PROJECT ID:

"DEVELOPING A PANDEMIC RESILIENCE FRAMEWORK FOR HIGHWAY PROJECTS: CASE OF COVID -19 DISEASE IN RWANDA"

A DISSERTATION

Submitted by

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DECLARATION

I Jean Paul KAMALI, with Reg. No 221028269, from University of Rwanda College of Science and Technology, School of Engineering; Department of Civil, Environmental and Geomatics Engineering, following studies of Master of Science in Highway Engineering and Management Program, hereby declare that this work is of my original and has never been submitted for any academic award in any other University or Institution or anyone else where he/she had the same purpose.

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CERTIFICATION

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DEDICATION

This project is dedicated to God and my loving, caring, and hardworking family, whose efforts and sacrifices have made my goals of obtaining this degree come true. Words cannot fully express my gratitude to all. I pray that you will live long enough to reap the results of my work.

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God has done tremendous things. I appreciate your excellent provisions, protections, and assistance throughout this Journey.

My gratitude also goes to my family for their encouragement and ideas as I develop in life.

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ABSTRACT

Covid-19 pandemic have not only significantly disrupted the highway construction projects worldwide but also in Rwanda. Leading to the delays, increased costs, workforce shortage and supply chain disruptions. The aim of this project was to develop a pandemic resilience framework for highway construction projects in Rwanda to mitigate the adverse impact of future pandemics and improve construction efficiency. We examined the major five highways projects undertaken during the covid-19 pandemic period, such chosen project are Nyagatare-Rukomo road upgrading project (73 Km); Upgrading works of Huye-Kibeho-Ngoma/Munini (66.3Km); Asphalt Road Pindura- Bweyeye Upgraded (32 km); 13 Km(Sonatubes-Gahanga) of urban roads in CoK and other secondary Cities were constructed and Maintenance of 65km Kigali- Kayonza road. The mixed methods of surveys and interviews and Focus Group Discussions were used in data collection from the different key informant including Client (RTDA and Government Agency), Consultants (Astrik International, CRBC, Etc.) and contractors (NPD, HNRB, Real contractors). The study identified the primary challenges faced during the pandemic, evaluated the effectiveness of mitigation strategies implemented and proposed a structured roadmap to enhance resilience in future highway construction projects. This study provides the valuable insights for police makers, construction firms and government agencies to enhance the resilience and sustainability of Rwanda's highway sector.

Keywords: Highway construction, infrastructure, covid-19, Pandemic resilience, Risk Mitigation

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LIST OF ABBREVIATIONS

%: Percentage

GDP: Gross Domestic Product

HIV: Human Immunodeficiency Virus

AIDS: Acquired Immunodeficiency Syndrome

RTDA: Rwanda Transportation Development Agent

CoK: City of Kigali

BIM: Building Information Modeling

ESIA: Environmental and Social Impact Assessments

HCM: Highway Capacity Manual

OxCGRT: Oxford COVID-19 Government Response Tracker

UAE: United Arab Emirates

NS: Not significant

CHAPTER ONE

INTRODUCTION

1.1.Background to the study

The construction industry is globally recognized as a dynamic sector that significantly contributes to the economic growth of nations by fulfilling key development objectives, such as generating employment, income, and output, with expectations that the volume of global construction output will grow by 85% to $15 trillion by 2030 (Dosumu & Mahame, 2022). In Rwanda, the construction industry is equally vital to the national economy, accounting for about 7% of the national GDP and 8% of employment over the last five years. The sector is projected to continue to grow at an annual rate of 9%, positioning it as the second-fastest-growing construction industry in Sub-Saharan Africa (Dosumu & Mahame, 2022).

The construction industry encounters numerous global challenges, which are heightened by socio-economic pressures, persistent resource shortages, and institutional weaknesses (Charef et al., 2021). Further, diseases like cardiovascular illnesses, cancer, and malaria continue to pose significant health threats. Infectious diseases can spread rapidly, thus overwhelming the healthcare systems and causing widespread disruption (Biselli et al., 2022). An example is the COVID-19 pandemic that led to global lockdowns and prompted major shifts in how nations approach public health management across the economic sectors (Morel et al., 2021).

While the above challenges have hampered the progress of many industries, the construction industry was particularly affected in many ways that lead to divesting effects on the productivity of the sector, the health of workers, and the growth of the nations. For instance, when the COVID-19 disease broke out in 2019, it rapidly spread and became a global pandemic (Bhatt et al., 2021). After the public health emergency issued by the World Health Organization, to slow down the increasing number of cases day by day, many countries chose to impose nationwide lockdowns as a rapid action (Jung et al., 2020).

COVID-19 lockdowns were implemented globally as governments sought to control the pandemic. In the United States of America, California's state-wide lockdown began on March 19, 2020, followed by New York on March 22 (Ren, 2020). India imposed one of the strictest lockdowns worldwide on March 25, 2020, affecting over a billion people (Ray & Subramanian, 2020). Italy initiated a nationwide lockdown on March 9, 2020, making it the first country in Europe to implement, and Spain followed on March 14, 2020 (Martucci, 2021).

In Africa, South Africa enforced a lockdown on March 27, 2020 (Migliori et al., 2022). Similarly, the Rwanda government officially commenced lockdown on 22nd March 2020 and continued partial lockdown in different districts of the country (Musanabagnwa et al., 2020). Due to the lockdown and other health-related impacts of the disease, the COVID-19 pandemic affected almost every aspect of the construction process such as supply chain delays and impacts, scheduling and adjustment of contract or project notices for defaults, project suspension, termination, and reinstatement, Occupational Safety and Health Administration (OSHA) and workplace safety compliance, workforce, material, subcontractor management, and insurance, claims avoidance/ management, and the disputes process (Ataei et al., 2021).

The COVID-19 lockdown in Rwanda caused major disruptions in the construction sector, as the freeze on non-essential activities led to delays from supply chain interruptions, workforce shortages, and rising costs associated with health protocols, placing financial strain on firms (Rwigema , (2020). Additionally, safety measures such as travel restrictions, social distancing, and quarantines further delayed projects, increased costs, and created uncertainty in project delivery. The absence of government workers for inspections exacerbated the situation, resulting in the suspension or abandonment of new and ongoing projects to curb transmission (Adhikari & Poudyal, 2020; Alsharef et al., 2021). Hence, the impact of the COVID-19 pandemic profoundly decimated the lives of construction workers and the completion time, cost, and quality of construction projects. While substantial research has been conducted in many areas of the global pandemic, especially COVID-19, a few studies have channeled efforts toward the resilience of global pandemics like COVID-19, especially in developing countries like Rwanda. Yet an investigation is crucial to prevent the future loss of lives and properties. Africa appears to be more on the receiving end because of its overreliance on the approval of the Western world's dominance. Therefore, this study investigates the pandemic resilience strategies to develop a framework to prevent future unpalatable experiences on highway projects in Rwanda.

1.2.Statement of research problem

The COVID-19 pandemic has been an unprecedented global event, disrupting economies, societies, and industries worldwide. Its far-reaching effects have reshaped how sectors operate, highlighting vulnerabilities and prompting the need for adaptive strategies. Kawmudi et al. (2021) investigated the challenges imposed by the COVID-19 pandemic on Sri Lankan construction projects and found the major obstacles to be delays in project completion, issues with supply chain management, and changes in public perception regarding site operations. Kassem et al. (2023) conducted research on the impacts and Response strategies of the COVID-19 pandemic in the construction industry using structural equation modeling. The study found that it is necessary to focus on the impacts related to the project, develop the obligatory strategies from a financial point of view, and supply the required materials and equipment. It further proposed that organizational management, information exchange, and a project's workforce, provision should be enhanced during a similar occurrence. The researcher however failed to establish a set of guidelines for the resilience of future global pandemic occurrences.

Pamidimukkala and Kermanshachi (2021) evaluated the impact of COVID-19 on the field and office workforce in the construction industry and discovered that the project managers and authorities in the construction industry understand the challenges of the pandemic and adopt effective strategies that will improve the health and safety of their workforce. However, a resilience framework to improve future occurrences on the health and safety of their workforce was not developed thus leading to increased risks in construction environments. Additionally, the absence of such a framework undermines compliance with regulations and construction industry standards, potentially exposing the organization to legal risks and reputational harm.

AlMaian and Qammaz(2023) investigated the learning role in construction organizations' resilience during the COVID-19 pandemic. It was discovered that organizational learning practices can help construction organizations navigate the threats posed by pandemics and create new opportunities categorized into enhancing management awareness, investing in information and communication technology (ICT), and adopting standardized business practices. However, the resilience framework on management awareness, ICT investment, and standardized business practices was not developed for adaptive decision-making during the COVID-19 pandemic.

Chih et al.(2022) investigated the resilience of organizations in the construction industry amid COVID-19 disturbances, highlighting the urgent need for response strategies to enhance both short-term and long-term performance. They proposed a roadmap for construction organizations to systematically scan their environments for threats or opportunities (sensing), formulate response strategies (seizing), and build resilience over time (reconfiguration). However, a specific pandemic resilience framework was not developed, underscoring the need for such a framework to prevent future adverse occurrences.

The absence of a pandemic resilience framework may lead to grave consequences for construction projects and workers in the future. It will affect the performance of nations in terms of infrastructure development, employment, and socio-economic values. It will lead to a repeat or a more grievous situation than the havoc wrecked by the Covid 19 pandemic. Therefore, developing a roadmap for completing resilience against future pandemics is expedient, especially for developing countries like Rwanda. Thus, this study aims to fill this gap by raising a pandemic resilience framework for highway construction projects, complementing existing global research on the pandemic, and improving communication and project management efficiency.

1.3 Research questions

The following research questions have been developed for this study:

1. What were the adverse impacts of covid 19 on highway construction projects and workers?
2. What strategies were adopted to mitigate the impact of Covid 19 on highway construction projects and workers?
3. What are the steps to prevent the future adverse impacts of a pandemic on highway construction projects and workers?
4. Can a pandemic resilience framework be developed for highway construction projects and workers?

1.4. Aim and objective of the study

1.4.1. Aim of the study

The aim of the study is to develop a pandemic resilience framework for construction highway projects in Rwanda to prevent future adverse effects and improve construction efficiency.

1.4.2. Objectives of the study

The objectives of this study are:

1. To identify the adverse impacts of COVID-19 on highway construction projects and workers.
2. To evaluate the strategies adopted to mitigate the impact of COVID-19 on highway construction projects and workers.
3. To establish the steps to prevent the future adverse impacts of pandemics on highway construction projects and workers.
4. To develop a pandemic resilience framework for highway construction projects and workers.

1.5. Scope of the study

The Scope of this study Focus on developing pandemic resilience framework specifically for highway Project in Rwanda. This framework addresses Key Areas, Including Health and Safety Protocols, Workforce management, Digital infrastructure and Remote Monitoring and Supply Chain Management.

Rwanda is an ideal choice due to its strategic location as a regional hub and ambitious infrastructure growth, which is crucial for enhancing economic connectivity and development. This study has prioritized Kigali, border regions, and key economic areas to protect trade, connectivity, and essential industries during disruptions. The focus on highway projects is significant, because this is the backbone of trade and mobility, important for national and regional economic resilience. Finally, Engineers and project managers has been Identified as key respondents for this study, given their central role in coordinating operations, managing resources, and ensuring timely project delivery, which are vital for adapting to and mitigating pandemic-related disruptions.

1.6. Justification of the study

The COVID-19 pandemic has underscored the critical need for robust resilience frameworks in various sectors, including highway construction. In Rwanda, highway projects are vital for economic development, facilitating trade, connectivity, and access to essential services. Identifying the adverse impacts of COVID-19 on highway projects and workers yields significant benefits in managing and mitigating these challenges effectively. By understanding how the pandemic disrupts project timelines, delays procurement processes, and affects material availability, stakeholders can implement targeted strategies to maintain construction schedules and minimize economic losses. Recognizing the health risks faced by workers allows for the implementation of stringent safety protocols to safeguard their well-being, thereby ensuring continuity in project execution.

Evaluating strategies to mitigate the impact of COVID-19 on highway projects and workers offers significant benefits. It allows stakeholders to assess the effectiveness of health and safety measures, ensuring they adapt to evolving conditions. Successful strategies for maintaining project timelines and supply chain stability can be identified and replicated in future projects. The evaluation also provides insights into financial implications, optimizing budget allocations for greater efficiency. Establishing steps to prevent future adverse impacts of pandemics on highway projects offers numerous benefits. It fosters a proactive approach, ensuring swift responses to disruptions and maintaining project timelines while enhancing worker safety through clear health protocols. Additionally, it improves supply chain resilience, facilitates better financial planning, and ensures operational continuity, promoting sustainable development in the construction industry.

Developing a pandemic resilience framework for highway construction projects ensures worker safety through robust protocols and enhances project continuity by preparing for disruptions. It strengthens supply chain management with contingency planning and supports better financial planning to mitigate unexpected costs and avoid budget overruns. Global, this framework promotes a resilient and adaptable construction industry capable of withstanding future health crises and ensuring sustainable infrastructure development.

1.7. Definition of terms

COVID-19: is defined as an illness caused by a novel coronavirus called severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2; formerly called 2019-nCoV), which was first identified amid an outbreak of respiratory illness cases in Wuhan City, Hubei Province, China.

Construction industry: The national economy sector engaged in land and construction planning, modification, and renovation of buildings, infrastructure, and real estate.

Commercial risks: Broadly cover all non-political risks. These may include, for example, completion and financing risks in the construction phase and demand, or supply and exchange rate risks in the operational phase of infrastructure projects.

A pandemic: is the widespread occurrence of a disease across a large geographic area, affecting a substantial portion of the population.

Resilience: refers to the ability of individuals, communities, systems, or organizations to withstand, adapt to, and recover from adverse situations, challenges, or disruptions.

Workforce: refers to the group of people who are employed or available for employment in a specific organization, industry, sector, or geographic area.

Roadmap: a strategic plan or guide that outlines the steps, milestones, and actions needed to achieve a specific goal or vision over a defined period**.**

Supply chain: refers to the interconnected network of organizations, people, activities, information, and resources involved in producing and delivering a product or service from its origin to the final customer

Respondents: a person or entity who gives information, answers questions, or responds to inquiries in a specific context. The term is commonly used in surveys, research studies, legal proceedings, and interviews.

CHAPTER TWO

LITERATURE REVIEW

2.1. Introduction

This chapter briefly explains the COVID-19 pandemic and resilience framework for highway projects and it identifies the pandemic's adverse impacts on highway construction projects and workers, evaluates mitigation strategies, and establishes a roadmap to prevent future disruptions. By integrating these insights, the framework aims to enhance the resilience of highway construction and protect workers, supporting sustainable infrastructure development in the face of potential crises

2.2 History of Pandemic and their Occurrence

A pandemic refers to the occurrence of an infectious disease outbreak across a vast geographical area, affecting a substantial portion of the global population. It involves the rapid spread of a new pathogen for which there is limited pre-existing immunity, allowing the disease to spread more easily (Trovato et al., 2020). According to (Morens and Fauci, 2020) pandemics are distinguished by their potential to cause widespread health crises due to the novel nature of the pathogen. As these diseases spread globally, they tend to overwhelm healthcare systems and significantly disrupt societies. The following are the catalogue of pandemics that have ravaged the world in the past:

2.2.1 **The Antonine Plague (165–180 AD)**

The Antonine Plague (165–180 AD) was one of the earliest recorded pandemics, possibly caused by smallpox or measles. It devastated the Roman Empire, leading to an estimated 5 million deaths and weakening the empire's military and economic strength (Harbeck et al., 2016)

2.2.2 Justinian Plague (541–542 AD)

Similarly, the Justinian Plague (541–542 AD), caused by Yersinia pestis, killed up to 50 million people and marked the beginning of the Byzantine Empire's decline (Stathakopoulos, 2017).

2.2.3 The Black Death (1347–1351)

also caused by *Yersinia pestis*, is one of the most notorious pandemics in history. It wiped out an estimated 30-60% of Europe's population, leading to severe labor shortages and economic upheaval, while also sparking social changes such as the weakening of feudalism (Benedictow, 2004).

2.2.4 Cholera Pandemic (1852–1860)

In the 19th century, the Third Cholera Pandemic (1852–1860) spread across Asia, Europe, and North America, killing over a million people. It prompted major public health reforms, especially improvements in sanitation and clean water systems (Hays, 2005).

2.2.5 Influenza Pandemic (Spanish Flu)

In the 20th century, the 1918 Influenza Pandemic (Spanish Flu) infected a third of the global population and caused an estimated 50 million deaths, making it one of the deadliest pandemics of modern times. Its effects were exacerbated by World War I, and it strained healthcare systems globally (Taubenberger and Morens, 2006). The Asian Flu (1957–1958), caused by the H2N2 influenza virus, led to 1-2 million deaths worldwide, particularly impacting children and the elderly, while spurring the development of flu vaccines (Kilbourne, 2006).

2.2.6 The HIV/AIDS pandemic

The HIV/AIDS pandemic, which began in the 1980s, continues to affect millions globally. More than 36 million people have died from AIDS-related illnesses, and the virus has caused major public health crises, particularly in sub-Saharan Africa. Its long-term social and economic effects have included a significant loss of workforce and the strain on healthcare resources (Sharp and Hahn, 2010). The 2009 H1N1 Influenza Pandemic (swine flu) was milder in terms of fatality but still caused significant global disruption, with an estimated 151,700 to 575,400 deaths worldwide (Dawood et al., 2012).

The effects of pandemics are far-reaching, with significant health, economic, and social impacts. In terms of health, pandemics cause widespread mortality and strain healthcare systems to the brink of collapse. Economically, they disrupt trade, cause unemployment, and lead to recessions, as seen during COVID-19 (Nicola et al., 2020). Socially, pandemics cause panic, fear, and isolation, contributing to psychological stress and long-term mental health challenges, particularly due to quarantine and lockdown measures

2.2.7 The Covid-19 Pandemic

COVID-19 stands for **Coronavirus Disease 2019**, refers to a family of viruses known as *Coronaviridae*, which were primarily responsible for causing respiratory infections in humans and animals (Baloch et al., 2020). These viruses were characterized by their distinctive crown-like spikes on the surface, giving them the name "corona" (meaning "crown" in Latin). Coronaviruses ranged in severity from causing mild respiratory illnesses, such as the common cold, to more severe diseases like Severe Acute Respiratory Syndrome (SARS) and Middle East Respiratory Syndrome (MERS) (Nassar et al., 2021). The most recent and widely known member of this family was SARS-CoV-2, the virus responsible for the COVID-19 pandemic, which emerged in late 2019 (WHO, 2020).

SARS-CoV-2, like other coronaviruses, spreads primarily through respiratory droplets when an infected person coughs, sneezes, or talks (Ranga, 2021). While many people infected with the virus experienced mild symptoms, such as fever, cough, and shortness of breath, others especially older adults and those with underlying health conditions like cardiovascular disease, diabetes, or chronic respiratory diseases were more susceptible to severe complications, including pneumonia, organ failure, or death (Dhand and Li, 2020). The rapid global spread of COVID-19 led to widespread public health measures, including social distancing, mask mandates, and vaccination campaigns, all aimed at reducing transmission and managing the healthcare burden (Filip et al., 2022).

COVID-19 spreads through multiple pathways, including contact, droplets, airborne particles, and fomites (Chen, 2021). The infection primarily caused respiratory illness, ranging from mild symptoms to severe complications and even death, and some infected individuals remained asymptomatic (Nam and Ison, 2019). SARS-CoV-2 transmission occurs through direct, indirect, or close contact with an infected person’s secretions, such as saliva or respiratory droplets, which are expelled when coughing, sneezing, talking, or singing, generally within a 1-meter range (Yenny et al., 2021). Airborne transmission happens when tiny droplets, or droplet nuclei, linger in the air over long distances and time (Randall et al., 2021). Respiratory droplets could also settle on surfaces, creating fomites (contaminated surfaces), and although SARS-CoV-2 was shown to survive on certain surfaces, there was no definitive evidence proving fomite transmission (Ijaz et al., 2023). People who came into contact with potentially contaminated surfaces often also had close contact with an infected person, making it challenging to distinguish between respiratory droplet and fomite transmission (Stephens et al., 2019). Key preventive measures included surface disinfection, hand hygiene, and personal protective equipment like masks and eye protection (Rai et al., 2020). COVID-19 is an airborne and surface-transmitted contagious disease marked by symptoms such as fever, shortness of breath, and coughing (Pradhan et al., 2020).

2.3. The adverse impacts of COVID-19 on construction highway projects and workers

This section Discuss the Impacts of Covid-19 on Highway construction Project and Workers from the experience of different countries as it were observed by different researches and Publications.

2.3.1. Adverse Effects of Covid 19 on construction projects

According to **Timilsina et al., (2021),** the construction industry of Nepal was affected at three levels: financial, operational, and institutional. **Government budget cuts** have reduced the number of construction projects available due to the COVID-19 pandemic. Additionally, contractors are facing worsening financial conditions due to the industry's poor performance, along with issues such as delayed payments and project cost overruns. On the operational side, impacts include **delays in project completion**, **supply chain disruptions**, **challenges in workforce management**, and **ensuring worker health and safety**. On the institutional side, the industry has faced a lack of adequate support, with no special packages or incentives from the government, and minimal support from professional associations to navigate the crisis. Furthermore, there is a shortage of skilled labor at the local level in the construction industry.

In Ethiopia, covid-19 severely disrupted the construction industry (Gashahun, 2020). While the pandemic did not entirely make project completion impossible, it **caused delays and disruptions**, primarily due to the severe disruption of supply chains. In particular, temporary workers and daily laborers in construction were most affected, as small and medium projects faced a sharp decline in demand, leading to a complete loss of income for these workers (Chetty et al., 2020). Overall, the Ethiopian construction industry experienced major challenges, including shortages and rising costs of construction materials, limited availability of foreign currency, reduced productivity, labor shortages, project delays (resulting in time extensions), and increased costs

Mohsen et al. (2021) Discovered that COVID-19 had a significant impact on Malaysia's industries, with the construction sector facing multiple challenges. These included **extended project timelines, disrupted revenues**, **delayed permits**, **travel restrictions**, **major health and safety concerns**, and shortages of labor and equipment. All these factors hindered the timely completion of infrastructure projects.

Umar (2022) similarly analyzed the key impacts of COVID-19 on GCC (Gulf Cooperation Council) and the construction industry, focusing on **project delays, workforce management, health and safety concerns, and legal issues**. In the GCC region, the primary factors contributing to project delays include border closures, a reduced workforce at construction sites, **and disruptions in supply chain management** (Khalafallah et al., 2022).

In Oman, the construction industry employs a significant portion of the labor force and bore the largest share of labor and unemployment (Al Amri and Marey-Perez, 2020). With the rapid spread of COVID-19, Oman implemented checkpoints and restricted major industrial supplies (Saidi et al.). **Many construction projects were suspended**, while others **faced delays**, resulting in **substantial financial losses** (Al-Mohsin, 2012). The reduction in construction activity was expected to **increase the unemployment rate in the country** (Al Amri, 2021). However, the industry already suffered from a shortage of skilled workers (Al Amri and Marey-Perez, 2020). The ongoing pandemic was likely to further reduce the number of both Omani and expatriate construction workers (Al Fahdi et al., 2021).

