance activities on a busy road to ensure its robustness**

Strongly Agree	Agree	Maybe	Disagree	Strongly Disagree
1	2	3	4	5

- **From a scale of 1-5 please rate the following: These are some of the factors considered when designing roads and bridges to be robust (1=Highly likely and 5= Less likely)**

Highly likely	Likely	Maybe	Not likely	Less likely
1	2	3	4	5

- **Road redundancy is an important consideration.**

Strongly Agree	Agree	Maybe	Disagree	Strongly Disagree
1	2	3	4	5

- **You plan for alternative routes in case of disturbances/ emergences?**

Strongly Agree	Agree	Maybe	Disagree	Strongly Disagree
1	2	3	4	5

- **Finance is one of the main challenges faced in trying to complete activities related to road redundancy and rapidity.**

Yes	No	Maybe

- **By having the right people to do the job, funds, avoiding the miss use of funds, considering factors such as network redundancy and system maintenance etc, one can ensure the reliability of road rapidity systems.**

Yes	No	Explain

- **South Africa still lacking/behind with a little bit of development when it comes to the future of transportation infrastructure design in South Africa.**

Yes	No	Explain

- **Road redundancy is an important factor to consider during floods.**

Yes	No	Maybe

- **Rate the following on a scale of 1-5: floods have a negative impact on South African roads (1=Likely and 5=Extremely so).**

Less likely	Likely	Neutral	Not likely	Extremely so
1	2	3	4	5

- **Shortage of finance hinders roads maintenance.**

Strongly Agree	Agree	Maybe	Disagree	Strongly Disagree
1	2	3	4	5

- **Would you say climate change is considered on road design?**

Yes	No	Maybe

- **Research, making sure that our infrastructure is resilient, road monitoring, etc these are some of the measures taken to reduce the risks of road damage due to extreme weather conditions/ events.**

Strongly Agree	Agree	Maybe	Disagree	Strongly Disagree
1	2	3	4	5

- **Research and development are some of the strategies employed by government agencies and other stakeholders to address climate change-related challenges in road construction in South Africa.**

Strongly Agree	Agree	Maybe	Disagree	Strongly Disagree
1	2	3	4	5

- **By aligning to sustainable development goals, coming up with proper systems that will sustain road infrastructure and development management, research etc. The above measures should be undertaken to reduce the risk of road flooding.**

Strongly Agree	Agree	Maybe	Disagree	Strongly Disagree
1	2	3	4	5

- **Would you rate the negative consequences of floods on road transport in South Africa on a scale of 1-5 (1=Highly likely and 5= less likely).**

Highly likely	Likely	Maybe	Not likely	Less likely
1	2	3	4	5