Sami Ur Rehman et al. (2022) Explored the impact of COVID-19 on project performance in the UAE (United Arab Emirates) construction industry. The industry encountered numerous challenges, i**ncluding project schedule delays, disrupted cash flows, postponed permits, approvals, and inspections, travel restrictions, significant health and safety issues, and shortages of materials and equipmen**t. These factors, among others, impeded the timely completion of construction projects.

Chaudhary et al. (2020) observed that the widespread effects of COVID-19 in India's construction industry led to unforeseen financial losses, unexpected obstacles, and difficult conditions, contributing to both global and national economic recessions. (Sahoo and Ashwani, 2020) highlighted that the construction industry has been significantly affected by **reduced demand, project delays, and the prolonged impact of lockdowns on supply chain management and**

labor mobility. Over 30% of the workforce left construction sites due to **fears of contracting** the disease, greatly affecting project completion rates.

The construction industry was one of the hardest hit by **supply chain disruptions** caused by the COVID-19 pandemic (Raj et al., 2020). Economic recessions and widespread market uncertainty led project owners to reconsider both new investments and ongoing construction projects during the pandemic's initial two years (Alsharef et al., 2021). Despite this, many U.S. cities and states classified construction as essential, so it did not completely halt. However, due to supply chain issues and **labor shortages**, some projects were forced to pause or find alternative materials (Khalef et al., 2022)

The COVID-19 pandemic caused widespread disruptions to global supply chains, particularly in the construction industry (Meier and Pinto, 2020). One of the primary challenges was the severe **shortage of construction materials**, as factories worldwide were forced to shut down or reduce their operations due to lockdowns and health regulations (Xu et al., 2020). Key materials such as steel, cement, and aggregates experienced significant delays in production, leading to **project delays and rescheduling in many construction projects** (Tanjangco et al., 2021).

In many countries, construction projects were completely halted during the peak of lockdowns. For instance, in Europe and North America, governments imposed restrictions that forced construction sites to close or operate with limited capacity (Goniewicz et al., 2020). The World Bank noted that these interruptions were particularly severe in large-scale infrastructure projects, where even a short halt in work could lead to months of delays (World Bank, 2020). This was compounded by the need for new health and safety protocols, such as ensuring adequate distancing between workers and implementing rigorous cleaning procedures, which further slowed down construction activities (Russell, 2020).

2.3.2 Adverse effects of Covid-19 on construction workers

The pandemic's impact on the construction industry varied significantly across countries where the impact of the COVID-19 pandemic has reached beyond construction projects, significantly **affecting the mental well-being of the construction workforce** (Helliwell et al., 2021). The virus and related factors such as **physical distancing, fear of infection, and job loss have heavily impacted workers' mental health** (Alsharef et al., 2021). Many construction workers experienced **increased levels of stress, anxiety, and depression**, with some even developing post-

traumatic stress disorders. The pandemic **disrupted their daily routines and priorities**, shifting their outlook on work and intensifying concerns over their safety and livelihoods (Russell, 2020). Additionally, the social stigma and discrimination associated with the virus further heightened the psychological strain on workers. These mental health challenges directly influenced project performance, as workers' well-being significantly affected their motivation, concentration, and overall ability to work effectively (Albrecht, 2012).

In the United Kingdom, the Construction Leadership Council **introduced operating guidelines that enforced social distancing, routine sanitization, and mandatory use of personal protective equipment (PPE)** (Stiles et al., 2021). Similarly, Australia introduced detailed site safety protocols, including the installation of additional handwashing stations and contact tracing systems (Felsenstein et al., 2020). In South Africa, workplace monitoring measures such as mandatory temperature checks and health screenings were implemented to safeguard workers' health (Husien et al., 2021).During natural disasters, the workers working on construction projects help the general public in affected areas and allow the most affected parties to have access to these areas on a priority basis (Assaad and El-adaway Islam, 2021) .

It was reported that 68% of construction workers experience **excessive pressure in their jobs** (Jebelli et al., 2018). On one hand, **financial strain and unemployment** caused by delayed or suspended construction projects increase **job insecurity for workers** (King and Lamontagne, 2021). On the other hand, the high infection and mortality rates associated with COVID-19 have triggered fear and panic among construction workers. These factors, coupled with the unique demands of the construction industry, are expected to further deteriorate both the **psychological and physical well-being of workers** (King & Lamontagne, 2021)

In India, the COVID-19 pandemic had a severe impact on construction workers, especially **migrant laborers** (Ranjan, 2020). With nationwide lockdowns, **many workers were left stranded on construction sites or forced to return to their rural hometowns**, which resulted in significant disruptions to ongoing projects (Adhikari and Poudyal, 2021). The sudden exodus from cities not only depleted the workforce but also led to a shortage of skilled laborers, hampering the completion of construction projects on schedule (Khanna et al., 2020). Furthermore, the lack of government support and insufficient safety measures on worksites worsened the situation, **leaving workers vulnerable to both health risks and financial instability** (Ferdos and Islam, 2023).

in Mexico, the construction sector faced **widespread delays and workforce displacement** due to COVID-19, Many workers, particularly those in **informal employment**, were either temporarily laid off or left their jobs due to the **unsafe working conditions** created by the pandemic (Cook et al., 2020). The closure of construction sites and reduced project demand resulted in **financial instability for many workers** (Prieto-Silva et al., 2023). The Mexican construction industry, which depends on a high number of informal workers, found it challenging to maintain adequate health and safety standards during the pandemic (Alfaro et al., 2020).

According to (Husien et al., 2021) In developed countries, where formal labor laws and safety standards are better enforced, workers often have **access to medical support and receive some form of financial assistanc**e (Gerard et al., 2020). However, in regions like Southeast Asia and Latin America, where a large percentage of the construction workforce **operates informally, workers faced severe financial hardship and limited access to healthcare**, which heightened their vulnerability to COVID-19 (Wijayaningtyas et al., 2022). Countries with extensive informal **labor forces struggled with enforcing health and safety measures**, leading to a more rapid spread among workers and their families (Canton, 2021).

Psychologically, construction workers in Italy, Spain, and France reported **increased levels of stress and anxiety** (Thibaut and van Wijngaarden-Cremers, 2020). Uncertainty about job security, fear of contracting the virus, and social isolation exacerbated mental health issues, which were already prevalent in the industry (Dubey et al., 2020). These **psychological impacts were compounded by the nature of construction work**, which often **lacks adequate support systems or mental health resources, making workers in many countries particularly vulnerable to stress and burnout** (ILO, 2020).

These disruptions resulted in lost wages and extended **unemployment for workers globally** (Yu et al., 2021). In Canada and the United Kingdom, where government support programs were implemented, workers fared somewhat better financially (Picot and Hou, 2023). However, in countries like India, where **lockdowns halted nearly all construction activity**, **many migrant workers were stranded without income or shelter, highlighting the social and economic inequities in the secto**r (Shrivastava et al., 2020). With many projects halted or delayed, construction workers across Africa experienced severe wage cuts and job losses (Aigbavboa et al., 2022). In countries like Ghana and Ethiopia, workers in the informal construction sector, who were already financially vulnerable, faced substantial income reductions, leading to widespread economic hardship (Mella and Savage, 2018)

According to (Debata et al., 2020) COVID-19 has had a profound impact on people, the environment, and the economy. In India's construction sector, which employs over 51 million people, including construction professionals and both skilled and unskilled workers, the pandemic triggered a severe shock (Rani et al., 2022). **Migrant workers faced significant challenges such as income loss, panic over the disease, and food shortages, additionally, temporary closures in various sectors resulted in substantial revenue losses** (Kuriakose et al., 2022) .

2.4. The strategies adopted to mitigate the impact of COVID-19 on construction projects and workers.

This section explores the Various Strategies Implemented Globally to address the unprecedented challenges posed by covid-19 pandemic on the construction industry, Focusing on both project and workforce.

2.4.1 The strategies adopted to mitigate the impact of COVID-19 on construction projects

Jeanne et al. (2023) highlighted that Provides empirical evidence for policymakers to justify investment in transport infrastructure. To mitigate the impacts of the COVID-19 pandemic on construction project.

Iqbal et al. (2021) Many countries adopted rigorous safety measures to minimize the spread of COVID-19 on construction sites. The COVID-19 pandemic severely **disrupted the construction sector's supply chains**, necessitating the adoption of robust mitigation strategies to ensure project continuity (Ghansah and Lu, 2023). **Construction companies diversified suppliers**, including local vendors, to reduce dependency on a single source and mitigate risks from international trade restrictions and delays (Ivanov and Dolgui, 2020). **The adoption of digital tools and technologies played a pivotal role in addressing supply chain** challenges during the pandemic (Dubey et al., 2023). Construction firms **utilize advanced technologies like block chain, artificial intelligence** (AI), and **predictive analytics to enhance supply chain visibility and efficiency** (Ogundipe et al., 2024a). **Block chain-enabled real-time tracking of shipments, ensuring transparency and accountability**, while **AI-powered tools helped predict potential disruptions and optimize procurement plans** (Sabri and Amir, 2024).

Inventory management strategies were also crucial in mitigating supply chain disruptions (Kamalahmadi and Parast, 2016). Many construction companies shifted from just-in-time to just-in-case inventory models, **increasing safety stock levels** to ensure material availability during delays (Elwood, 2020). This approach, while involving higher storage costs, minimized project downtime and ensured the continuity of critical operations (Chowdhury et al., 2021). Additionally, prioritizing essential materials and equipment allowed projects to progress without significant interruptions

Government support and policy adjustments, including expedited customs clearance, financial incentives for local manufacturing, and relaxed import/export restrictions, significantly mitigated the impact of COVID-19 on the construction supply chain by ensuring access to essential materials and equipment despite global disruptions (Schleicher, 2020). T**he collaboration between the public and private sectors** underscored the importance of coordinated efforts in overcoming supply chain challenges in the construction industry (Caldwell et al., 2017)

Contract renegotiation also played a pivotal role in mitigating cost overruns (Xiong et al., 2018). By introducing flexible contract terms, such as **force majeure clauses and provisions for cost-sharing, construction firms** were able to address unexpected expenses caused by delays and disruption (Iossa et al., 2007). This approach not only minimized disputes between stakeholders but also provided a framework for equitable risk allocation (Pettit et al., 2021).

Intelligent software has become essential in construction projects, contributing significantly to planning, ordering, and bidding processes (Wong et al., 2005). **Analyzing available data** can identify where, when, and how tasks should be executed, as well as their associated costs (Costin et al., 2018). This data-driven approach enhances efficiency and supports informed decision-making, helping construction projects adapt to the challenges posed by COVID-19. Technological solutions take all of this data into account to ensure that contractors perform as effectively as possible regardless of the solution (Costin et al., 2018).

Raoufi and Fayek (2020) identified 177 potential actions for controlling and mitigating the effects of the pandemic, organized into 16 categories. The top five categories were health and public health directives, global economic impact on the construction market, workforce, communication, and suppliers and subcontractors.

2.5.2 The strategies adopted to mitigate the impact of COVID-19 on construction workers

The project workforce, comprising both skilled and unskilled laborers, is essential to the construction industry. Therefore, all necessary measures and available resources should be utilized to **protect this workforce from risks and severe health impacts** (Investigators, 2021). This forces all key players in the implementation of projects, whether construction organizations or contractors, to develop new occupational safety standards and protocols to face the critical health challenges that are a result of COVID-19. Thus, it maximized the safety factor for construction workers at the site (Gashahun, 2020). Construction management achieved this factor by adopting strict health policies, including **ensuring a safety distance between workers** and **the use of protective masks** (despite the difficulty in achieving these two conditions during work), **urging workers to maintain physical hygiene** and use disinfectants, ensuring good ventilation, and improving health care **(Kaushal and Srivastava, 2021).**

To control COVID-19 spread, construction sites in Singapore and Hong Kong implemented rigorous health screenings, including temperature checks and symptom questionnaires at entry points (Sathiyamoorthi and Kim, 2022). These protocols helped identify potential cases early and limited the virus's reach within construction sites (Richards et al., 2020). Contact tracing systems were also employed, ensuring timely response to any reported cases, which helped keep operations safe and controlled (Ahmed et al., 2020). **The enforcement of PPE usage**, including masks, gloves, and shields, became widespread as part of pandemic control strategies (Rowan and Laffey, 2021). In countries such as the United States and Australia, construction sites made PPE mandatory and accessible, supported by **regular training in its correct use** (Ling et al., 2022). Studies noted that mask compliance, when enforced properly, reduced the likelihood of virus transmission, especially in settings where social distancing challenged (Howard et al., 2021).

The U.K. adopted a **strategy of staggered shifts to reduce worker density on construction sites**. By alternating shifts and extending working hours, construction firms minimized the number of individuals on-site simultaneously (Assaad and El-adaway, 2021). This allowed for effective social distancing and prevented crowding during entry and exit times, limiting potential COVID-19 spread among workers (Zaami et al., 2020). In India, the construction sector experienced increased attention on mental health, as many workers faced anxiety and stress related to the pandemic (Mondal and Roy, 2021). Companies established support systems, such as counseling services and helplines, to help workers cope with the psychological impacts of the pandemic, aiming to address mental health challenges, provide emotional support, and sustain morale and productivity amidst significant disruptions and uncertainty (Yu et al., 2021).

South Africa **launched health and safety campaigns to educate construction workers** on COVID-19 prevention (Mbunge, 2020). **Frequent training sessions on hygiene, PPE usage, and safe distancing protocols fostered a cultural shift toward heightened safety awareness, empowering workers to consistently adhere to measures and protect themselves from infection**.

Bou Hatoum et al. (2021)compiled a list of 100 recommended practices to address workforce concerns and provide insights into safety and health trends on construction sites. These practices were grouped into 11 themes, including access points, communication and awareness, compliance, daily tasks, engineering controls, exposure-response plans, human interactions, hygiene and sanitation, delivery management, physical and mental health, and safety wearables. In terms of ensuring project continuity during COVID-19, owners identified the most effective strategies as **utilizing online virtual teams**, **working remotely**, and **leveraging building information modeling** and **modern technology**. From the contractors' perspective, key strategies implemented included **staggering break times to minimize group sizes**, **reanalyzing contingency reserves to maintain project schedules**, **reviewing contract clauses to address claims and dispute resolution, and adopting double shift work to enhance productivity while adhering to safety protocols**.

One of the most widely used methods to manage COVID-19 has been the implementation of public health measures, such as lockdowns and mask mandates, exemplified by China's strict lockdowns in Wuhan, which significantly reduced virus spread during the pandemic's early stages. Zhu et al. (2020b) Italy, facing one of the worst outbreaks in Europe, quickly imposed nationwide restrictions, closing schools, and businesses, and **limiting movement to essential activities** (Remuzzi and Remuzzi, 2020). Meanwhile, South Korea relied on widespread mask-wearing and public cooperation with social distancing guidelines rather than lockdowns, **ensuring a balance between public safety and economic activity** (Park et al., 2021).

2.6 Steps for pandemic prevention on highway construction Projects

Preventing the adverse impacts of future pandemics on highway projects requires a comprehensive approach that **includes risk management, supply chain resilience, and the integration of new technologies**. A critical first step is **conducting thorough risk assessments to identify potential vulnerabilities related to workforce shortages**, supply chain disruptions, and project delays, enabling the development of effective contingency plans (Silao et al., 2021). Another important strategy is **diversifying the supply chain** to mitigate the risks associated with global supply disruptions. This can involve sourcing materials locally and ensuring that alternative suppliers are available to keep projects on track (Cruz and Sarmento, 2021). Additionally, **flexible contractual agreements** with built-in provisions for delays and cost adjustments are essential to safeguard against financial losses during future pandemics (Ataei et al., 2021).

The adoption of **remote work technologies** for management and design teams is another key measure, ensuring continuity when on-site presence is restricted (Nguyen-Duc et al., 2022). Tools such as cloud-based project management platforms and virtual collaboration technologies were shown to be effective during the COVID-19 pandemic (Ferguson et al., 2022). On-site, **health and safety protocols** must be reinforced to protect workers, including the **use of personal protective equipment (PPE)** and **regular health screenings** (Alzarrad et al., 2022). In addition, **adopting modular and prefabricated construction methods** can reduce the need for large on-site workforces, enabling projects to continue even with reduced labor availability (Brennan et al., 2020).

Upskilling the workforce to ensure they are trained in both pandemic-specific safety protocols and digital tools is crucial for maintaining productivity (Monitor, 2020). **Integrating** automation technologies **such as drones for site inspections** and **robotic equipment for construction tasks** can also **reduce reliance on human labor and help keep projects on schedule** (Sobczak, 2022). Furthermore, **establishing financial reserves** and **pandemic-specific insurance policies** can help absorb financial shocks caused by project delays (Thompson et al., 2021). **Collaborative governance models** that enhance communication between government agencies, contractors, and suppliers will facilitate more effective decision-making and crisis management during future pandemics (Lai, 2012).

One of the primary vulnerabilities exposed during the COVID-19 pandemic was the fragility of global supply chains (Pujawan and Bah, 2022). To mitigate future disruptions, construction project stakeholders should focus on enhancing supply chain resilience (Mehmood et al., 2024). This can be achieved through diversification of material sources and developing partnerships with multiple suppliers across different regions. Reducing dependency on a single supplier or region helps minimize project delays caused by pandemics or other global crises (Handfield et al., 1999). Additionally, promoting local sourcing of construction materials, where possible, can further reduce the risk of delays and ensure continuous access to essential supplies (Alsharef et al., 2021).

Incorporating predictive supply chain management tools, such as artificial intelligence (AI) and block chain, can also help monitor and predict potential disruptions before they significantly impact project timelines (Ogundipe et al., 2024b).These tools can enhance transparency, allowing stakeholders to proactively identify vulnerabilities in the supply chain and take steps to mitigate them (Queiroz et al., 2020). Thus, construction projects can achieve greater agility and adaptability in the face of future pandemics through the effective use of technology in supply chain management.

Another critical strategy to prevent future pandemic-related disruptions in highway projects is **improving workforce management** (Waheeb et al., 2023). A flexible workforce plan that includes teleworking options for administrative roles and staggered shifts for on-site workers can help limit the spread of infectious diseases (Thomas Stephen et al., 2021) . On-site personnel should also be equipped with personal protective equipment (PPE), and strict sanitation protocols should be enforced to maintain worker safety during pandemics (Wudil et al., 2023). Ensuring that workers feel safe and supported can help maintain productivity and reduce absenteeism, which is essential for keeping projects on track (Lee, 2021).

Regular health screenings and implementing vaccination programs for workers can contribute to a safer work environment, and construction companies should collaborate with health authorities to ensure workers have access to vaccines and are well-informed about health risks (Zhu et al., 2020a). By prioritizing the well-being of their workforce, construction companies can minimize disruptions and maintain steady progress on highway projects (Berkeley et al., 2010).

The **adoption of digital tools and technologies** can also play a pivotal role in reducing the impact of pandemics on highway projects (Lei et al., 2021). Building Information Modeling (BIM) and other digital platforms enable remote collaboration and real-time monitoring of construction activities, reducing the need for physical presence on-site (Goh et al., 2020).Project managers can oversee progress, track material usage, and address issues remotely, which minimizes the risk of virus transmission and helps maintain project schedules (Telin and Esmail, 2021).

Reviewing and adjusting insurance policies to include pandemic-related disruptions can protect stakeholders from financial losses (Pitakpon and Susilo, 2023). Many construction companies were unprepared for the economic impact of COVID-19, as traditional insurance policies did not cover pandemic-related delays and cost overruns. Moving forward, contractors and project owners should work closely with insurance providers to develop policies that offer coverage for similar crises, ensuring greater financial resilience in the face of future pandemics (Downs et al., 2021).

The strategy to reduce future impacts of pandemics on highway projects is **adopting more flexible project scheduling and contract terms** (Telin and Esmail, 2021). Pandemic-specific clauses should be introduced in construction contracts, allowing for extensions or renegotiations in the event of unforeseen global health emergencies, thereby enabling stakeholders to manage delays and adjust schedules without incurring significant penalties (Nation et al., 2021).

Strong **collaboration with government and public health authorities** is critical for minimizing the future adverse impacts of pandemics on highway projects, as establishing clear communication channels with local, regional, and national health agencies enables construction companies to stay informed about health risks and regulatory change (Hubbard et al.). Early access to reliable information allows project managers to promptly implement health and safety measures, preventing widespread disruptions (Brauer, 2006).

Strategic risk management frameworks are vital for preparing construction projects for future pandemics, as they should identify critical project risks, set up early warning systems, and build contingency reserves to manage unforeseen financial or operational challenge (Mentis, 2015). In addition, contractors should explore pandemic-specific insurance policies to cover potential losses from delays or workforce shortages (Telin and Esmail, 2021).. By implementing these strategies chain diversification, technology integration, flexible contracting, workforce safety, and strategic risk management construction projects can be better equipped to handle the adverse impacts of future pandemics (Malik et al., 2022).

The COVID-19 pandemic highlighted significant vulnerabilities in the UK construction sector's supply chains and workforce management (Stride et al., 2023). To enhance resilience, companies diversified suppliers across regions, adopted digital tools for procurement transparency, and incorporated alternative materials to mitigate disruption risks (Negri et al., 2021). These measures improved flexibility and reduced project delays during crises (Choquette-Choo et al., 2021). Workforce stability was equally essential, requiring robust health protocols such as staggered shifts, personal protective equipment (PPE), and mental health support programs to ensure productivity and worker well-being (Gaitens et al., 2021).

Construction contracts included clauses addressing pandemic-related delays, buffer periods, and contingency measures, while cooperation between government agencies, contractors, and stakeholders optimized decision-making and resource allocation (Assaad and El-adaway, 2021). Regular risk assessments, tailored insurance policies, and proactive tools like Building Information Modeling (BIM) and remote management systems facilitated seamless communication and rapid responses to disruptions, ensuring project continuity and resilience (Zhang et al., 2021). Insurance and contractual adjustments are necessary to safeguard financial interests (Mayers and Smith Jr, 1981). **Projects should include clauses that address pandemic-related delays, allowing for flexibility in completion dates and compensation terms without triggering disputes** or financial penalties. According to (Smith et al., 2023), force majeure clauses in contracts should be re-evaluated to cover not just natural disasters but also pandemics, providing clearer avenues for compensation in the case of unavoidable delays.

2.7. Theoretical framework of the studies

Barasa et al. (2018) defined resilience as a system's ability to maintain performance and meet objectives when faced with challenges. They stressed that resilience involves not only withstanding shocks but also adapting and transforming. (Luthans, 2002) highlighted resilience as a positive capacity within organizational behavior, suggesting it contributes to organizational success. Kimhi (2016) identified three distinct but interconnected levels of resilience: individual, community, and national, each of which addresses the consequences of adversity and works together to build overall resilience.

According to (Amoa-Mensah et al., 2022) The COVID-19 pandemic has driven the development of resilience frameworks within the construction industry, highlighting risk management and preparedness. The Risk Management Resilience Framework is one approach that focuses on identifying potential disruptions and implementing risk-mitigation measures tailored to construction projects. This framework emphasizes the preemptive identification of risks associated with labor shortages, material delays, and financial constraints. By assessing these risks early, construction firms can adapt quickly to external pressures, improving resilience through flexibility in sourcing, adjusting schedules, and establishing diversified supplier relationships.

2.7.1 Covid-19 Strategic Response Planning Framework by WHO

According to (World Health Organization,(2020) the COVID-19 pandemic spurred the development of various public health frameworks aimed at enhancing preparedness, response, and recovery in the face of health crises. One prominent framework is the *World* Health Organization's (WHO) COVID-19 Strategic Preparedness and Response Plan (SPRP*)*. This framework emphasized key strategies such as rapid detection, containment, and mitigation efforts to prevent widespread transmission(World Health Organization, 2020) The SPRP provides a blueprint for national and international response, focusing on building health system resilience through resources such as surge capacity, coordination, and equitable access to healthcare services. The WHO's phased approach allowed countries to tailor their responses to each stage of the pandemic, thus creating a more adaptive approach to handling emerging infectious diseases. The COVID-19 Strategic Preparedness and Response Plan (SPRP) focused on public health measures to mitigate pandemic effects, including healthcare system readiness, lockdown protocols, and public health guidance. In contrast, a pandemic resilience framework for highway projects is specifically designed to address disruptions in the construction sector, ensuring the continuity of projects despite challenges like supply chain issues, workforce shortages, and financial difficulties.

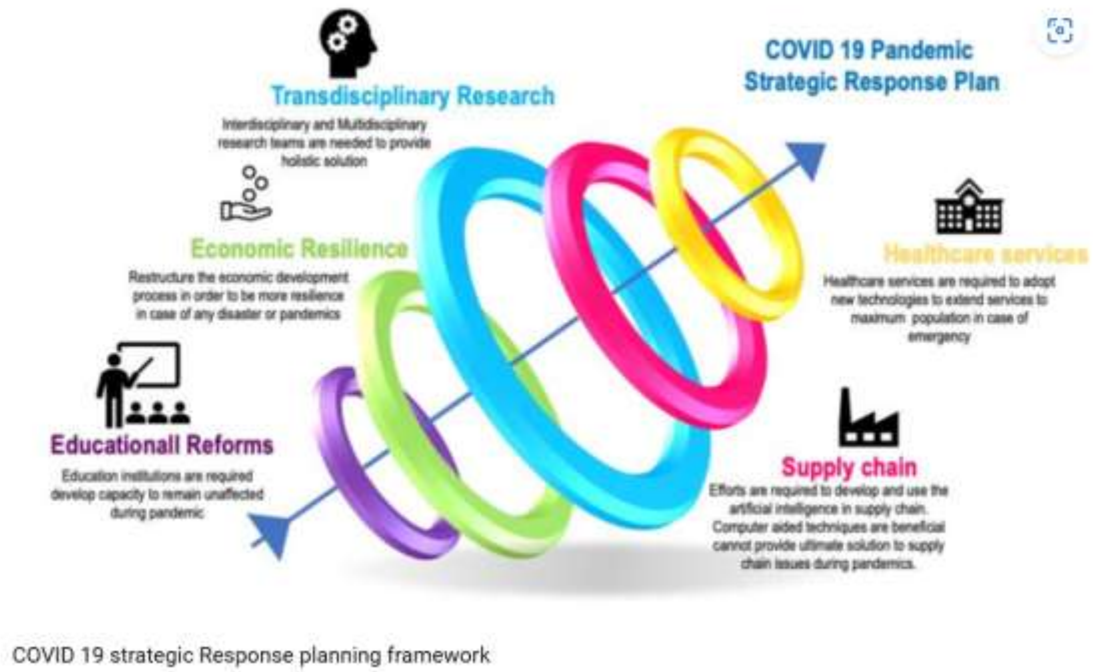


Figure 2-1:COVID 19 strategic Response Planning Framework by WHO

2.7.2. Pandemic Intervals Framework by Centers for Disease Control and Prevention

The Centers for Disease Control and Prevention (CDC) Pandemic Intervals Framework strengthens resilience by defining stages from detection through recovery, emphasizing early detection, rapid testing, and consistent communication for effective outbreak control (CDC, 2020). It incorporates non-pharmaceutical interventions (NPIs) like mask mandates and social distancing, guiding containment efforts to protect healthcare systems. This model underscores proactive public health measures to limit transmission and prevent system overload. In contrast, a pandemic resilience framework for highway projects is specifically designed to address disruptions in the construction sector, ensuring the continuity of projects despite challenges like supply chain issues, workforce shortages, and financial difficulties.

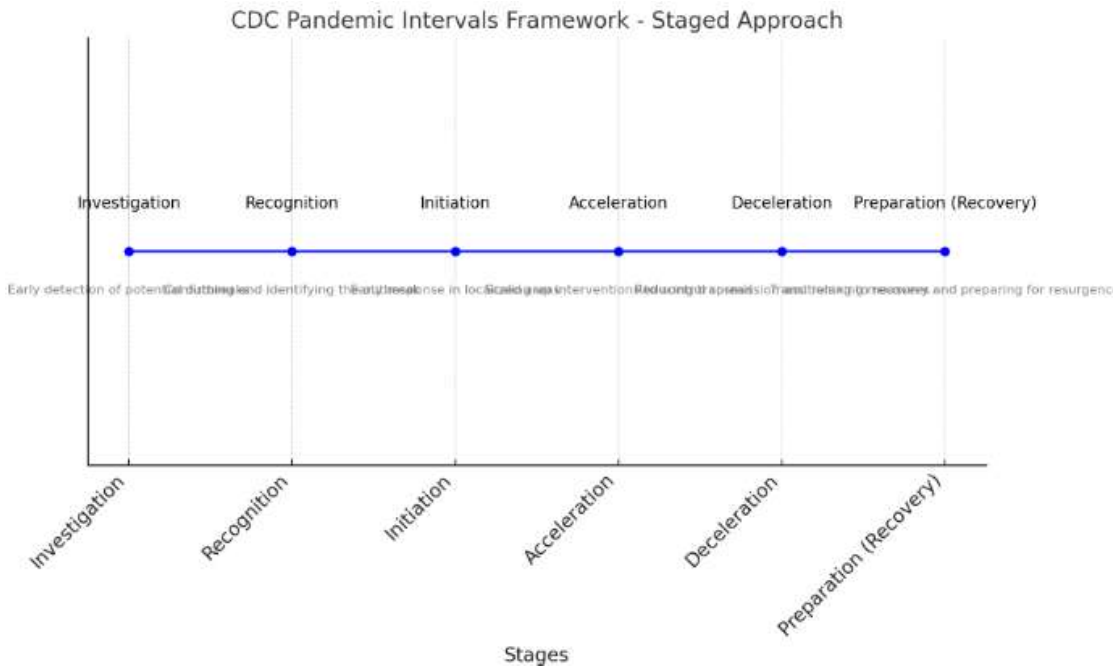


Figure 2-2:(CDC) Pandemic Intervals Framework (CDC, 2020)

2.7.3. Integrated Health System Response Model by Zhong et al., 2024

Health system became essential during COVID-19, with the Surge Capacity Framework widely adopted to manage patient surges (Kaji et al., 2019). This model prepares hospitals to expand capacity by reallocating resources, mobilizing staff, and using makeshift facilities as necessary (Ranney and Griffeth,2020). Addressing shortages in personnel, supplies, and ICU beds, allows rapid scaling to meet high demands, ensuring resilience during intense phases of the pandemic. Another significant resilience model is the *Integrated Health System Response Model*, which emphasizes continuity of care during health crises. This model advocates for leveraging telemedicine, mobile health clinics, and community-based care systems to maintain essential healthcare services while managing the pandemic response (Zhong et al., 2024). By decentralizing care and incorporating digital tools, healthcare systems can enhance their flexibility and resilience, ensuring non-COVID patients receive care. In contrast, a pandemic resilience framework for highway projects is specifically designed to address construction sector disruptions, ensuring project continuity despite supply chain issues, workforce shortages, and financial difficulties.

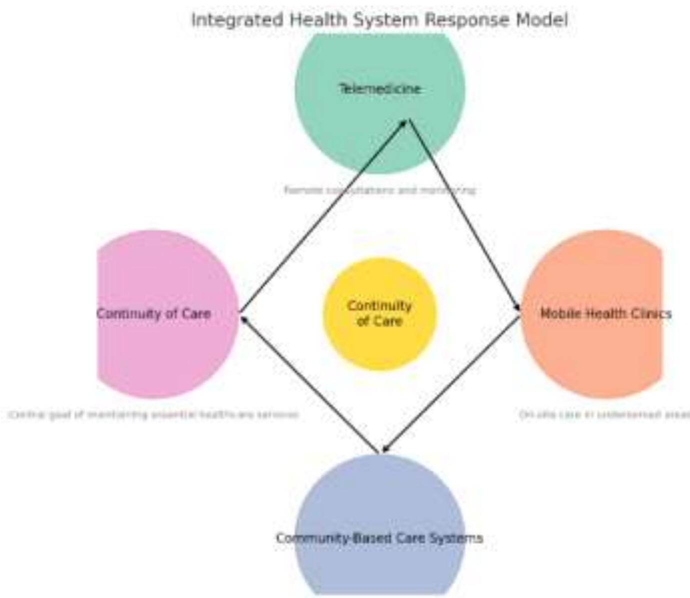


Figure 2-3:Integrated Health System Response Model (Zhong et al., 2024)

2.7.4. The Oxford COVID-19 Government Response Tracker

COVID-19's economic impact led to the development of various models to foster resilience in economies affected by the pandemic. *The* Oxford COVID-19 Government Response Tracker (OxCGRT) *i*s one such model, providing real-time data on global government responses to the pandemic. OxCGRT analyzes various economic policies, including fiscal stimulus, income support, and business loans, helping countries understand the effectiveness of interventions (Hale et al., 2021). By highlighting policy responses that promote economic stability, this model serves as a resilience tool for mitigating the financial fallout of future pandemics and supporting long-term recovery. In contrast, a pandemic resilience framework for highway projects is designed to address construction sector disruptions, ensuring project continuity despite supply chain issues, workforce shortages, and financial difficulties.

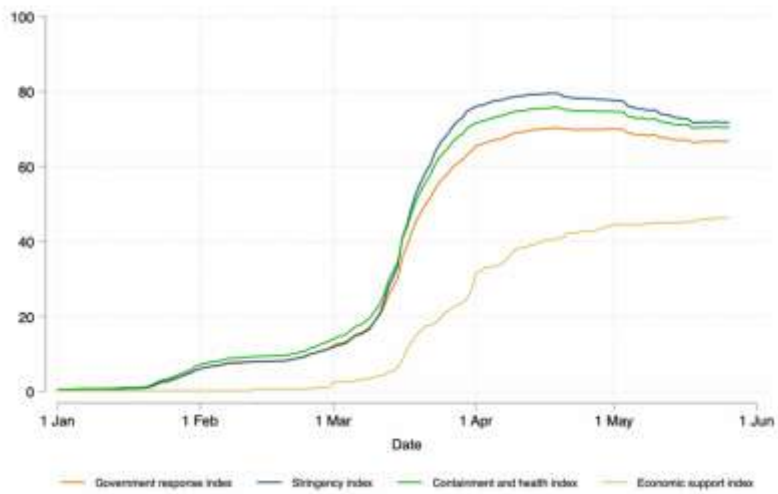


Figure 2-4:The Oxford COVID-19 Government Response Tracker(Hale et al., 2021)

OxCGRT has collected information on the level of government responses for over 150 countries. This information was aggregated into a series of four policy indices,

- Overall government response index
- Stringency index
- Containment and health index
- Economic support index

Each index was composed of a series of individual policy response indicators. We created a score for each indicator by taking the ordinal value and adding an extra half-point if the policy is general rather than targeted, if applicable. We then rescale each of these by their maximum value to create a score between 0 and 100, with a missing value contributing 0.3 These scores are then averaged to get the composite indices

2.7.5. Enterprise Risk Management (ERM) Framework

The COVID-19 pandemic highlighted the need for organizations to enhance resilience through risk management frameworks (Wulandhari et al., (2023) . The Enterprise Risk Management (ERM) Framework was adopted during COVID-19 to address new risks, such as supply chain disruptions, workforce shortages, and remote work challenges (Trkman and McCormack, 2021). This model encourages organizations to assess vulnerabilities, diversify suppliers, and adopt digital solutions to maintain continuity (Nkomo & Kalisz, 2023). In contrast, a pandemic resilience framework for highway projects is specifically designed to address construction sector disruptions, ensuring project continuity despite supply chain issues, workforce shortages, and financial difficulties.

Figure 2-5:Enterprise Risk Management (ERM) Framework (Wulandhari et al., (2023)

According to Rob van der Meulen, (2020), as the coronavirus spread beyond China, organizations reacted in varying ways. Some acted swiftly in response to just one or two cases among employees, suppliers, or clients, while others adopted a more cautious, wait-and-see approach. This disparity likely reflects differences in enterprise risk management (ERM) strategies, underscoring the importance of having well-defined methods, processes, response thresholds, and actions to safeguard enterprise goals, earnings, and capital.

2.7.6. Business Continuity Planning Model

Another important model is the Business Continuity Planning (BCP) Framework*,* which focuses on maintaining essential functions during crises. The BCP framework provides strategies for crisis communication, workforce flexibility, and operational recovery, ensuring that businesses can adapt quickly in response to disruptions (Herbane, 2020) . Organizations that adopted this framework during COVID-19 with a focus on resilience could transition to remote work and continue operations, even in the face of significant challenges. BCP also emphasizes contingency planning, allowing organizations to manage uncertainties better and protect essential functions.

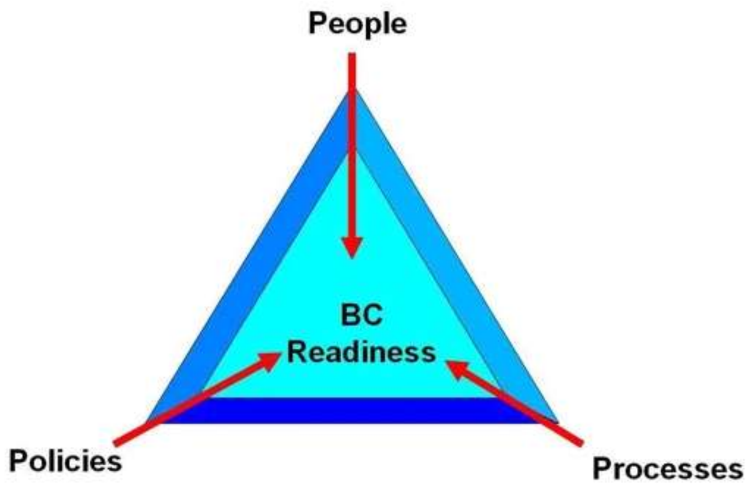


Figure 2-6:Business Continuity Planning (BCP) (Herbane, 2020)

Goh, M. H. (2021). It indicates that the framework is guided by three essential elements: Policies, Processes, and People. These components must align with a unified BCP strategic mission. In this context, the example I will present is "BC Readiness," which illustrates how the organization ensures it remains prepared for any potential disruptions.

According to Slaoui and Hepburn, (2020) The rapid development and distribution of COVID-19 vaccines demonstrated the need for resilient vaccine distribution systems. The Operation Warp Speed (OWS) Framework was a public-private initiative in the United States designed to accelerate vaccine production and distribution. This model involved coordinated efforts between pharmaceutical companies, research institutions, and government agencies, reducing vaccine development timelines by streamlining clinical trials and manufacturing processes.

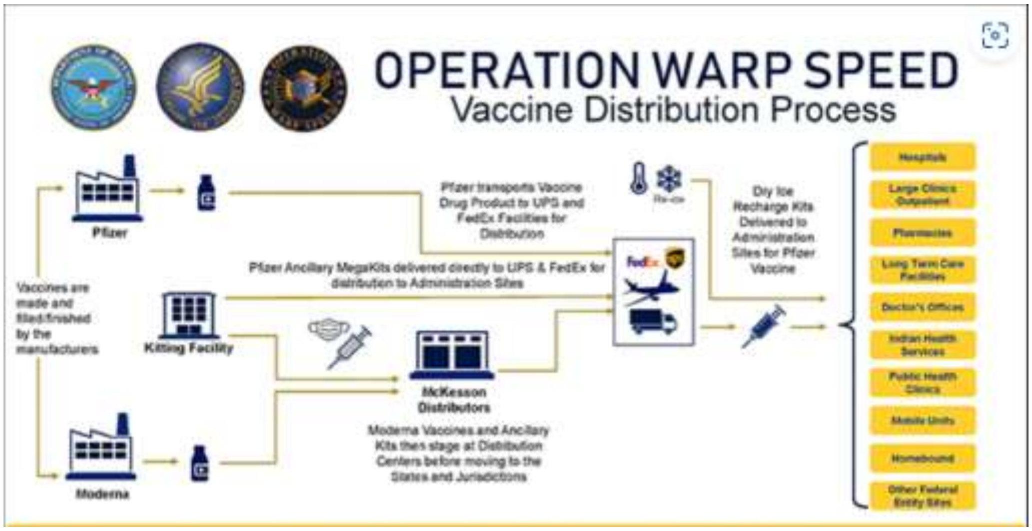


Figure 2-7:Operation Warp Speed Slaoui and Hepburn, (2020)

The Policy Resilience Model*,* developed in response to the disproportionate impact of COVID-19 on low-income and marginalized communities, focuses on addressing health and economic inequalities (Parenteau et al., 2023). This model advocates for policies that prioritize equitable access to healthcare, economic support, and social services for vulnerable populations (Berkman et al., 2021). A pandemic resilience framework for highway projects is specifically designed to address construction sector disruptions, ensuring project continuity despite supply chain issues, workforce shortages, and financial difficulties.

According to Amoa-Mensah et al., (2021)The COVID-19 pandemic has driven the development of resilience frameworks within the construction industry, highlighting risk management and preparedness. The Risk Management Resilience Framework is one approach that focuses on identifying potential disruptions and implementing risk-mitigation measures tailored to construction projects. This framework emphasizes the preemptive identification of risks associated with labor shortages, material delays, and financial constraints. By assessing these risks early, construction firms can adapt quickly to external pressures, improving resilience through flexibility in sourcing, adjusting schedules, and establishing diversified supplier relationships.

2.8. Conceptual Framework for the Development of a Pandemic Resilience Framework for Highway Projects.

For this study the conceptual framework integrates various theoretical perspectives on resilience and crisis management to develop a tailored pandemic resilience framework specifically for Highway projects in Rwanda. It directly links the understanding of pandemic impacts, Mitigation strategies and future prevention measures to the ultimate development of the Framework.

The proposed Conceptual framework for developing a pandemic resilience framework for highway project in Rwanda is built upon the pillars informed by the theoretical Models discussed: the pillar forms the operational backbone, drawing heavily from the Risk Management Resilience Framework, Enterprise Risk Management (ERM) Framework and the Business Continuity Planning (BCP) Framework. These model provides the systematic approach for identifying Potential disruptions, implementing risk mitigation measures, and Establishing the processes for rapid adaption and recovery. The Pillar acknowledges the direct influence of Health crises on construction projects and workers. While the who Covid-19 Strategic preparedness and Response Plan; and the CDC Pandemic interval framework primarily focusing on the public health, similarly, the Integrated Health system responses Model highlight the importance of health system readiness. Those insights inform the design of health and safety Protocols and comprehensive Workforce management strategies within the highway project context. The pillar also acknowledges considering the broader economic environment and technological solutions. The Oxford COVID-19 Government Response Tracker (OxCGRT) Model provides context on government economic policies that can impact construction projects. Critically, the need for Digital infrastructure and Remote Monitoring emerges as key strategy.

This conceptual framework posits that a robust pandemic resilience framework for highway projects must be integrated approach. It strategically combines proactive risk management and business continuity planning with the essential safeguarding of workforce health and leveraging digital infrastructure, all within the context of responsive economic and policy environment. This holistic perspective will guide the research to produce a practical and effective framework for the Rwandan Context.

Below is the diagram showing the conceptual framework integrates various theoretical perspectives on resilience and crisis management to develop a tailored pandemic resilience framework specifically for Highway projects in Rwanda.

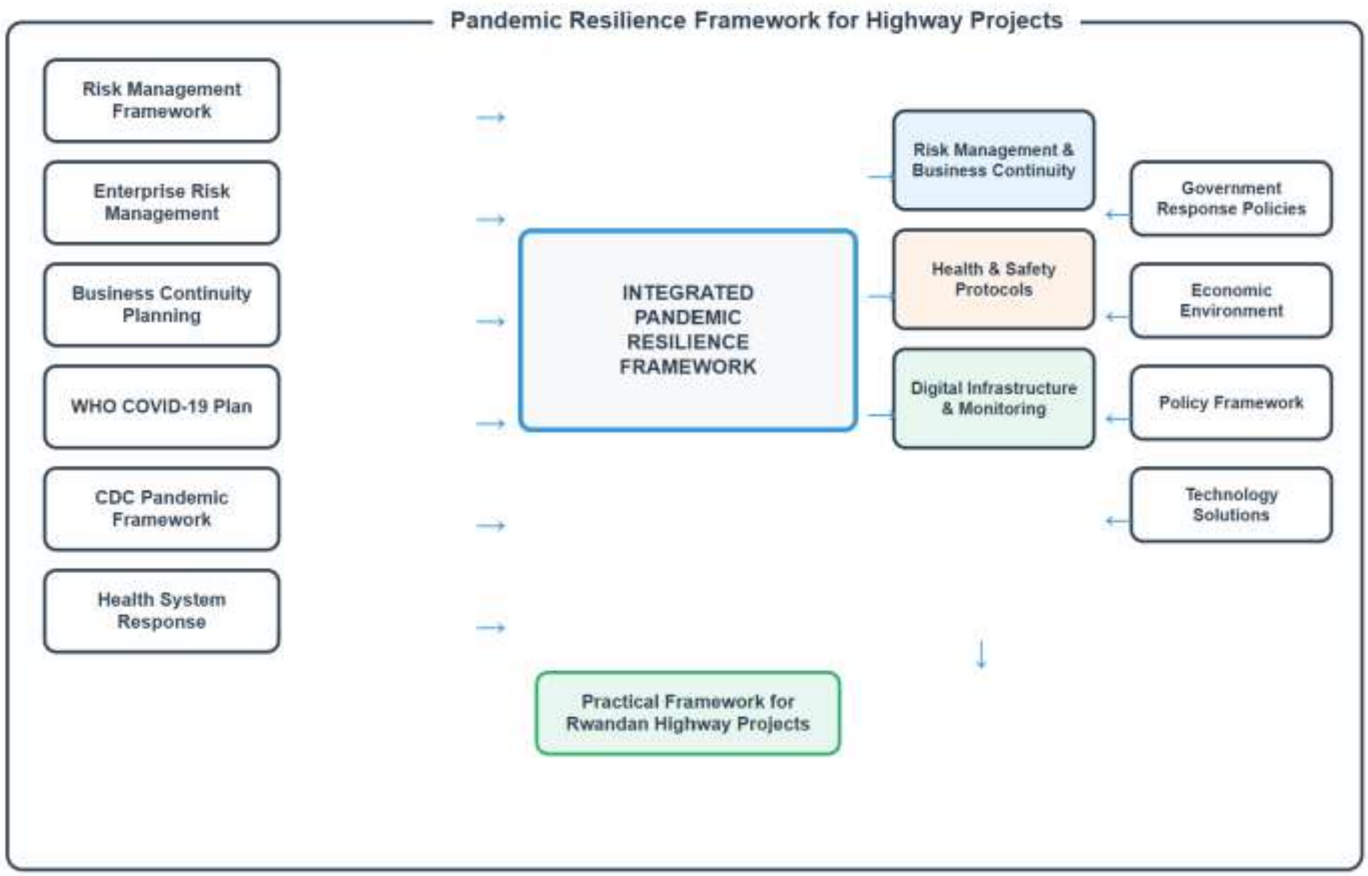


Figure 8 Integrated Pandemic Resilience Framework

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter describes the approaches, methods, techniques and tools used to conduct this Project. The research employed a case study about developing a pandemic resilience framework for highway projects: case of Covid -19 disease in Rwanda. The strategy to operationalize research questions adopted a mixed methods approach whereby both qualitative (surveys, interviews, focus groups and observation) and quantitative methods were employed in data collection and analysis to enhance the validity of the results. It also presents the methods used to collect both primary and secondary data in order to acquire a deeper understanding on the selection and use of indicators in identifying the current status for developing a pandemic resilience framework for highway projects.

3.2. Study area description.

The study covered 5 highway projects impacted by COVID-19; The selected highway projects were carried out during the COVID-19 period to address critical infrastructure needs, enhance connectivity, and support economic recovery despite the pandemic's challenges. Projects like Nyagatare-Rukomo and Huye-Kibeho-Ngoma upgrading aimed to improve rural accessibility and promote regional development. Urban projects such as the Sonatubes-Gahanga road and maintenance of the Kigali-Kayonza road were prioritized to reduce traffic congestion and maintain essential transport links.

These projects, undertaken during the pandemic, faced challenges such as workforce disruptions, supply chain delays, and health concerns, making them critical case studies for assessing the impact of COVID-19 on highway construction and developing a resilience framework for future infrastructure projects. the projects are the Nyagatare-Rukomo road upgrading project (73 km) and the Huye-Kibeho-Ngoma/Munini road upgrading project (66.3 km). While the Sonatubes-Gahanga urban route (13 km) facilitates urban mobility in the City of Kigali and secondary cities, the Asphalt route Pindura-Bweyeye (32 km) improves connectivity in outlying locations. In order to guarantee efficient traffic movement along a vital corridor, the 65-kilometer Kigali-Kayonza route was also given top priority for renovation.

Figure 3-1: Project locations alongside Rwanda country

3.3 Sources of data

In this study, both primary and secondary data were adopted.

3.3.1 Primary data

Ajayi,(2017), Primary data is original and unique data, that is directly collected by the researcher from sources such as observations, surveys, questionnaires, case studies, and interviews. Primary data is crucial for creating a pandemic resilience framework for highway construction projects as it offers direct insights into sector-specific challenges and solutions. Collected through methods like questionnaire surveys, it enables researchers to assess the impacts of pandemics, such as delays, workforce shortages, and supply chain disruptions

3.3.2 Secondary data

Secondary data is easily accessible but is not pure as they have undergone many statistical treatments. Sources of secondary data are government publications, websites, books, journal articles, internal records (Ajayi, 2017). Secondary data is essential for developing a pandemic resilience framework for highway construction projects, offering pre-existing insights into past pandemics, economic disruptions, and industry responses. Sourced from government reports, academic research, and industry case studies, it helps identify patterns and tested solutions, such as analyzing global project delays during COVID-19 to uncover vulnerabilities and effective crisis management strategies.

3.4. Research Design

The design allows researchers to hone in on research methods suitable for the subject matter and set up their studies for success. There are five types of research design: descriptive research design, Experimental research design, correlational research design, diagnostic research design, explanatory research design, and so many. Descriptive Research Design is well-suited for developing a pandemic resilience framework for highway projects, as it systematically captures conditions, patterns, and practices in specific contexts (Sadler et al., 2024). This design helps gather detailed information on pandemic-related challenges like supply chain disruptions, labor shortages, and health and safety issues, along with the measures implemented to address them. This study adopts the mixed method of research design because it allows to gathering of critical insights from a wide range of stakeholders, including project managers, contractors, workers, and government officials (Doloi, 2014). This approach provides data on the specific challenges, needs, and best practices experienced during the pandemic, such as supply chain

disruptions, workforce safety concerns, and project delays.

3.4.1. Population

Participation in the study covers the responsible officials of employers, consultants, and contractors working on these 5 projects. The sample size considered is small because the personnel considered for this sample size are technical officer level or higher like engineers, contract managers, and other construction personnel. After all, it is assumed that responses obtained from those would give the right justification to the given questions. The study will be conducted in Kigali city due to the city's rapid urban growth and the strategic importance of its transportation infrastructure. Here the source of information is The Rwanda Transport Development Agency (RTDA), Astrik International, NPD, Real Contractors and so on provides valuable updates on both ongoing and completed highway projects, offering insights into the progress and challenges faced during their implementation.

3.4.1. population size

The population size for the five highway projects mentioned was organized based on the roles of the respondents and their involvement across the project. Below is the Table showing the sample size

Table 3-1:Population of the sample by Project

Project Name	Clients (RTDA)	Contractors (NPD, Real Contractor, CRBC, etc.)	Consultants (Astrik International Ltd, Tecos Ltd, Etc.)	Total Population
Nyagatare-Rukomo Road Upgrading Project	1	8	5	14
Huye-Kibeho-Ngoma/Munini Upgrading Works	1	8	6	15
Asphalt Road Pindura-Bweyeye Upgrade	1	7	6	14
Urban Roads in Sonatubes-Gahanga (CoK)	1	8	7	16
Maintenance of Kigali-Kayonza Road	1	8	6	15

3.4.2. sample size

Sample size refers to the number of subjects selected from the population to participate in the study. The determination of appropriate sample size is crucial for ensuring the validity and reliability of research findings. However, when dealing with small populations, researchers may opt for a total population census approach rather than sampling techniques.

Population Census Approach

Given the relatively small size of the target population in this study, a total population census approach was adopted instead of statistical sampling methods. The total population consisted of 65 construction professionals involved in highway construction projects during the COVID-19 pandemic in Rwanda, including clients, contractors, consultants, and engineers.

Justification for Total Population Census

The decision to use a total population census was based on the Enhanced Validity by Surveying the entire population eliminates sampling error and provides complete representation of all relevant stakeholders in highway construction projects affected by COVID-19.

Comprehensive Coverage: A census approach ensures that perspectives from all categories of construction professionals (clients, contractors, consultants, and engineers) are captured without the risk of under-representation that might occur with sampling.

Research Precision: Given the specialized nature of highway construction during pandemic conditions, including all available experts maximizes the precision and reliability of findings.

Target Population Coverage

The study targeted all 74 construction professionals involved in highway projects during the COVID-19 pandemic, distributed across different professional categories:

Civil/Building Engineers; Consultants; Contractors; Client representatives; Quantity Surveyors; **Geotechnical Engineers; Other construction specialists**

Response Rate Considerations

While the census approach targeted all 74 professionals, the actual response rate was 100% (74 respondents), which represents a highly satisfactory response rate for this type of professional survey. The high response rate validates the appropriateness of the census approach and ensures robust data for analysis.

This total population census approach aligns with best practices for small population research and ensures that the study captures the complete spectrum of experiences and perspectives from Rwanda's highway construction professionals during the COVID-19 pandemic.

Chosen from client =5; Chosen from contractor 10; Chosen from consultant =10; Chosen from engineer=49

Table 3-2:Sample Size

Organization	Total population	Sample size
client	5	5
contractor	39	39
Consultant	30	30

3.5. Research tools

The most appropriate research instrument for developing a pandemic resilience framework for highway projects is a questionnaire and interview. This instrument is particularly suitable because it allows us to gather detailed insights from a broad range of stakeholders, including project managers, contractors, government officials, and on-site workers, who each experienced unique challenges and employed various strategies during the pandemic.

3.5.1 Research Matrix

The matrix below indicates the relationship between research questions, Specific objectives, Data collection, and analysis techniques, which were used in developing a pandemic resilience framework for construction highway projects in Rwanda to prevent future adverse effects and improve construction efficiency.

Table 3- 3:Research Matrix

Specific objectives	Research Methods	Data sources
To identify the adverse impacts of COVID-19 on highway construction projects and workers.	Survey interview with Likert scale and open-ended Questions Focus Group Discussions	Potential workers and managers involved in the highway construction project during COVID-19
To evaluate the strategies adopted to mitigate the impact of COVID-19 on highway construction projects and workers.	Key informant interview Surveys with open ended question	Contractors, Governmental officials Managers, and workers involved in highway project

To establish steps to prevent the future adverse impacts of pandemics on highway construction projects and workers.	Focus Group Discussions Key informant interview Data analysis from SPSS	Data collected from the FGD and Key Informant interview
To develop a pandemic resilience framework for highway construction projects and workers.	Development of a pandemic resilience framework for highway construction projects and workers tailored to the Kigali context, based on Data analysis and user Feedback	Findings from the literature review Data from Focus group discussions and key informant interviews

3.5.3 Research instrument

The most appropriate research instrument for developing a pandemic resilience framework for highway projects is a questionnaire and an interview. Those instruments are particularly suitable because they helped in gathering detailed insights from a broad range of stakeholders, including project managers, contractors, government officials, and on-site workers, who each experienced unique challenges and employed various strategies during the pandemic.

3.5.4. Questionnaire Design

The questionnaire is designed for different key informants, including project managers, contractors, and governmental officials. The rate will be based on the level of Agreement with the adverse effects of COVID-19 on highway construction projects. Respondents will score their agreement and importance of the above characteristics on a 5-point Likert scale.

Table 3- 4: Likert scale

Objective 1: Identify the adverse impacts of COVID-19 on highway construction projects and workers	5	Very Significant
	4	Significant
	3	Moderately Significant
	2	Slightly Significant
	1	Not Significant

Objective 2: Strategies adopted to mitigate the impact of COVID-19 on highway construction projects and workers.	5	Highly Adopted
	4	Adopted
	3	Moderately Adopted
	2	Slightly Adopted
	1	Not Adopted

Effectiveness of the strategies adopted to mitigate the impact of COVID-19 on highway construction projects and workers.	5	Highly Effective
	4	Effective
	3	Moderately Effective
	2	Slightly Effective
	1	Not Effective

3.6.Data collection procedure

During the survey, 74 Participants in the study covered the responsible officials of employers, consultants, and contractors working on these 5 projects. Were selected to complete questionnaires and participated in Key Informant Interviews. To ensure a sufficient sample representative of the total population, surveys were delivered at strategic institutions in areas where potential respondent are working. Each respondent has gone through some initial screening, including a brief discussion, to ensure that they match the study's requirements, which include demographic and socioeconomic factors, and familiarity with the project performed during covid19. The survey was completed only by those who match the criteria. This survey assumed a 100% response rate, however a number greater than 75% would be acceptable(Mchopa, 2021).

The performed activities during data collection were:

1. Got authorization from the university.
2. Obtained approval from the RTDA and Kigali City officials.
3. Engaged with the many institutions involved in the project Implementations.
4. Set up Google Forms for digital data collection.
5. Performed data collection and surveying
6. Recorded the Key Informant interview.
7. Entered and processed obtained data.

3.6.1 Method of data collection

To develop a pandemic resilience framework for highway projects in Rwanda during the COVID-19 pandemic, a combination of primary and secondary data collection methods was employed. Primary data were gathered through semi-structured interviews with key stakeholders, including government officials, project managers, contractors, engineers, and construction workers, to explore their experiences and challenges. questionnaires were distributed to a broader group of stakeholders to collect quantitative and qualitative insights on project delays, workforce management, supply chain disruptions, and implemented safety measures. Focus group discussions with contractors, and engineers, had further provide diverse perspectives and validate findings.

Secondary data were obtained through a detailed review of RTDA reports, and construction company records to understand pandemic-related disruptions and responses. Academic literature, case studies) were analyzed to identify trends and best practices.

3.6.2 Reliability and validity

Cronbach's alpha test was used to determine the reliability of the study instrument. Questions in the research instrument was pre-coded, pre-tested, and updated to address flaws discovered during the pre-testing process. the data collection and observations had simplified cross-checking and improved the reliability of the outcome or judgment.

Table 3- 5: Reliability table test

Objectives	Cronbach's Alpha	Number of Items
Objective 1: Identifying the adverse impacts of COVID-19 on highway construction projects and workers	0.930	26
Objective 2: strategies adopted to mitigate the impact of COVID-19 on highway construction projects and workers.	0.947	26
Effectiveness of the strategies adopted to mitigate the impact of COVID-19 on highway construction projects and workers.	0.935	26

From the above table all factors show acceptable to excellent internal consistency ($\alpha > 0.75$)
The validity of this study was determined through triangulation of acquired data and the research approach or procedures used. Data gathering and analysis were carried out using a variety of methods or procedures. For example, questionnaire administration with an acceptable sample size and sampling methodologies. In addition, to ensure that the study instrument has a suitable level of validity; analytical procedures will incorporate both descriptive and parametric techniques.

3.7.Method of data analysis and presentation

The data were collected using Google Forms surveys, and the compilation had completely automated. After extracting the data, it was analyzed using SPSS (Statistical Package for Social sciences) and Python. The methods used to analyze the data collected for the study and their presentation are discussed. In this study, quantitative and qualitative data analysis methods were used. Quantitative data through descriptive statistics i.e., percentages, frequency, mean value, and T-tests were used to analyze the data. qualitative data through content analysis was used to interpret data in the form of text.

the primary goal of this research was to develop pandemic resilient framework for highway projects. To do this, basic descriptive statistics including frequency distribution, cross tabulation, percentages, and ratios were used to assess the data that was gathered. In order to enable the study to derive important conclusions from the data, more sophisticated analysis was performed, such as the use of measures of associations, such as cross-tabulation. The relationship between Strategies adopted and the effectiveness of those strategies adopted among different Project was determined using the cross-tabulation technique and Bivariate. Regression analysis and content analysis was utilized to uncover the most important characteristics that determine and explain the effect of Pandemic on both workers and project.

The analysis above was done with respect to each objective according to meet with the expected result, for example for objective 1: to see the adverse of Civid-19 pandemic Spss was used to determine the Descriptive, Crosstabs, Chi-square; for Objective 2: Mitigation strategies the analysis was done to determine Frequencies, t-test/ANOVA and Logistic Regression; for objective 3: the Factor analysis of strategies and Expert Themes from KII data were done to determine steps to prevent future pandemic impacts. And Finally, the synthesis for regression, Factor results and KII framework was done to work on the development of pandemic resilience framework as an objective 4.

A set of recommendations were developed based on the results of the Questionnaire surveys and Key Informants Interview

This evaluation was used to develop pandemic resilient Framework for Highway construction project.

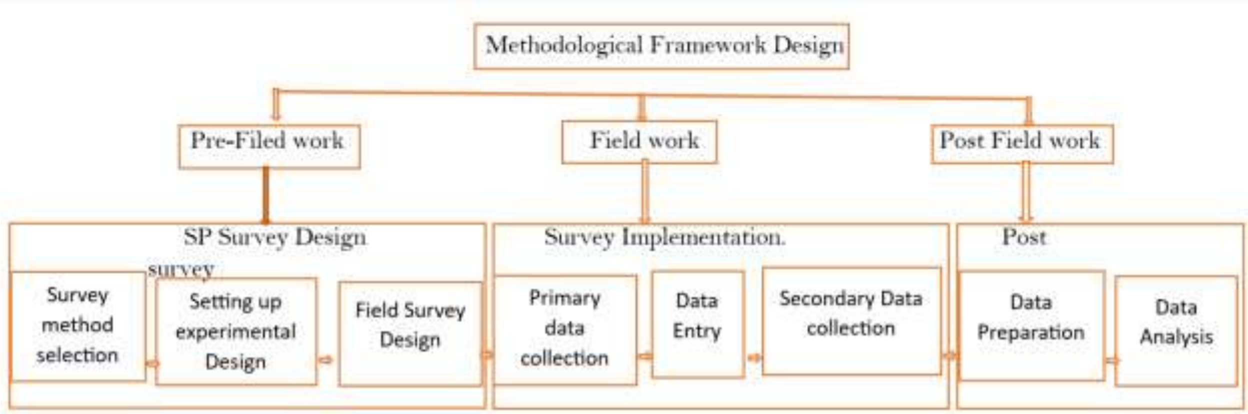


Figure 3-5 Methodological Framework

CHAPTER FOUR

RESULT AND DISCUSSIONS

4.1. Introduction

This chapter presents the result and discussions of the findings from a comprehensive survey done on 74 targeted respondent including 54 Engineers in survey Questionnaire and 20 Key Informants Interview done on construction professionals involved in highway projects during the COVID-19 pandemic in Rwanda. The study addresses four key research questions and objectives related to developing a pandemic resilience framework for highway construction project.

4.2.Demographic profile of respondents

4.2.1. Sample Characteristics

Table 4- 1: Demographics of the respondents

VARIABLES	CATEGORY	FREQUENCY	Total
Gender	Female	11	54
	Male	43	
Age Group	18-25 Years	19	54
	26-35 Years	26	
	36-45 Years	6	
	46-55 Years	2	
	56 Years and above	1	
Education	Master's Degree	7	54
	Bachelor's Degree	46	
	PhD	1	
Profession	Building/Civil Engineer	39	54
	Quantity Surveyors	5	
	Geotechnical Engineers	4	
	Others	6	
Working Experience	Less than 1 Year	12	54
	1-3 Years	12	
	4-6 Years	14	

	7-10 Years	15	
	10+ Years	1	
Nature of Involvement	Supervision and Quality Control	25	54
	Construction Execution	18	
	Project Planning and Design	5	
	Contract Administration	6	
Organizational Type	Governmental Agency	5	54
	Consulting Firm	14	
	Contracting Firm	26	
	Other	9	
Type of Highway Projects	Road Maintenance	23	54
	New Road Construction	17	
	Road Upgrading/Rehabilitation	12	
	Bridge Construction	2	
Professional Registration	Institution of Engineers Rwanda	27	54
	Project Management Professional	5	
	Rwanda Institute of Architects	4	
	Rwanda Institute of Quantity Surveyors	3	
	None	13	
	Other	2	
Role in Project	Government official	22	54
	Project Manger	12	
	Site Engineer	6	
	Contractor	5	
	Construction Worker	9	

Organization	Public	19	54
	Private	35	
Respondent by Project	Nyagatare-Rukomo	10	54
	Huye-Kibeho-Ngoma	5	
	Asphalt Road Pindura-Bweyeye	9	
	Sonatubes-Gahanga	8	
	Kigali-Kayonza	11	
	Others	11	

4.2. Identified Adverse Impact on Project and Workers

Impact on Workers

The impact of the COVID-19 pandemic has significantly revealed through different factors including but not limited to the mental well-being of the construction workforce, reduced job security, Increased absenteeism due to COVID-19 restrictions, Increased stress levels among workers, Higher levels of burnout during lockdowns, Reduced motivation and morale among workers, Fear of contracting COVID-19 while working on-site and so on.

Impact of Covid-19 Impact on Highway Construction Workers-Inferential Statistical analysis

A. **Gender Based analysis of COVID-19 impact on workers**

See the Table 4- 2 In the Appendices

This table reveals significant gender differences in how COVID-19 impacted workers, with women generally experiencing more severe effects than men. The most critical finding is that reduced job security ranked as the top concern for both genders (overall mean 4.52), though women felt this impact more acutely (4.82 vs 4.44 for men, p=0.039). Women also reported significantly higher levels of ineffective communication with team members (4.27 vs 3.53 for men, p=0.016) and greater loss of life among workers (3.73 vs 2.91 for men, p=0.047). Other top concerns included fear of contracting COVID-19 (4.35 overall) and financial constraints (4.25 overall), with women consistently showing higher mean scores across most impact categories. While many differences weren't statistically significant, the pattern suggests that female workers faced disproportionately greater challenges during the pandemic, particularly in areas of job security, workplace communication, and health-related concerns.

Impact of COVID-19 on Highway Construction Workers by Age Groups

See Table 4- 3:Impact of COVID-19 on Highway Construction Workers by Age Groups in the appendices

The analysis indicated that there is significant impact of covid-19 on highway construction workers especially for Absenteeism (p = 0.021), ineffective communication (p = 0.018), job security (p = 0.032), burnout (p = 0.015), and depression/anxiety (p = 0.044) all showed age-sensitive variations, with older workers (particularly those aged 56 and above) reporting higher negative impacts. In contrast, stress levels, access to healthcare, and financial strain were uniformly perceived across age groups

Impact on Project

The result of Findings shows that Highway construction projects in Rwanda faced significant operational and logistical challenges during the COVID-19 pandemic.

Project delays were the most significant impact (88.9% significant/very significant), followed by contract renegotiation (57.4%) and increased project costs (51.8%). Supply chain disruptions affected 50% of projects significantly, while utility service disruptions had lower impact (37%). See Table 4 4:Impact of covid-19 pandemic on highway construction by organization in the Appendices

Organizational Analysis of Covid-19 Impact on Projects

The result of the table above shows the impact of covid-19 on highway construction projects by organization type in Rwanda based on the survey responses.

Impact of COVID-19 on Highway construction Project by Organization

Type see Table 4- 5:Impact of COVID-19 on Highway construction Project by Organization Type in the appendices

The table result above shows that Impacts of COVID-19 on road construction projects create significant variations across different organizational categories, with seven out of twelve effect factors showing statistically significant variations ($p < 0.05$). Project progress delays were the most severe effect uniformly in consulting companies, and client, whereas contracting firms ranked it second. Increased project cost and Supply chain disruptions and delayed material delivery were the second and third most critical effects. The rankings also varied significantly by organization type, indicating varying priorities and experiences with COVID-19 impacts. For instance, contracting firms identified Increased project cost as their primary concern, while consulting firms were most affected by project delays. The largest statistical variation happened in Re-negotiation of Contracts ($p = 0.001$), which shows extreme variation in how different organizations had reacted to contract changes during the pandemic. These findings echo the complexity of COVID-19 impacts on the construction industry and stress the need for organization-level mitigation strategies.

4.2.1. Evaluated strategies adopted to mitigate the impact of COVID-19 on highway construction projects and workers.

The findings show that the most commonly used techniques were varied suppliers (72.2% adopted/highly adopted), stockpiling crucial materials (68.5%), and staggered shifts (59.3%). 44.5% of firms used digital project management tools, and 59.3% implemented vaccination programs. As demonstrated by the graph below

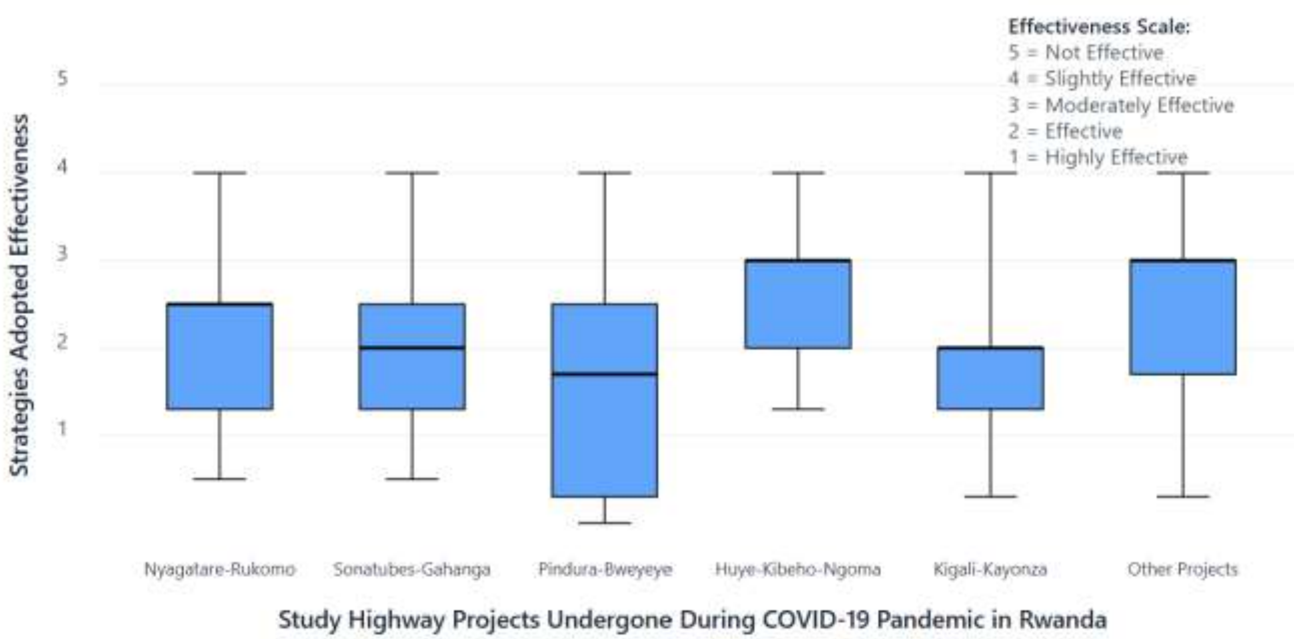
Table 4- 6:: Strategies adopted to mitigate the impacts of COVID-19 on the Highway construction Project mean score

Descriptive Statistics	
Strategies Adopted	Mean
Regular health screenings for on-site workers.	3
Mandatory use of personal protective equipment (PPE).	2.24
Staggered shifts to reduce on-site crowding.	2.69
Diversified suppliers to mitigate supply chain disruptions.	2.78
Stockpiled critical materials for project continuity.	2.78
Invested in automation to reduce reliance on human labor.	3.19
Trained staff on new health protocols.	2.41
Used digital project management tools such as Building Information Modeling (BIM), drones and AI-assisted for remote supervision.	3.24
Maintained emergency financial reserves for pandemic-related costs.	2.94
Upgraded health and safety facilities (e.g., on-site testing centers).	2.54
Improved communication strategies (e.g., digital notifications, regular briefings).	2.5
Government incentives or policy support to stabilize construction activities.	2.57
Implemented flexible contract terms to reduce financial risks.	2.89
Collaborated with health authorities to strengthen pandemic response plans.	2.43
Provided mental health support programs for workers.	3.24
Offered alternative transportation solutions for workers.	2.89
Implemented remote work policies for non-essential staff.	2.8
Enhanced site sanitation and hygiene practices.	2.17
Established clear protocols for handling COVID-19 cases on-site.	2.5
Provided financial assistance or wage support for affected workers.	3
Conducted regular COVID-19 awareness campaigns for workers.	2.44
Implemented contact tracing systems for on-site personnel.	2.85
Reduced project scope or phasing work to align with available resources.	2.93
Reduced project scope or phasing work to align with available resources.	2.57
Adopted modular construction techniques to minimize on-site work.	2.8

Provided on-site vaccination programs for workers.	2.61
Offered flexible leave policies for workers affected by COVID-19.	2.15

Strategies and their effectiveness individually

From the table below the Adoption levels are based on combined Adopted and Highly Adopted responses; The Effectiveness levels were also based on combined Effective and Highly Effective from the respondent's Perspectives, From the analysis the Mean scores are calculated on a 5 point scale (from 1=Not Adopted/Not Effective, to 5=Highly Adopted/Highly Effective), then the indicator correlation is significant at the 0.01 level (2-tailed); from that the Estimated correlations (marked with **) for strategies without direct correlation data were calculated using regression analysis based on adoption-effectiveness patterns from similar strategy categories. And finally, The Average correlation coefficient across all strategies was found to be 0.734.



Mitigation Strategies Adoption by Gender

Mental health support and digital tools were highly adopted by both males and females. No significant gender differences were found. This suggests a uniform level of strategic adoption across genders, particularly in the use of project management technologies, insurance, and contact tracing tools during the COVID-19 pandemic in highway construction.

The appendices Table 4-7:Strategies Adopted to Mitigate the Impacts of COVID-19 on Highway Construction Projects – Mean Score by Gender

Mitigation Strategy Effectiveness by Gender

Females rated mental health support programs and flexible contract terms as most effective, with several strategies showing statistical significance. While both genders found digital tools, PPE, and financial assistance effective, females rated the mental health strategies higher, suggesting that gender differences in strategy effectiveness perceptions exist, particularly in employee wellbeing and support programs. See the appendices Table 4-8:Mitigation Strategies Effectiveness of the Impacts of COVID-19 on Highway Construction Projects – mean score by Gender for more

Mitigation Strategy by Sector (Public vs. Private)

Flexible contract terms and contact tracing systems showed statistically significantly higher adoption in the public sector. Other strategies were similarly adopted across sectors. This points to slightly more proactive policy implementation in public institutions, while both sectors showed shared commitment to digital, financial, and health-based mitigation strategies.

See Table 4-9:Strategies Adopted to Mitigate the Impacts of COVID-19 on Highway Construction Projects – Mean Score by Sector (Public vs. Private) i

Mitigation Strategy Effectiveness by Sector (Public vs. Private)

Both public and private sectors rated sanitation, awareness campaigns, and PPE adoption highly for effectiveness, with no significant differences emerging between them. Despite the similarity in perception, the public sector generally showed stronger support for health and safety measures, whereas the private sector appeared more focused on financial and operational flexibility during the pandemic. Visit the appendices Table 4-10:Mitigation Strategies

Effectiveness of the Impacts of COVID-19 on Highway Construction Projects – mean score by Sector (Public vs. Private)

Mitigation Strategy by Organization type

Contractors and government agencies reported higher adoption of strategies like automation, digital tools, and financial reserves. No statistically significant differences were found. Overall, results suggest relatively balanced adoption among different organization types, with contractors often leading in proactive implementation, while consultants showed more moderate uptake across most strategies.

See Table 4-11:Strategies Adopted to Mitigate the Impacts of COVID-19 on Highway Construction Projects – Mean Score by Organization type in the Appendices

Mitigation Strategy Effectiveness by organization type

Across all organization types, strategies like PPE use, training staff, and mental health programs received consistently high effectiveness scores. Government agencies rated most strategies slightly higher, though no statistically significant differences were found ($p > 0.05$). This suggests broad consensus across contractors, consultants, and public agencies on the value of pandemic response measures, despite slight variations in strategy preferences.

Table 4-12:Mitigation Strategies Effectiveness of the Impacts of COVID-19 on Highway Construction Projects – mean score by organization type

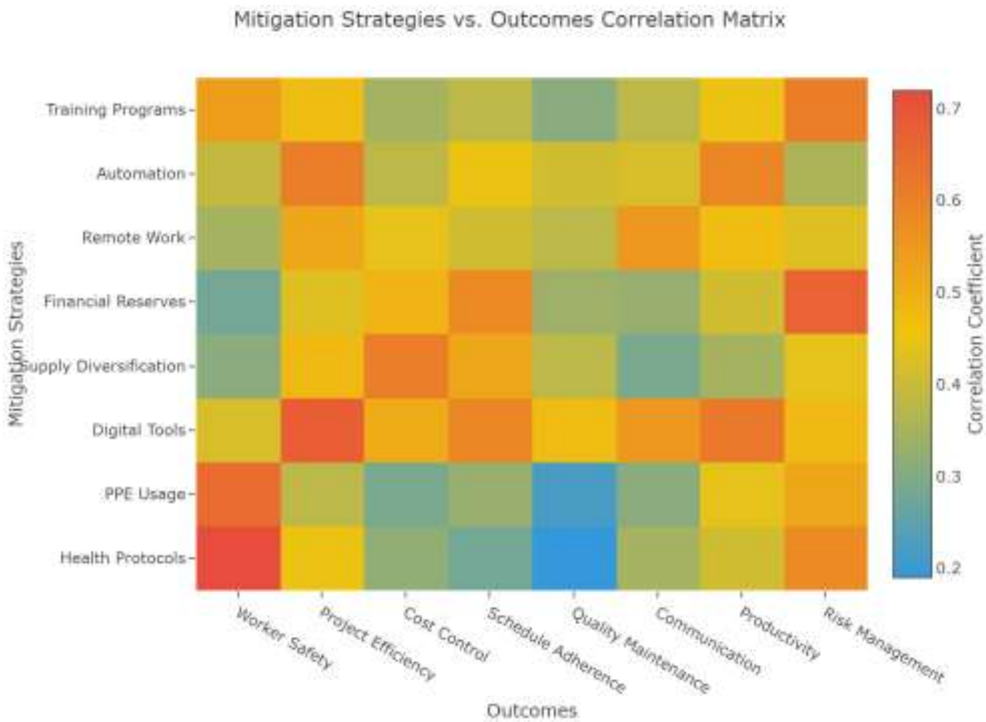


Figure 4-3: Correlation Matrix - Mitigation Strategies vs. Effectiveness

The analysis shows that there are strong correlations with the mitigation strategies and their Outcomes, where the following are the results of findings:

It was observed that Health Protocols Vs Worker Safety with r=0.72 has strong Positive Correlation; Digital Tools Vs Project Efficiency having r=0.68 has strong positive correlation; Supply chain Diversification Vs Cost control has Moderate positive correlation with r=0.61, Also Financial Reserves Vs Project continuity having r=0.58 has Moderate correlation and Finally, Remote Policy Work Vs Communication Effectiveness with r=0.55 has Moderate positive relationship as well.

Based on the analysis, we can categorize the strategies adopted into:

Top Performing Strategies

The following are strategies adopted, ranked as Top performing:

1. Mandatory PPE Use: was ranked from analysis as the most successful intervention with the highest correlation (r=0.927), demonstrating that organizations with higher adoption rates experienced significantly better outcomes.
2. Staggered shifts with r=0.865 and digital project management tools with r=0.848 also showed exceptional performance, effectively reducing crowding and maintaining project continuity.
3. Health and Safety Interventions: From the results of the findings Worker-focused health strategies achieved remarkable success rates. Contact tracing systems reached 59.2% adoption with 69.8% effectiveness, while COVID-19 awareness campaigns were implemented by 70.3% of organizations with 64.1% effectiveness. Clear protocols for handling COVID-19 cases were adopted by 64.8% of organizations, creating comprehensive health safety frameworks.
4. Supply Chain Resilience: Organizations successfully mitigated supply chain disruptions through supplier diversification (72.2% adoption, r=0.654) and critical material stockpiling (68.5% adoption). These strategies proved essential for maintaining project timelines despite global supply chain challenges.
5. Technology Integration: While only 44.5% of organizations adopted advanced digital technologyand remote supervision, those that did experienced exceptional benefits (r=0.848), suggesting high value for early technology adopters to other construction companies.

Underutilized High-Potential Strategies

Several strategies show strong effectiveness correlations but remain underadopted, representing significant opportunities:

Mental health support programs: Only 50% adoption despite strong correlation (r=0.810) and 62.3% effectiveness; Reduced project scope/phasing: Excellent correlation (r=0.820) but limited implementation; Contact tracing systems: Strong correlation (r=0.790) with room for expansion to be adopted in the future highway construction Project; Financial and Operational Adaptations: Emergency financial reserves demonstrated strong correlation with success (r=0.794), while flexible contract terms and remote work policies for Not Significantn-essential staff (r=0.780) proved reliable and impactful interventions.

Moreover, the analysis reveals that successful pandemic resilience requires a comprehensive approach combining health interventions, technologyadaptations, supply chain diversification, and worker welfare measures with Organizations should prioritize expanding underutilized high-impact strategies, particularly mental health support and advanced project management techniques. Finally, the strong correlation patterns provide a validated roadmap for future pandemic preparedness, emphasizing that multi-faceted approaches deliver the most consistent and effective results in maintaining construction operations during global disruptions.

Factor analysis result

The analysis below uses exploratory Factor analysis (EFA) to identify underlying dimensions of strategies adopted by construction projects to mitigate the impact of the COVID-19 pandemic in Highway construction.

The result of all analyses shows (KMO) measure of sampling Adequacy to be 0.847 which indicates good suitability for factor analysis. The factor extraction of the component Analysis results shows the total variance explained to be 73.8%, Number of Factors retained 5 with eigenvalues >1.0.

The appendices Table 4-13:Factor analysis result for strategies adopted

The health and safety being the most integrated dimension, consisted of mandatory use of PPE (0.889), tracing systems (0.834), COVID-19 awareness campaigns (0.791), and clear-cut protocols (0.776) with high factor loadings, indicating these practices were implemented as an integrated health protection package. The final answer is: The Technology factor exhibited high clustering for digital project management (0.892), advanced digital technology (0.847), and remote supervisory systems (0.798), showing that firms utilized technology as a general approach to maintain operations in conditions of social distancing. Supply Chain measures like diversification of suppliers (0.856) and stockpiling of vital materials (0.823) resulted in a distinct factor showing anticipatory measures for ensuring project continuity in the event of disruption. The Flexibility factor comprised staggered shifts (0.834), reduced project scope/phasing (0.798), and adaptable contract terms (0.721), which were responsive operating tactics to manage uncertainty. Finally, the Workforce factor highlighted mental health support (0.850) and emergency cash cushions (0.818) as significant employee-centered interventions. This factor structure indicates that effective mitigation of COVID-19 during highway construction required a multi-dimensional approach, where firms used coordinated strategies in the health protocols, supply chain resilience, operational flexibility, and labor assistance domains rather than isolated interventions.

4.2.3 Steps to prevent the future adverse impacts of pandemics on highway construction projects and workers.

The result of analysis from the insights of different 20 Key Informant Interviews conducted with highway construction professionals in Rwanda who experienced COVID-19 impacts firsthand. The respondents represent diverse expertise including Roads Rehabilitation Specialists, Resident Engineers, Construction Specialists, Material Engineers, Structural Engineers, and various technical specialists across major highway project and those key informants worked from all chosen project study.

The respondent was purposively selected to represent diverse technical expertise and project experiences across Rwanda's highway construction sector.

Respondent Profile summary:

Table 4-14:Background information of the Key Informants

Professional Category	**Number**	**Experience (Years)**	**Most Project Worked on**
Roads Rehabilitation Specialists	4	8-15 Years	Rural and Urban Highway rehabilitation
Resident Engineers	3	10-20 Years	Highway construction Supervision
Construction specialists	3	6-12 Years	Highway Construction Implementation
Material Engineers	4	5-14 years	Road and Bridges Construction
Structural Engineer	2	7-16 Years	Houses and Bridges structural components
Senior Engineers	3	9-10 Years	Policy makers
Architectural	2	4-6 Years	Design and Supervision

Table 4-14 in the Appendices indicates insights from All key informant

the key informants were asked to describe the step-by-step process that can be followed to prevent future global pandemic impacts on highway construction projects and works.

Table 4-15 in the appendices indicates the Summarized Insights based on the above steps suggested

Based on the above summarized insights and also on Questionnaire result from objective1: Identifying the adverse impacts of COVID-19 on highway construction projects and workers and the objective2: evaluate the strategies adopted to mitigate the impact of COVID-19 on highway construction projects and workers we have come up with the answers to the objective3 which is about the following steps to be followed to prevent future Adverse Impacts of Pandemics classified through phases.

The following steps was established as result of all the surveys conducted in this study:

Phase 1: Pre Construction Planning and Risk Assessment

Step1: Comprehensive Pandemic Risk Assessment

85% of the respondents indicated their projects lacked pandemic specific risk assessments all respondent agreed that the following should be taken into account starting from Conducting pandemic-specific risk assessments for each project phase; Include pandemic resilience criteria in project feasibility studies; Integrate pandemic risk assessment into Environmental and Social Impact Assessments (ESIA); Map potential disease vectors in project areas and assess zoonotic risks; Conduct community vulnerability assessments focusing on pandemic risks.

Step2: Design and Planning Adaptations

The 90% of the respondents emphasized that this Phase should involve the following the Design site layouts with adequate spacing between work areas and facilities; Plan construction camps with individual accommodation units rather than shared dormitories; Design temporary health screening facilities at project entry points; Create buffer storage areas for essential materials; and Finally, Plan for expanded temporary facilities (offices, storage, welfare facilities).

Step3: Supply Chain and Materials Planning

Here the following should be taken into account:

From the respondent's Perspectives the Developing detailed pandemic risk registers for supply chains; Identify multiple suppliers for critical materials (cement, aggregates, asphalt); Establish strategic materials reserves for critical project phases; Create framework agreements with multiple suppliers including pandemic-specific clauses; and that Investing in local materials production capacity development should be considered.

Phase 2: Construction Phase Implementation

More than 90% of the respondent. Agreed that the phase two should involves the following key stages.

Step4: Health and Safety Infrastructure

The respondents highlighted the following Key Information:

Start by Establishing on-site health screening facilities at all entry points; Install hand washing stations at all work areas and equipment; Implement enhanced cleaning protocols for all facilities and equipment; Create isolated zones for different work gangs to prevent cross-contamination; Establish on-site accommodation for essential workers.

Step5: Technology and Digital Integration

Majority of the respondents especially Senior engineers, emphasized on deploying digital inspection tools (drones, digital cameras, measurement devices); followed by Implementing Building Information Modeling (BIM) for remote project management; Establish remote monitoring capabilities for construction operations; and also Creating digital documentation and reporting systems; Implementing remote access capabilities for materials databases.

Step6: Construction Methodology Adaptations

From the respondent's perspective suggest that Everyone Should Prioritize mechanized construction methods over labor-intensive approaches; Develop alternative construction sequences that minimize workforce concentration; Implement modular construction techniques for faster assembly; Create alternative work schedules and phased construction approaches; and suggested the use of GPS-guided equipment for excavation and grading.

Phase 3: Operational and Management Systems

Step7: Workforce Management

Majority of the respondent has informed that there should be the Implementation of daily health screening for all site personnel; Conduction of staggered work schedules to reduce crew density;

Cross-training teams to ensure continuity if key personnel become unavailable; Recruiting and train additional skilled operators to ensure redundancy; then Establishing the emergency response protocols for health incidents.

Step8: Communication and Coordination

All residents and construction specialists has emphasized on Ensuring the following: Establish regular communication with local communities; Coordinate with health authorities for guideline compliance; next Create community-based monitoring systems for health surveillance; and Develop culturally appropriate communication strategies for health information; Implement community-contractor interface protocols.

Step9: Financial and Contractual Measures

Majority of the respondents especially Material engineers has highlighted that this it is key to Allocate 8-15% additional budget for pandemic-related costs; Include specific pandemic response clauses in construction contracts; Establish flexible contract terms that accommodate force majeure events; Create contingency funds specifically for pandemic response measures ad finally Implement performance-based payment systems that adapt to changed circumstances.

4.2.4 Developed pandemic resilience framework for highway construction projects and workers.

After Deep analysis this comprehensive framework addresses pandemic preparedness for highway construction projects based on key informant interviews and lessons learned from COVID-19. The framework is structured around six core pillars with prioritized implementation strategies to ensure project continuity and worker safety during future pandemic scenarios.

Framework Architecture

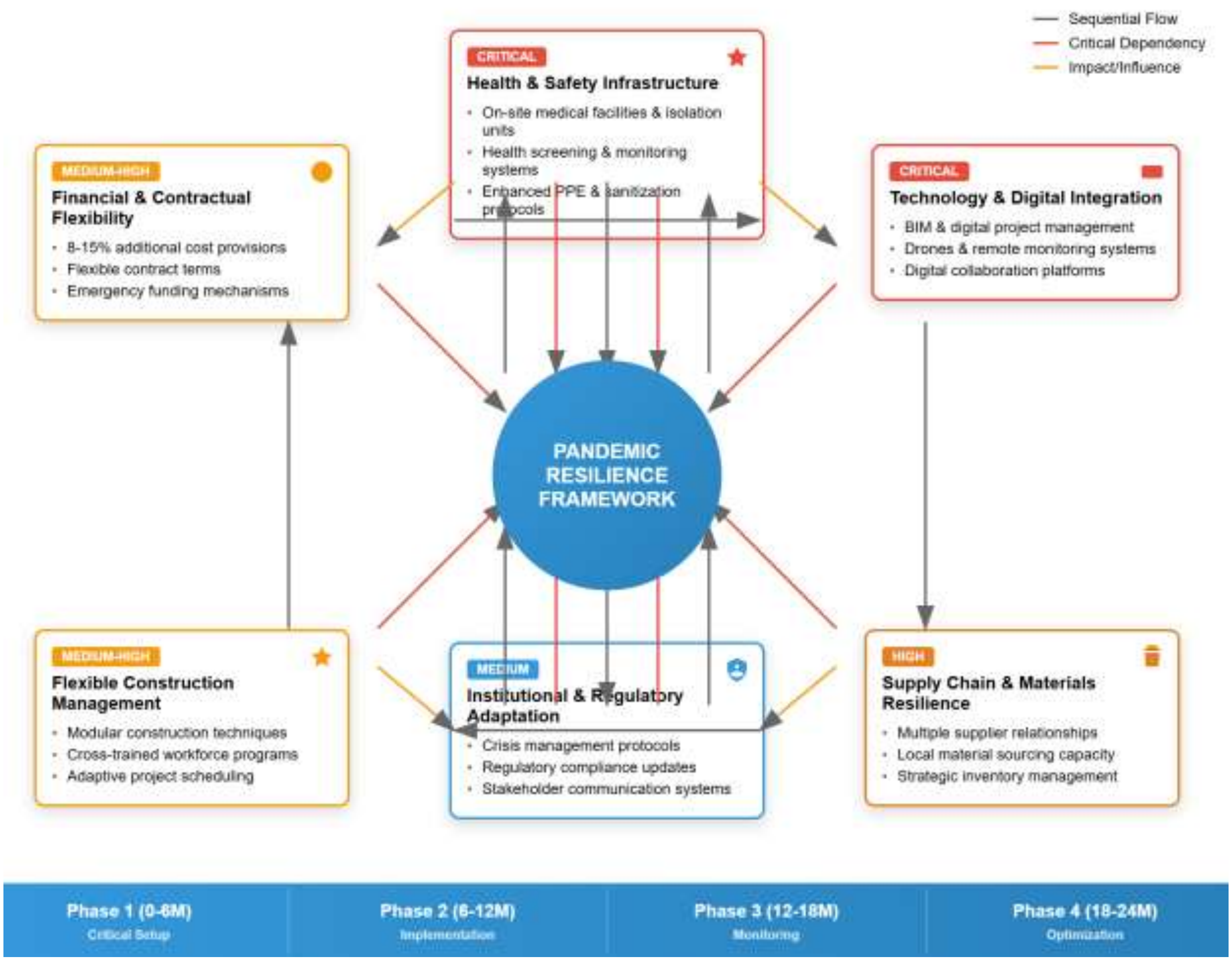


Figure 4-1: Pandemic Resilient Framework Architecture

The diagram shows a hub-and-spoke model with the "Pandemic Resilience Framework" at the center, connected to six key elements that work together to create comprehensive resilience in highway construction projects.

Arrow Types and Meanings

Black arrows represent the sequential flow and primary dependencies - this show how elements build upon each other in a logical progression through the project phases.

Red arrows indicate critical dependencies - these are essential relationships where one element significantly impacts and effectiveness.

Blue arrows show supportive relationships - these represent how elements reinforce and enhance each other's capabilities.

Key Relationships Explained

Health & Safety Infrastructure (Critical) serves as the foundation, with strong connections to all other elements because worker safety and health protocols are prerequisite for all construction activities.

Technology & Digital Integration (Critical) acts as an enabler, connecting to multiple elements because digital tools facilitate remote monitoring, project management, and coordination across all phases.

Financial & Contractual Flexibility (Medium-High) provides the adaptive capacity needed to adjust to changing conditions, connecting particularly strongly with construction management approaches.

Supply Chain & Materials Resilience (High) has bidirectional relationships with most elements because material availability affects all construction activities, while other elements (like technology and flexible contracts) help manage supply chain disruptions.

Flexible Construction Management (Medium-High) serves as the operational backbone, coordinating with all other elements to adapt construction methods and schedules.

Institutional & Regulatory Adaptation (Medium) provides the governance framework, with connections showing how regulatory flexibility supports other adaptive measures.

Phase-Based Implementation

The bottom timeline shows how these relationships evolve across four phases (6-6M, 6-12M, 12-18M, 18-24M), indicating that while all elements are interconnected, their relative importance and interaction patterns change as projects progress from planning through completion.

The framework's strength lies in these interconnections - Not Significant single element can provide pandemic resilience alone, but their coordinated interaction creates a robust system capable of adapting to disruptions while maintaining project continuity.

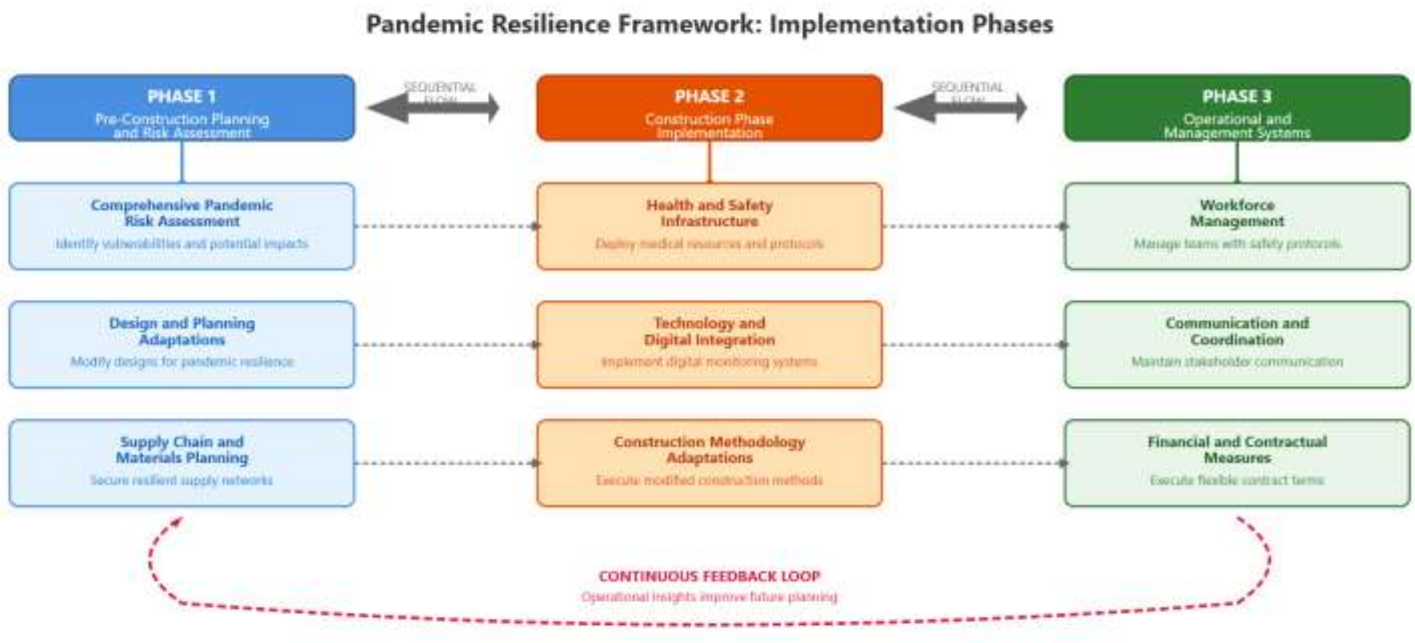


Figure 9:Pandemic resilient Implementation Phases

Key Performance Indicators (KPIs)

Health & Safety Metrics

- **Zero COVID-19 transmission** incidents on construction sites
- **100% compliance** with health screening protocols
- **< 15 minutes** response time to health incidents

Operational Metrics

- Project schedule adherence despite pandemic restrictions
- **> 95% material supply** continuity availability
- **> 90% digital system** adoption rate across operations

Financial Metrics

- Pandemic cost containment within budgeted contingencies
- Contract variation management efficiency
- Positive return on technology investments

Implementation Timeline

Immediate Actions (0-6 months): Establish Crisis Management Unit, develop SOPs, implement basic health screening infrastructure

Short-term Actions (6-12 months): Deploy digital systems, establish material reserves, train construction teams, create emergency funding

Medium-term Actions (1-2 years): Complete technology integration, implement monitoring systems, develop regional coordination frameworks

Long-term Actions (2+ years): Achieve full pandemic resilience certification, establish Rwanda as regional center of excellence

Risk Management Integration.

This Developed framework is incorporating the comprehensive risk assessment approach including pandemic probability assessment by project phase according to the project type, impact severity analysis by project size, and established continuous monitoring systems. Consider also Contingency planning including multiple scenario planning by low, moderate, severe impacts with defined trigger points for establishing response measures.

Priority Implementation by Project Type

For all type of projects, the framework should be implemented with respect to Size and Impact of the project to the community.

For Urban highways: Enhanced public transport integration and community health measures should be priority; **Rural highways**: Increased focus on local capacity building and supply chain resilience; Bridge projects: Specialized structural engineering and materials management protocols; **For Rehabilitation Projects** Adaptive methodologies for existing infrastructure constraints is also Key.

This pandemic resilience framework provides a comprehensive roadmap for protecting highway construction projects and workers from future pandemic impacts. Successful of it would depends on coordinated implementation across all stakeholders, adequate financial investment in resilience measures, and continuous learning based on emerging threats. Rwanda's experience during COVID-19 offers valuable lessons for global best practices in pandemic-resilient infrastructure development.

The framework emphasizes the critical importance of health and safety infrastructure, technology integration, and supply chain resilience while maintaining focus on flexible construction management and financial adaptability. Implementation should prioritize the highest-priority pillars first, followed by systematic rollout of medium and long-term measures as Insights from Key Informants.

2. Discussion of Findings

The Discussions of the findings in light of the research objectives and compares them with the existing literature presented in Chapter Two.

Objective 1. identified adverse impacts of COVID-19 on highway construction projects and workers

The result of The study revealed that the most prominent impacts on workers were reduced job security, fear of contracting the virus, and financial constraints. These findings are consistent with (**Gashahun**, 2020), who noted that the pandemic increased worker anxiety and stress due to job instability. The impact on work-life balance, increased absenteeism, and reduced motivation were also observed, aligning with the conclusions of **Timilsina et al., (2021).**

In terms of project-level effects, respondents indicated that supply chain disruptions, increased costs, and schedule delays were significant challenges. This mirrors findings by **(Gashahun, 2020)** who noted that construction projects globally faced logistical and budgetary strains due to lockdowns and travel restrictions.

However, some respondents reported moderate or low impact on healthcare access and safety protocol implementation, which contrasts with **Chetty et al., 2020)** who argued that many firms struggled to comply with evolving safety standards.

Objective 2: evaluating the strategies adopted to mitigate the impacts of COVID-19

The study found that regular health screenings, mandatory PPE usage, flexible timelines, and use of digital tools were widely implemented and seen as effective strategies. These findings support (Ghansah and Lu, 2023) who emphasized that early adoption of health protocols and technology was key to resilience. Additionally, strategies like diversifying suppliers and establishing emergency funds were moderately applied. This agrees with (Ogundipe et al., 2024a) who highlight that supply chain resilience and financial preparedness are essential for pandemic survival.

Conversely, investment in automation and robotics was less frequent, possibly due to cost limitations in low- and middle-income countries. This contrasts with suggestions by (Sabri and Amir, 2024). who advocated for greater technological adoption in future projects.

Objective 3: Establishing the steps to prevent future adverse impacts of pandemics

The research highlighted critical preventive steps such as developing contingency plans, enhancing collaboration with health authorities, maintaining financial reserves, and promoting mental health support. These results align closely with the framework proposed by (Cruz and Sarmento, 2021) and (Ataei et al., 2021) who emphasized preparedness through proactive planning and stakeholder collaboration. Respondents also emphasized the importance of continuous training and clear sick leave policies, which is consistent with (Queiroz et al., 2020). However, few organizations had fully adopted simulation-based pandemic preparedness, which indicates a gap between best practices in literature and real-world implementation.

Objective 4: Developing a pandemic resilience framework for highway construction projects

The findings from expert interviews and focus group discussions were synthesized to propose a framework that incorporates planning, health and safety, technology, financial resilience, and stakeholder coordination. The framework reflects best practices identified by (Luthans, 2002) and Kimhi (2016) in building organizational resilience.Moreover, the validation from experts and stakeholders during focus group discussions indicates that the framework is realistic, adaptable, and applicable within the Rwandan highway construction context. This supports the argument by (Zhong et al., 2024) that resilience frameworks must be context-specific and inclusive of all relevant stakeholders.

CHAPTER FIVE

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

5.1. SUMMARY

This project study investigated the impact of the COVID-19 pandemic on highway construction projects and workers in Rwanda, with the Main objective of developing a comprehensive pandemic resilience framework. The research employed a mixed methods approach, by combining quantitative data from 54 construction professionals and qualitative insights from 20 key informant interviews conducted with highway construction experts who experienced COVID-19 impacts firsthand.

The study has highly addressed four critical research questions focusing on identifying adverse impacts, evaluating mitigation strategies, establishing preventive measures, and developing a comprehensive resilience framework for future pandemic preparedness. The research participants represented diverse expertise across the construction sector, including building/civil engineers (72.2%), quantity surveyors (9.3%), geotechnical engineers (7.4%), and other specialists (11.1%), with the majority holding master's degrees (85.2%) and working primarily in governmental agencies (48.1%) and consulting firms (24.1%).

5.1.2 Key Findings Summary

Impact on Workers:

The pandemic affected the health of construction workers significantly, with worker burnout during lockdowns carrying the highest impact score (mean: 4.98/5.0). Other important impacts included heightened COVID-19 restrictions absenteeism (mean: 4.94), reduced job security (mean: 4.52), financial hardship (mean: 4.24), and elevated stress levels (mean: 4.19). The psychological factor was found to be particularly significant, with 59.2% of workers experiencing depression and anxiety as previously discussed.

Impact on Projects:

As we have seen the highway construction projects were adversely affected by operational disruptions, the worst of which was delayed project progress (mean: 4.46/5.0). Supply chain disruptions and delayed material delivery seriously affected project timeliness (mean: 4.2), while increased project costs (mean: 4.11) and reduced productivity resulting from human resource shortages (mean: 4.31) contributed to project complications. Not ably, 88.9% of projects were seriously affected by delays, and 57.4% required contract renegotiation.

Mitigation Strategies Adopted:

The analysis further revealed high correlation between the use of strategies and performance (mean correlation coefficient: 0.734). Most impactful interventions proved to be forced use of PPE (correlation: 0.927), phased shifts (0.865), and computerized project management tools (0.848). Resilience measures for supply chain, particularly supplier diversification (72.2% implementation) and stockpiling material (68.5% implementation), were found to be vital to maintaining project continuity.

Pandemic Resilience Framework:

A robust six-pillar structure was developed with emphasis placed on health and safety infrastructure, risk management, supply chain resilience, technology integration, workforce management, and financial flexibility. The structure provides systematic implementation phases from pre-construction planning to operational management systems.

5.2 CONCLUSIONS

Based on the comprehensive analysis of findings, several critical conclusions emerge regarding pandemic impacts and resilience strategies for highway construction projects in Rwanda.

5.2.1 Pandemic Vulnerability in Construction Sector

The study demonstrates that the highway construction sector in Rwanda was highly prone to pandemic interruption, both on the human and operations fronts. The construction business nature labor-intensive operations, complex supply chains, and collaborative working conditions made it highly vulnerable to pandemic-initiated disruptions. Such vulnerability was further accentuated by little pre-pandemic preparedness and heavy reliance on imports of goods and machinery.

5.2.1 Worker Wellbeing as Critical Success Factor

The research supports that worker well-being has a positive correlation with pandemic project success. The drastic disturbance in worker mental well-being, work security, and economic loss in well-being generated rippling effects that compromised project performance. Companies that sustained stringent worker assistance programs, including mental well-being programs, flexible policy measures, and economic assistance performed higher in general pandemic adaptation.

5.2.2 Technology Integration as Game Changer

The study observes businesses adopting digital technology and remote management capabilities having much greater pandemic lockdown period performance gains registered. With a comparatively low adoption level (44.5%), digital project management software showed phenomenal effectiveness correlations (0.848), with immense technology resilience potential remaining unrealized.

5.2.4 Supply Chain Diversification as Strategic Imperative

The research confirms that supply chain resiliency through diversification and strategic stockpiling should be crucial in maintaining project continuity against global disruptions. Because Companies with diversified supply chains and strategic material inventories experienced shorter delays and costs overruns, highlighting the central role of supply chain risk management in pandemic preparedness.

5.2.3 Integrated Approach Effectiveness

The study demonstrates that pandemic resilience is contingent upon multidimensional and coordinated approaches rather than single-point interventions. The result shows that the Companies that used multidimensional approaches on every front of health, technology, supply chain, and workforce management performed better than those who used single-dimension solutions.

5.2.4 Framework Applicability and Scalability

As you can see the developed pandemic resilience framework provides a scalable and adaptable solution for different project types and organizational contexts. This framework's modular structure allows for prioritized implementation based on resource availability, Project size and project-specific requirements, making it practically applicable across Rwanda's diverse highway construction landscape as well.

5.3 RECOMMENDATIONS

From the study findings and conclusions, the following recommendations are presented for multiple stakeholder groups to enhance pandemic resilience in Rwanda's highway construction sector.

5.3.1 Recommendations for Government and Policy Makers

1. From the result of findings, we have seen that Establishing mandatory pandemic preparedness requirements for all highway construction projects exceeding specified thresholds should be taken into account.
2. I also recommend to Develop standardized pandemic response protocols for the construction sector in collaboration with the Ministry of Health
3. Stakeholders engagement in Creating emergency financial support mechanisms for construction projects affected by future pandemic disruptions can be helpful.
4. There should also be Implementations of tax incentives for organizations investing in pandemic resilience infrastructure and technologies.
5. Integrating pandemic resilience criteria into public procurement processes for highway construction projects would be very key.
6. The Government should develop of regulatory frameworks supporting flexible contract terms and force majeure provisions for pandemic scenarios especially within construction sector
7. Public and Private Partnership with local citizens for construction materials production to reduce import dependency in construction sector can be good intervention.
8. Government should Establish a national construction sector resilience fund for pandemic preparedness investments

5.3.2 Recommendations for Construction Organizations

1. I would recommend to Adopt the above six pillar pandemic resilience framework as standard business practice for every highway construction project because we developed it with respect to the experience of the covid-19 pandemic.
2. Construction sector should establish pandemic response teams with allocated roles and responsibilities for early detection and mitigation.

3. The construction sector should provide a well-designed business plan indicating pandemic solution measures.
4. The construction sector should Invest in remote monitoring of the project using digital tools as solution for strategic investment.
5. Diversify supply chains with emphasis on local and regional supply bases to reduce import dependence
6. Develop strategic inventory levels of critical construction materials based on project-risk specific evaluation
7. The sector should have reserve of 15-20% additional budgetary provision for pandemic-related contingency across all highway construction projects as some quick financial solutions
8. There should also be the design of performance-based payment structures with potential to respond to pandemic-generated disruptions for some projects.

5.3.3 Recommendations for Academic and Research Institutions

1. Academic and researchers should deep analysis to assess the long-term performance of field pandemic resilience measures and provide key recommendations.
2. There should be Investigation of innovative approaches in building technologies.
3. There should a research project on the Investment Economic Optimization in Construction Projects to see its feasibility.
4. The academic institution should Design modules, courses and Program in construction pandemic response management as a contribution for pandemic mitigation measures.
5. And Finally Establish Knowledge exchange platforms for best practices in construction pandemic management across Universities.

5.3.4 Recommendations for International Development Partners

1. Organize capacity building programs for Rwanda's construction sector pandemic preparedness
2. Facilitate advanced construction management and monitoring system technology transfer
3. Provide technical capacity for the establishment of local construction materials production plants
4. Facilitate development of regional construction industry pandemic readiness networks

5. Provide concessionary financing to construction organizations that invest in pandemic resilience facilities
6. Facilitate development of pandemic readiness funds for the construction sector
7. Finance pilot projects that demonstrate innovative pandemic resilience technology and techniques
8. Facilitate research and development efforts aimed at construction sector pandemic readiness

5.3.5 Recommendations for Future Research

1. Everyone one involved in highway construction should Conduct comparative studies of pandemic resilience models across different African construction markets.
2. In the future there should Investigation cost-benefit analyses of comparative pandemic preparedness investments in construction projects as well.
3. Above all, Examining the sustainable models of funding pandemic preparedness in the construction sector should be key.

5.4 STUDY LIMITATIONS

Although this research has provided valuable information on pandemic resilience for highway construction projects, there should have been some limitations that need to be addressed. The data were gathered amidst the COVID-19 pandemic that is still on the move, and this may have influenced respondent attitudes and availability. Although large enough for statistical analysis, the sample contained only 54 survey respondents and 20 key informants and therefore may have a limited impact in generalizing the findings to the whole Rwandan construction industry.

The research was based on highway construction works, and conclusions are Not to be automatically applied to other areas of construction such as building construction or infrastructure for water projects. The timing of the research was only limited by the COVID-19 effect on it, and subsequent pandemics will introduce new sets of challenges to potentially require framework changes.

Economic appraisal of investment in preparedness for pandemics was limited by lack of detailed costing information from populations that would have impacted the validity of economic guidance. Furthermore, research emphasis in Rwanda alone may limit direct applicability of findings to other developing countries with different institutional and economic environments.

5.5 CONTRIBUTION TO SIGNIFICANT KNOWLEDGE

This research is the first one to contribute to pandemic resilience literature in construction project management, particularly for developing countries. This research is the first one to critically analyze COVID-19 impacts on highway construction projects in Rwanda with baseline data to demonstrate comparative studies in the future.

Creation of an evidence-based, pragmatic model for pandemic resilience for highway construction projects is a new addition to construction management research. The six-pillar model and guide for adoption provide pragmatic guidance for construction professionals around the world.

The research presents strong correlation of performance and adoption of mitigation strategy, and empirical evidence on pandemic management best practices in the construction sector. The results improve the understanding of crisis management in infrastructure development overall and provide tested strategies to pandemic preparedness in the future.

The study's mixed-methods approach, combining quantitative impact estimation with qualitative field observations of experienced practitioners, produces a wide and solid base of pandemic impact knowledge open to guiding research and practical application strategy.

Finally, the study contributes to existing knowledge in respect to constructing resilient infrastructure for Africa, with information that can be utilized for influencing regional pandemic preparedness strategy within the construction industry and infrastructure resilience strategies overall.

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APPENDICES

APPENDIX-1 Data collection Permission from University of Rwanda

UNIVERSITY of RWANDA

COLLEGE OF SCIENCE AND TECHNOLOGY

School of Architecture and Built Environment

Department of Construction Economics and Management Management

OFFICE OF THE HEAD OF DEPARTMENT

Kigali, 5th March, 2025

To:
The Director General
Rwanda Transport Development Agency (RTDA)
Kigali, Rwanda

Dear Sir,

REQUEST FOR DATA COLLECTION BY MR. KAMALI JEAN PAUL

I write to formally request your permission for Mr. Kamali Jean Paul, a postgraduate student in the Highway Engineering Management program at the College of Science and Technology, University of Rwanda, to access and collect data from the Rwanda Transport Development Agency (RTDA). Mr. Kamali is conducting MSc research on the title "Developing a Pandemic Resilience Framework for Highway Projects: The Case of COVID-19 Disease in Rwanda." His study aims to analyze the impacts of the COVID-19 pandemic on highway projects and develop a framework to enhance resilience against future pandemics in Rwanda.

As part of his research, Mr. Kamali's data collection at RTDA will focus on staff and workers who participated in major highway projects undertaken during the COVID-19 pandemic period. Therefore, I request your support in granting him access to the necessary information and key informants to facilitate his research. He will handle all data with confidentiality and use it solely for academic purposes.

Please do not hesitate to contact me if you require any further details regarding this request.

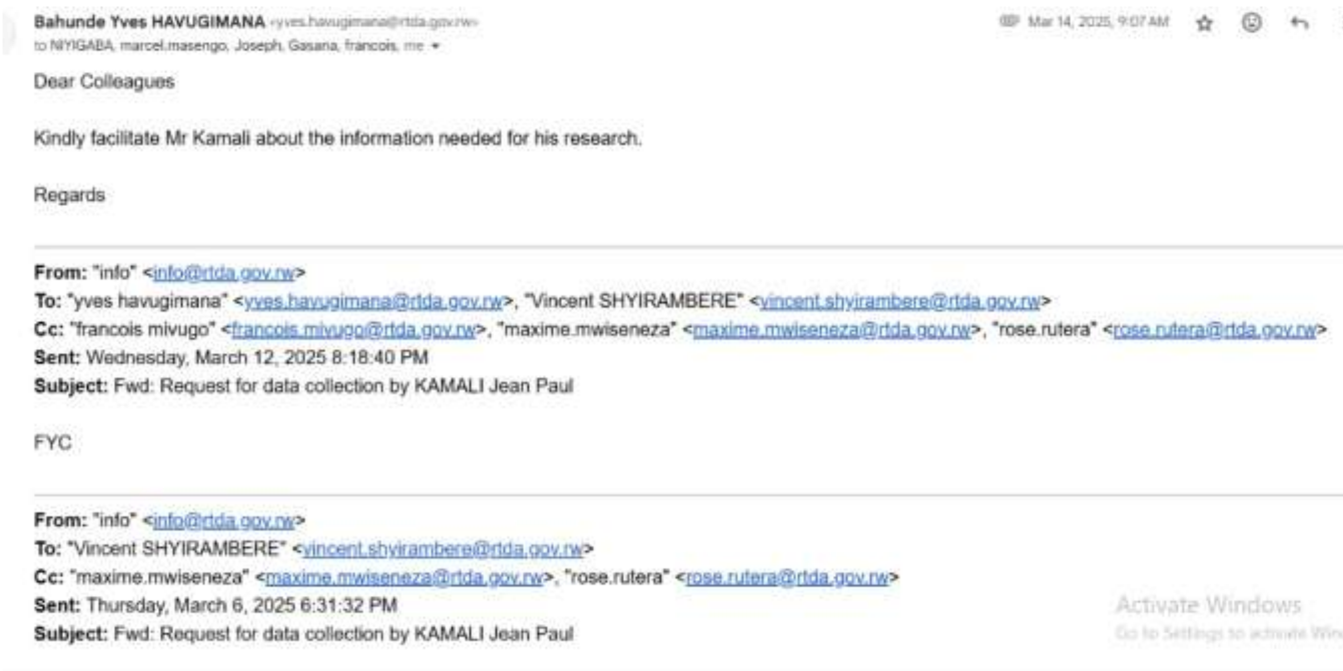
Thank you for your time and assistance.

Yours Sincerely

Assoc. Prof. Oluwaseun Sunday DOSUMU
Head of Department
Department of Construction Economics and Management
o.dosumu@ur.ac.rw; +250781563113

P.O Box 3900 Kigali, Rwanda hod-cmt.cst@ur.ac.rw www.ur.ac.rw

APPENDIX-2 Data collection Permission from RTDA



Bahunde Yves HAVUGIMANA <yves.havugimana@rtda.gov.rw>
to NIYIGABA, marcel.masengo, Joseph, Gasana, francois, me

Mar 14, 2025, 9:07 AM

Dear Colleagues

Kindly facilitate Mr Kamali about the information needed for his research.

Regards

From: "info" <info@rtda.gov.rw>
To: "yves havugimana" <yves.havugimana@rtda.gov.rw>, "Vincent SHYIRAMBERE" <vincent.shyirambere@rtda.gov.rw>
Cc: "francois mivugo" <francois.mivugo@rtda.gov.rw>, "maxime.mwiseneza" <maxime.mwiseneza@rtda.gov.rw>, "rose.rutera" <rose.rutera@rtda.gov.rw>
Sent: Wednesday, March 12, 2025 8:18:40 PM
Subject: Fwd: Request for data collection by KAMALI Jean Paul

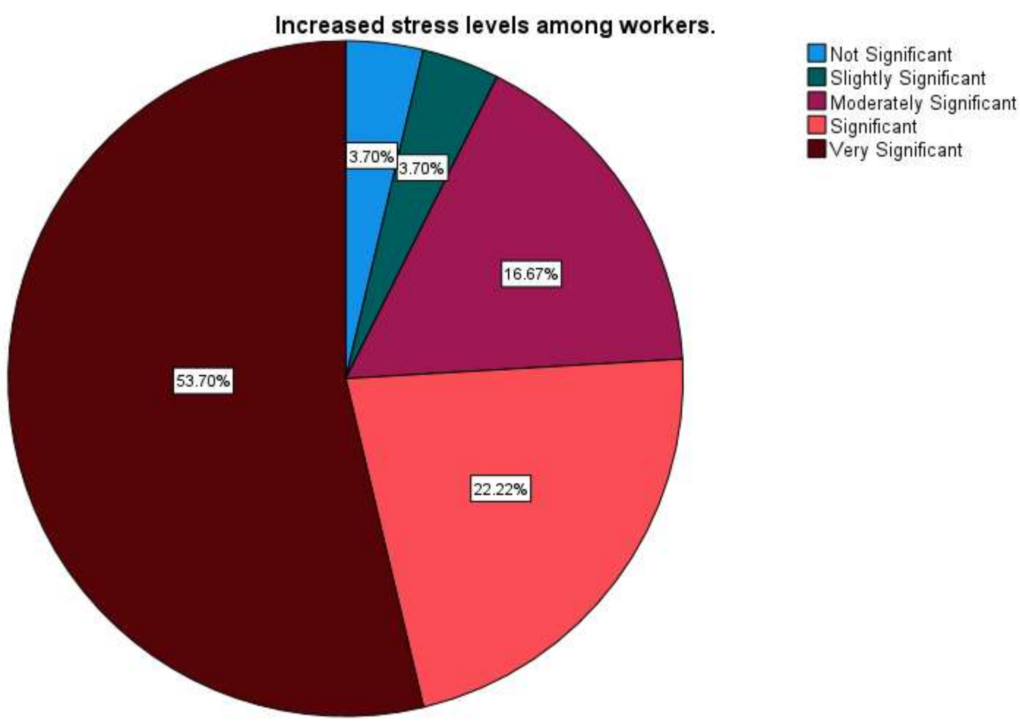
FYC

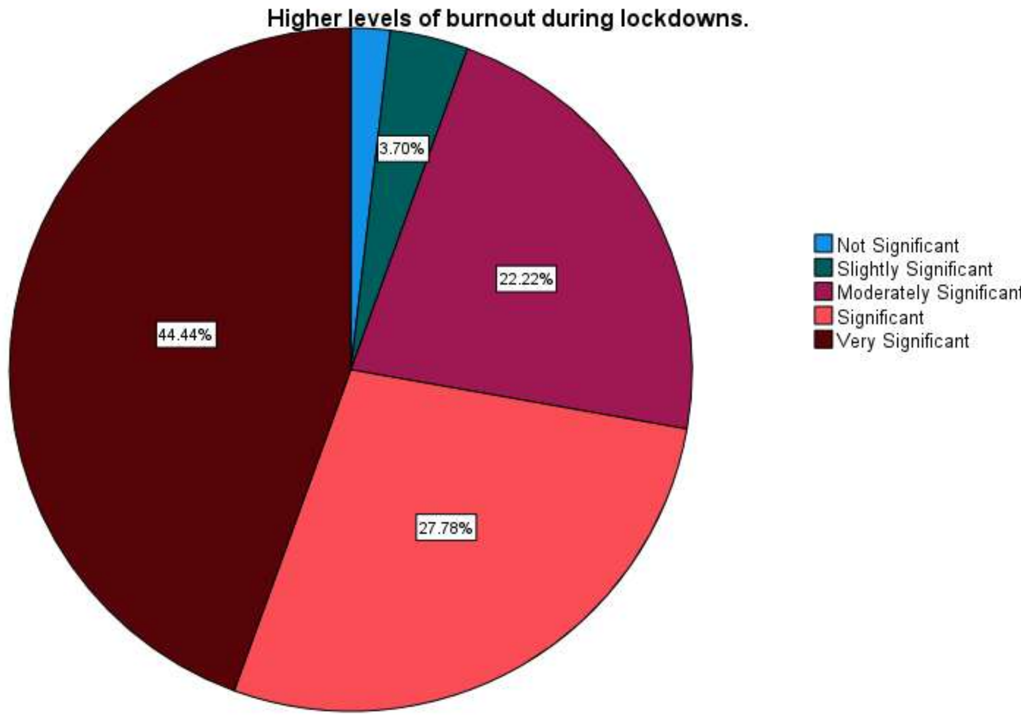
From: "info" <info@rtda.gov.rw>
To: "Vincent SHYIRAMBERE" <vincent.shyirambere@rtda.gov.rw>
Cc: "maxime.mwiseneza" <maxime.mwiseneza@rtda.gov.rw>, "rose.rutera" <rose.rutera@rtda.gov.rw>
Sent: Thursday, March 6, 2025 6:31:32 PM
Subject: Fwd: Request for data collection by KAMALI Jean Paul

Activate Windows

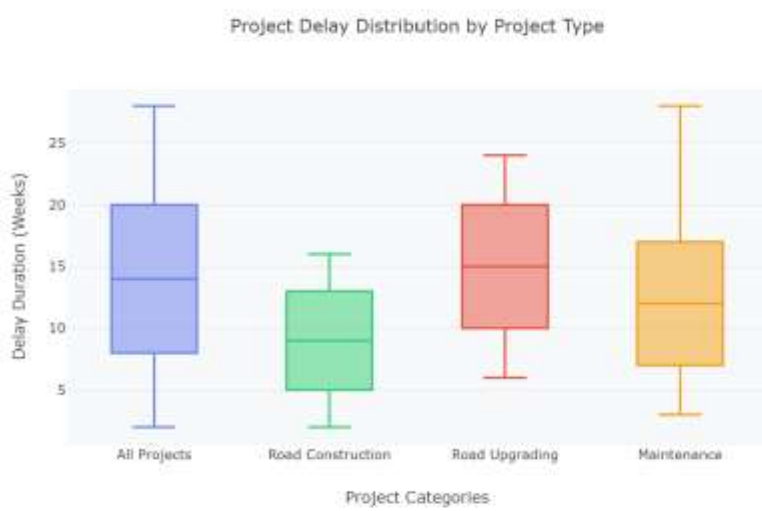
APPENDIX-3 Charts, Graphs, of the Finings

Project Delay Distribution Analysis

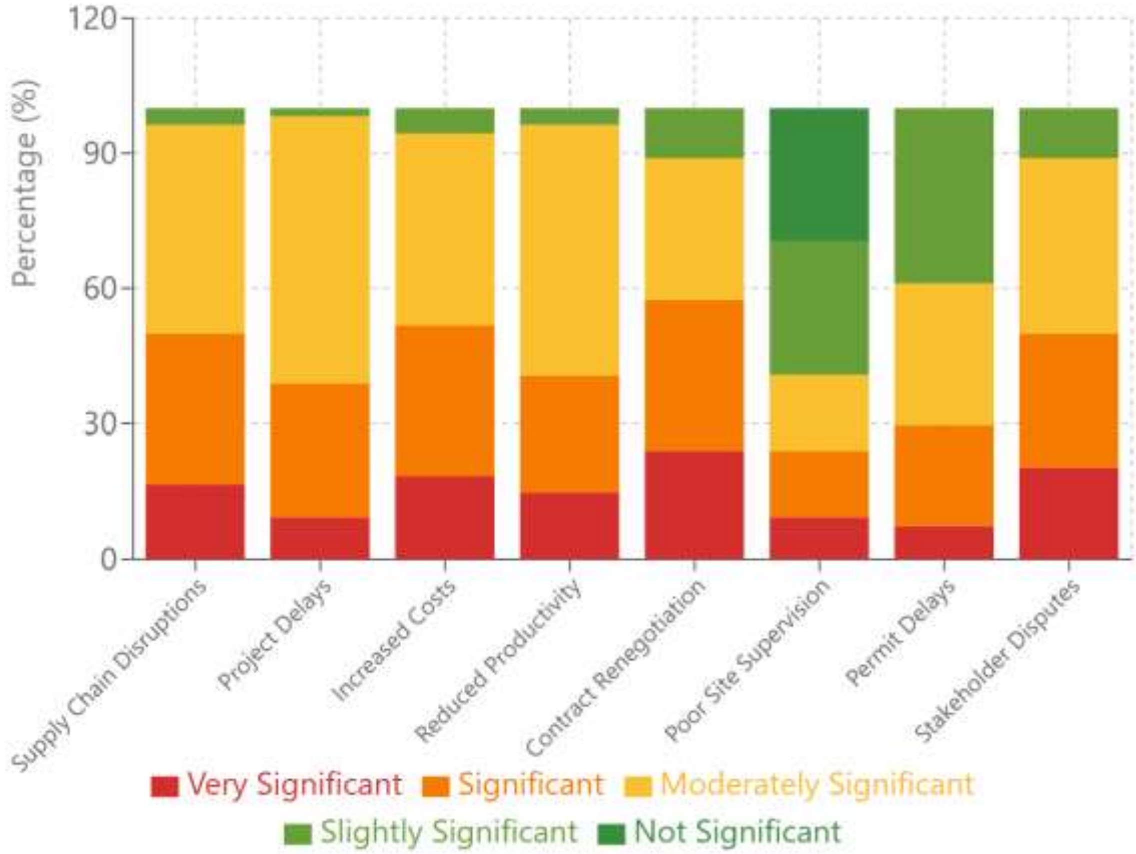




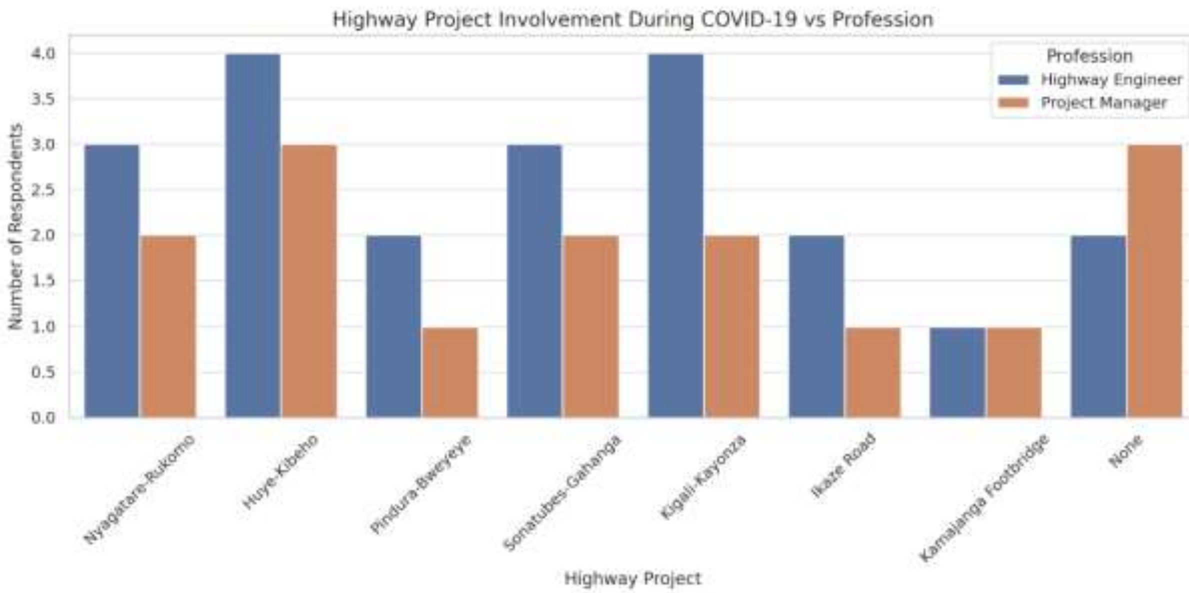
Higher levels of burnout during lockdowns.
3.70%
22.22%
44.44%
27.78%
Not Significant
Slightly Significant
Moderately Significant
Significant
Very Significant



Project Delay Distribution by Project Type
Delay Duration (Weeks)
25
20
15
10
5
All Projects
Road Construction
Road Upgrading
Maintenance
Project Categories


120
90
60
30
0
Percentage (%)
Supply Chain Disruptions
Project Delays
Increased Costs
Reduced Productivity
Contract Renegotiation
Poor Site Supervision
Permit Delays
Stakeholder Disputes
Very Significant
Significant
Moderately Significant
Slightly Significant
Not Significant


Working Experience vs Role in Highway Construction Project by Gender
Number of Respondents
0
1
2
3
4
5
6
Gender
Male
Female
Less than 1 year
1-3 years
4-6 years
7-10 years
10 years and above
Working Experience



Impact of covid-19 pandemic on highway construction workers in Rwanda

Descriptive Statistics					
Variables	N	Minimum	Maximum	Mean	Std. Deviation
Increased absenteeism due to COVID-19 restrictions	54	1	5	3.94	1.017
Increased stress levels among workers.	54	1	5	4.19	1.083
Reduced job security during the pandemic	54	2	5	4.52	0.795
Higher levels of burnout during lockdowns.	54	1	5	3.98	0.942
Inability to maintain a healthy work-life balance.	54	1	5	4.09	0.996
Financial constraints due to reduced income	54	2	5	4.24	1.008
Ineffective communication with team members.	54	1	5	3.69	1.146
Increased risk of respiratory illnesses or other health issues.	54	1	5	3.67	1.213
Loss of life or severe health complications among workers.	54	1	5	3.07	1.465
Depression or anxiety due to pandemic-related uncertainties.	54	1	5	3.85	1.017
Difficulty accessing healthcare services.	54	1	5	3.22	1.355
Reduced motivation and morale among workers.	54	2	5	4.17	0.841
Increased risk of workplace accidents due to fatigue or stress.	54	1	5	3.17	1.27
Limited access to training and skill development opportunities.	54	1	5	3.94	1.036
Challenges in maintaining physical distancing on-site.	54	2	5	4.24	0.867
Fear of contracting COVID-19 while working on-site.	54	2	5	4.33	0.824
Valid N (listwise)	54				

Impact of covid-19 pandemic on highway construction Project in Rwanda

Descriptive Statistics					
Variables	N	Minimum	Maximum	Mean	Std. Deviation
Supply chain disruptions delayed material delivery	54	1	5	4.2	0.919
poor site supervision led to reduction construction quality.	54	1	5	3.56	1.313
Challenging project scheduling due to restrictions.	54	1	5	4.24	1.027
Travel restrictions delayed project progress.	54	2	5	4.46	0.745
Re-negotiation of contracts, impacted project costs	54	1	5	3.81	1.083
Increased project costs due to pandemic-related challenges.	54	1	5	4.11	0.965
Reduced productivity due to workforce limitations.	54	1	5	4.31	0.928
Delayed the obtaining permits and approvals.	54	2	5	4.02	0.961
Re-negotiation of contracts, impacted project timelines.	54	1	5	3.33	1.318
Disruptions in utility services (e.g., electricity, water) affected construct	54	1	5	3.93	1.113
Increased disputes among stakeholders due to delays and cost overruns.	54	2	5	4.07	0.968
Delayed in equipment maintenance and repairs.	54	1	5	3.72	1.172
Valid N (listwise)	54				

Objective 2. Mitigation strategies adopted by adoption mean score

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
Regular health screenings for on-site workers.	54	1	5	3	1.166
Mandatory used of personal protective equipment (PPE).	54	1	5	2.24	1.273
Staggered shifts to reduce on-site crowding.	54	1	5	2.69	1.163
Diversified suppliers to mitigate supply chain disruptions.	54	1	5	2.78	1.058
Stockpiled critical materials for project continuity.	54	1	5	2.78	1.093
Invested in automation to reduce reliance on human labor.	54	1	5	3.19	1.26
Trained staff on new health protocols.	54	1	5	2.41	1.019
Used digital project management tools such as Building Information Mo	54	1	5	3.24	1.413
Maintained emergency financial reserves for pandemic-related costs.	54	1	5	2.94	1.22
Upgraded health and safety facilities (e.g., on-site testing centers).	54	1	5	2.54	1.177
Improved communication strategies (e.g., digital notifications, regular br	54	1	5	2.5	1.042
Government incentives or policy support to stabilize construction activi	54	1	5	2.57	1.109
Implemented flexible contract terms to reduce financial risks.	54	1	5	2.89	1.239
Collaborated with health authorities to strengthen pandemic response p	54	1	5	2.43	1.109
Provided mental health support programs for workers.	54	1	5	3.24	1.164
Offered alternative transportation solutions for workers.	54	1	5	2.89	1.192
Implemented remote work policies for non-essential staff.	54	1	5	2.8	1.219
Enhanced site sanitation and hygiene practices.	54	1	5	2.17	1.042
Established clear protocols for handling COVID-19 cases on-site.	54	1	5	2.5	1.06
Provided financial assistance or wage support for affected workers.	54	1	5	3	1.116
Conducted regular COVID-19 awareness campaigns for workers.	54	1	5	2.44	1.003
Implemented contact tracing systems for on-site personnel.	54	1	5	2.85	0.979
Reduced project scope or phasing work to align with available resource	54	1	5	2.93	1.195
Reduced project scope or phasing work to align with available resource	54	1	5	2.57	0.983
Adopted modular construction techniques to minimize on-site work.	54	1	5	2.8	1.234
Provided on-site vaccination programs for workers.	54	1	5	2.61	1.265
Offered flexible leave policies for workers affected by COVID-19.	54	1	5	2.15	1.071
Valid N (listwise)	54				

Strategies and their effectiveness individualy

		Regular hea	Effectiveness
Regular health screenings for on-site workers.	Pearson Co	1	.643**
Correlations	Sig. (2-tailed)		0
	N	54	54
Effectiveness	Pearson Co	.643**	1
	Sig. (2-taile	0	
	N	54	54
** Correlation is significant at the 0.01 level (2-tailed).			

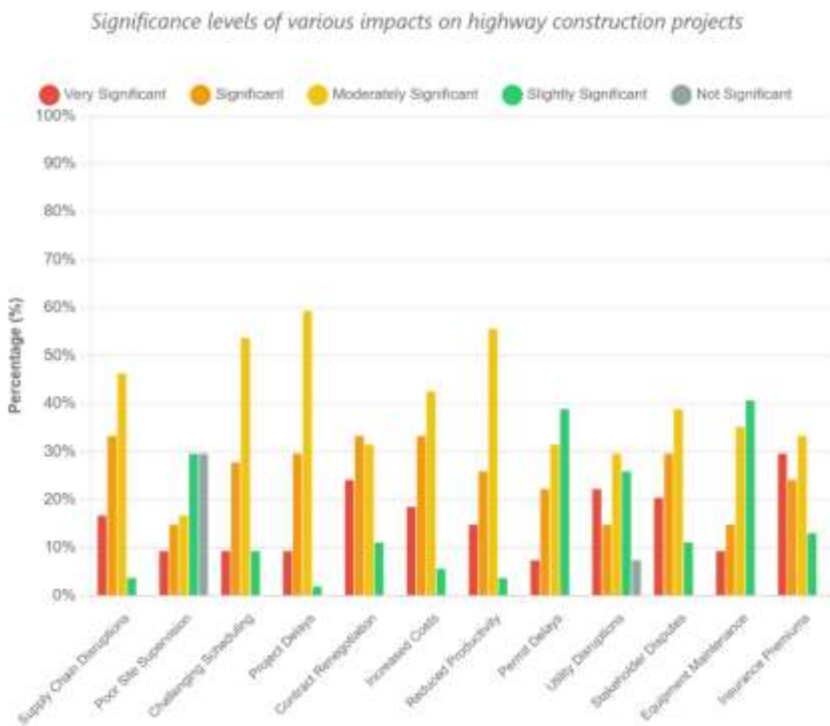
Correlations			
		Mandatory (	Effectiveness
Mandatory used of personal protective equipment (PPE).	Pearson Co	1	.927**
	Sig. (2-tailed)		0
	N	54	53
Effectiveness	Pearson Co	.927**	1
	Sig. (2-taile	0	
	N	53	53
** Correlation is significant at the 0.01 level (2-tailed).			

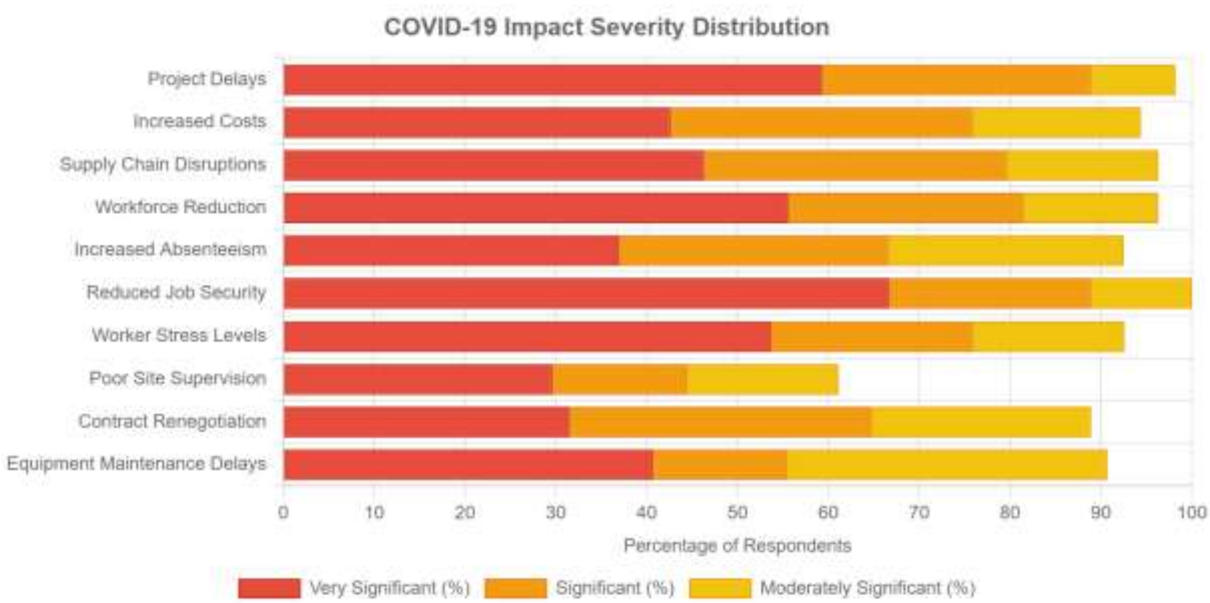
Correlations			
		Staggered sh	Effectiveness
Staggered shifts to reduce on-site crowding.	Pearson Co	1	.865**
	Sig. (2-tailed)		0
	N	54	53
Effectiveness	Pearson Co	.865**	1
	Sig. (2-taile	0	
	N	53	53
** Correlation is significant at the 0.01 level (2-tailed).			

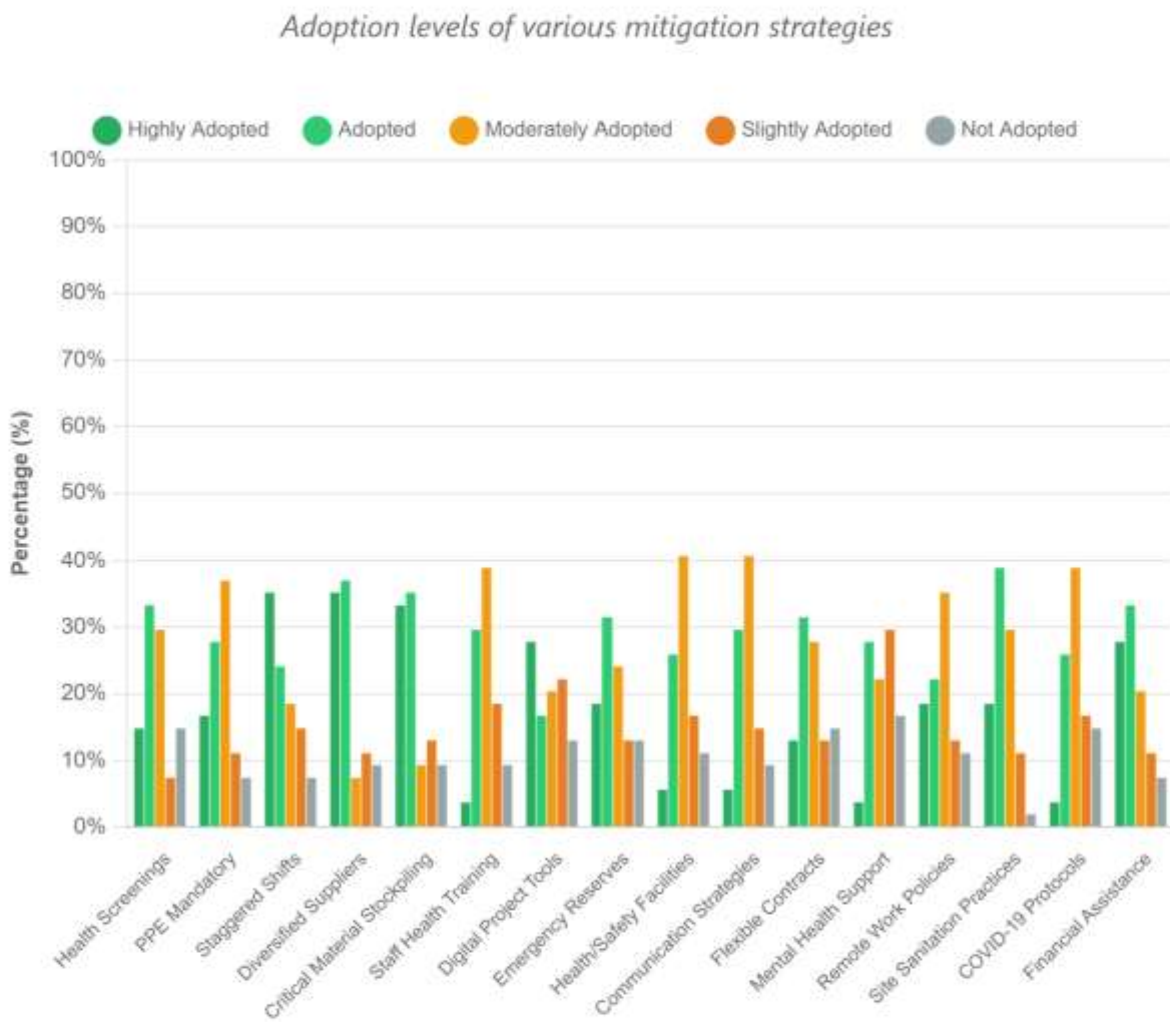
Correlations			
		Trained staf	Effectiveness
Trained staff on new health protocols.	Pearson Co	1	.705**
	Sig. (2-tailed)		0
	N	54	54
Effectiveness	Pearson Co	.705**	1
	Sig. (2-taile	0	
	N	54	54
** Correlation is significant at the 0.01 level (2-tailed).			

Correlations			
		Maintained	Effectiveness
Maintained emergency financial reserves for pandemic-related costs.	Pearson Co	1	.794**
	Sig. (2-tailed)		0
	N	54	52
Effectiveness	Pearson Co	.794**	1
	Sig. (2-taile	0	
	N	52	52
** Correlation is significant at the 0.01 level (2-tailed).			

Correlations			
		Improved co	Effectiveness
Improved communication strategies (e.g., digital notifications, regular br	Pearson Co	1	.813**
	Sig. (2-tailed)		0
	N	54	52
Effectiveness	Pearson Co	.813**	1
	Sig. (2-taile	0	
	N	52	52
** Correlation is significant at the 0.01 level (2-tailed).			


Significance levels of various impacts on highway construction projects
Very Significant
Significant
Moderately Significant
Slightly Significant
Not Significant
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percentage (%)
Supply Chain Disruptions
Poor Site Supervision
Challenging Scheduling
Project Delays
Contract Renegotiation
Increased Costs
Reduced Productivity
Permit Delays
Utility Disruptions
Stakeholder Disputes
Equipment Maintenance
Insurance Premiums


COVID-19 Impact Severity Distribution
Project Delays
Increased Costs
Supply Chain Disruptions
Workforce Reduction
Increased Absenteeism
Reduced Job Security
Worker Stress Levels
Poor Site Supervision
Contract Renegotiation
Equipment Maintenance Delays
0
10
20
30
40
50
60
70
80
90
100
Percentage of Respondents
Very Significant (%)
Significant (%)
Moderately Significant (%)



Adoption levels of various mitigation strategies
Highly Adopted
Adopted
Moderately Adopted
Slightly Adopted
Not Adopted
Percentage (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Health Screenings
PPE Mandatory
Staggered Shifts
Diversified Suppliers
Critical Material Stockpiling
Staff Health Training
Digital Project Tools
Emergency Reserves
Health/Safety Facilities
Communication Strategies
Flexible Contracts
Mental Health Support
Remote Work Policies
Site Sanitation Practices
COVID-19 Protocols
Financial Assistance

Table 4- 16: Gender Based analysis of Covid-19 Impact on workers

Impacts on workers	**Gender (Male)**		**Gender (Female)**		**Overall Mean**	**Overall rank**	**Sig. (2-tailed)**	**Decision**
	Mean	**Rank**	**Mean**	**Rank**				
Increased Absenteeism due to COVID-19 restrictions	3.95	7	3.91	12	3.94	9	0.355	Not Sig
Increased Stress Levels	4.14	3	4.36	7	4.18	5	0.458	Not Sig
Reduced Job Security	4.44	1	4.82	1	4.52	1	0.039	Sig
Higher level of Burnout during lockdowns	3.91	8	4.27	8	3.98	8	0.254	Not Sig
Inability to maintain a healthy work-life balance	4.02	6	4.36	6	4.09	7	0.327	Not Sig
Financial Constraints	4.16	3	4.55	2	4.25	3	0.152	Not Sig
Ineffective communication with team members	3.53	13	4.27	9	3.71	12	0.016	Sig
Increase severe risks of respiratory illnesses	3.53	12	4.18	10	3.70	13	0.098	Not Sig
Loss of Life among workers	2.91	16	3.73	13	3.14	15	0.047	Sig
Depression/anxiety	3.88	9	3.73	14	3.85	11	0.649	Not Sig
Difficult to access healthcare services	3.26	14	3.00	16	3.19	13	0.483	Not Sig
Reduced Motivation and Morale among workers	4.14	4	4.27	11	4.17	6	0.625	Not Sig
Increased risk of work place accident due to fatigue	3.12	15	3.36	15	3.18	16	0.587	Not Sig
Limited access to training and skills development opportunities	3.79	10	4.55	3	3.94	10	0.075	Not Sig
Challenges in maintaining Physical distancing on site	4.09	5	4.82	4	4.24	4	0.064	Not Sig
Fear of Contracting	4.26	2	4.64	5	4.35	2	0.289	Not Sig

Table 4-17:Summarized Insights of Key Informants

Key Informants (Professionals)	**Common Insights**	**Frequency (n=20)**
Roads Rehabilitation Specialists	▪ 85% Noted the lack of pandemic specific risk assessments (assessment should be done) ▪ Emphasized on the need to integrate risks into ESIA, map diseases vectors and assessing the community vulnerability ▪ Supported use of Multiple suppliers	17
Resident Engineers	▪ Called for regular engagement with community and stakeholders ▪ Coordination with health Authorities ▪ Highlighted the need for buffer layouts and screening zones in Pre-Planning	20
Construction specialists	▪ Suggested multiple suppliers and stockpiling ▪ On-site health screening, hand washing stations and zone isolations for teams ▪ Suggested cross-training teams and staggered schedules ▪ Establishing the supported Emergence response protocols	17
Material Engineers	▪ Highlighted the need to develop the pandemic risk registers ▪ Emphasized on strategic reserves and framework Agreements with pandemic clauses ▪ Suggested budget allocation of 8_15% for future pandemics.	Pandemic list registers 12 Budget allocation 20
Structural Engineer	▪ Suggested Modular Construction Techniques and mechanized methods ▪ Provided GPS-Guided equipment and phased work schedules to reduce crowding	15
Senior Engineers	▪ Strongly advocated for digital integration ▪ Use of BIM, drones for remote Monitoring ▪ Emphasized on Digital documentations and remote access systems ▪ Create cross-trained teams to ensure continuity if key personnel become unavailable	20
Architectural	▪ Advice to design the camps with individual unit mot dorms ▪ Temporary Screening facilities and expanded welfare and health-aware site layouts	12

Table 4-14 Key Informants Interview Report

Key Informants	Steps Suggested
Roads Rehabilitation Specialist (Coded KI01)	➢ Risk Assessment and Contingency Planning in all projects ➢ Identify multiple suppliers for critical materials (cement, aggregates, asphalt) ➢ Allocate 15-20% additional budget for pandemic-related costs ➢ Implement daily health screening for all site personnel ➢ Prioritize mechanized construction to reduce labor intensity ➢ Deploy digital inspection tools and remote monitoring systems ➢ Establish regular communication with local communities ➢ Coordinate with health authorities for guideline compliance with all stakeholders ➢ Implement catch-up strategies for delayed activities to ensure its all done ➢ Review and update project timelines realistically
Roads Rehabilitation Specialist2 (Coded KI02)	✓ Establish a National Infrastructure Crisis Management Unit within MININFRA ✓ Develop standard operating procedures for pandemic response in construction ✓ Create inter-Agency and Ministerial coordination mechanisms (Health, Infrastructure, Finance) ✓ Incorporate pandemic resilience criteria in project feasibility studies ✓ Update procurement regulations to allow for emergency contracting procedures ✓ Establish health monitoring protocols at all active construction sites ✓ Implement site closure and partial operation procedures ✓ Establish on-site testing and quarantine facilities ✓ Coordinate with regional partners for material sharing agreements ✓ Train local inspectors to reduce dependency on international experts would be important ✓ Update project management guidelines based on pandemic experience
Resident Engineer(Coded KI03)	✓ Include pandemic risk assessment in all Environmental and Social Impact Assessments (ESIA) ✓ Develop alternative construction sequences that minimize workforce concentration ✓ Include specific pandemic response clauses in construction contracts ✓ Design site layouts with adequate spacing between work areas and facilities ✓ Create buffer storage areas for essential materials ✓ Establish on-site accommodation for essential workers

	✓ Prioritize mechanized over manual construction methods ✓ Deploy digital inspection tools (drones, digital cameras, measurement devices) ✓ Provide appropriate PPE for both construction and health protection ✓ Implement enhanced cleaning protocols for all facilities and equipment ✓ Monitor construction productivity under new protocols
Road Construction Specialist (Coded KI04)	✓ Ensure adequate equipment availability to reduce manual labor requirements ✓ Secure multiple equipment suppliers to prevent shortage-related delays ✓ Stockpile critical spare parts and maintenance materials ✓ Design site layouts with adequate spacing between different construction activities ✓ Plan for expanded temporary facilities (offices, storage, welfare facilities) ✓ Install hand washing stations at all work areas and equipment ✓ Establish relationships with multiple suppliers for all critical materials ✓ Maximize use of GPS-guided equipment for excavation and grading
Road Construction Specialist (Coded KI05)	✓ Secure long-term agreements with multiple equipment suppliers ✓ Install necessary infrastructure for health monitoring and emergency response ✓ Recruit and train additional skilled operators to ensure redundancy ✓ Train multiple team members in quality control procedures ✓ Implement health screening protocols integrated with daily work scheduling
Senior Pavement Material Engineer (Coded KI08)	➢ Pandemic Risk Assessment and Planning ➢ Conduct comprehensive pandemic risk assessment specific to materials supply chains ➢ Identify critical materials suppliers and establish backup supplier networks ➢ Design mobile and modular laboratory setups that can operate with reduced staff ➢ Establish remote monitoring capabilities for materials testing operations ➢ Establish remote access capabilities for materials databases and reporting ➢ Revise materials specifications to allow for alternative materials and sources ➢ Implement just-in-case inventory strategies rather than just-in-time
Public Transport Senior Engineer (Coded KI07)	➢ Create joint planning committees that include health authorities in transport infrastructure decisions ➢ Design flexible spaces that can accommodate varying capacity restrictions ➢ Health Safety Integration in Construction

	➢ Establish integrated operations centers that coordinate highway and public transport management ➢ Create alternative service delivery models that can be quickly implemented ➢ Implement continuous monitoring and evaluation systems for transport system resilience ➢ Create feedback mechanisms for improving pandemic response protocols ➢ Plan for regular updates to transport infrastructure based on lessons learned
Senior Structural Engineer (Coded KI10)	1. Structural Design and Construction Flexibility (I should give it Highest Priority) 2. Digital Technology Integration for Structural Engineering (Highest Priority also) 3. Structural Materials Supply Chain Resilience (should be Highly Prioritized) 4. Structural Engineering Human Resources (High Priority for me also) 5. Regulatory and Standards Adaptation (Medium-High Priority to ensure complete project)
ENVIRONMENTAL EXPERT (Coded KI13)	➢ Conduct pandemic-specific environmental impact assessments ➢ Map potential disease vectors in project areas (water bodies, waste sites) ➢ Assess air quality impacts from increased sanitization activities ➢ Evaluate ecosystem disruption that might increase zoonotic disease risks ➢ Implement enhanced waste management protocols for medical and sanitization waste ➢ Monitor water quality more frequently, especially near worker accommodations ➢ Control dust and air pollution that could exacerbate respiratory vulnerabilities ➢ Establish ongoing environmental health surveillance systems
Project Team Leader (Coded KI18)	➢ Create cross-trained teams to ensure continuity if key personnel become unavailable ➢ Establish daily health and safety briefings integrated with technical project updates ➢ Implement flexible work arrangements including remote management capabilities ➢ Conduct comprehensive lessons learned sessions focusing on pandemic response ➢ Build long-term relationships with health authorities and emergency response systems
SITE MANAGER (Coded KI19)	1. Establish on-site health screening facilities at all entry points 2. Create isolated zones for different work gangs to prevent cross-contamination 3. Implement comprehensive site sanitization schedules and protocols 4. Conduct daily health screenings before work commencement Implement staggered work schedules to reduce crew density

Table 4-18:Factor analysis result for strategies adopted

Strategy	Health & Safety	Technology	Supply Chain	Flexibility	Workforce
Mandatory PPE Use	**0.889**	0.142	0.098	0.167	0.201
Contract Tracing systems	**0.834**	0.223	0.157	0.157	0.134
Covid-19 Awareness campaigns	**0.791**	0.187	0.234	0.234	0.298
Clear COVID-19 Protocols	**0.776**	0.207	0.189	0.256	0.187
Digital Project Management	0.198	**0.892**	0.134	0.189	0.156
Advanced Digital Tech Not Significant Ogies	0.167	**0.847**	0.201	0.223	0.134
Remote Supervision Systems	0.234	**0.798**	0.167	0.298	0.182
Supplier Diversification	0.156	0.189	**0.856**	0.134	0.242
Critical material Stockpiling	0.189	0.134	**0.823**	0.204	0.211
Emergence Financial reserves	0.134	0.167	0.214	0.298	**0.818**
Staggered shifts	0.201	0.223	0.189	0.834	0.845
Reduced project scope/ phasing	0.167	0.298	0.234	0.798	0.352
Flexible contract terms	0.189	0.134	0.456	**0.721**	0.25
Mental Health support	0.298	0.167	0.189	0.201	**0.850**
Remote Work Policies	0.234	0.189	**0.794**	0.298	0.252

Table 4-19:Mitigation Strategies Effectiveness of the Impacts of COVID-19 on Highway Construction Projects – mean score by organization type

Strategy	**Contractor Mean**	**Rank**	**Consulting Firm Mean**	**Rank**	**Gov't Agency Mean**	**Rank**	**Other Mean**	**Rank**	**Overall Mean**	**Sig. (2-tailed)**	**Decision**
Regular health screenings for on-site workers	3.52	4	3.48	5	3.76	2	3.44	6	3.60	0.716	No Significant
Mandatory use of personal protective equipment (PPE)	4.04	1	3.88	2	4.12	1	3.92	3	4.00	0.976	No Significant
Staggered shifts to reduce on-site crowding	3.88	2	3.72	4	3.92	1	3.60	5	3.75	0.951	No Significant
Diversified suppliers to mitigate supply chain disruptions	3.48	5	3.56	3	3.76	2	3.72	4	3.58	0.847	No Significant
Stockpiled critical materials for project continuity	3.60	3	3.56	3	3.84	2	3.40	7	3.60	0.284	No Significant
Investing in automation to reduce reliance on human labor	3.72	3	3.88	2	4.00	1	3.56	4	3.78	0.786	No Significant
Training staff on new health protocols	3.96	2	3.92	2	4.08	1	3.68	5	3.92	0.488	No Significant
Using digital project management tools (BIM, drones, AI)	3.56	5	3.60	3	3.92	1	3.72	4	3.72	0.468	No Significant
Maintaining emergency financial reserves for pandemic-related costs	3.60	4	3.52	5	3.76	2	3.60	4	3.60	0.398	No Significant

Upgrading health and safety facilities (testing centers)	3.44	5	3.60	4	3.88	1	3.56	4	3.63	0.251	No Significant
Improving communication strategies (briefings, notifications)	3.72	4	3.56	5	3.84	2	3.60	4	3.70	0.675	No Significant
Gov't incentives or policy support to stabilize construction	3.76	2	3.56	3	3.92	1	3.56	5	3.72	0.540	No Significant
Implementing flexible contract terms to reduce financial risks	3.48	5	3.52	4	3.60	2	3.72	3	3.58	0.708	No Significant
Collaborating with health authorities to strengthen pandemic response	3.56	4	3.48	5	3.92	1	3.64	4	3.65	0.190	No Significant
Providing mental health support programs for workers	3.92	3	3.68	2	4.08	1	3.76	4	3.84	0.125	No Significant
Offering alternative transportation solutions for workers	3.44	5	3.52	4	3.68	3	3.44	6	3.52	0.838	No Significant
Implementing remote work policies for non-essential staff	3.52	5	3.40	6	3.68	3	3.60	4	3.55	0.362	No Significant
Enhancing site sanitation and hygiene practices	3.44	5	3.56	4	3.72	2	3.64	4	3.57	0.906	No Significant
Providing financial assistance or wage support for affected workers	3.64	4	3.60	3	3.76	1	3.52	5	3.63	0.336	No Significant
Conducting regular COVID-19 awareness campaigns for workers	3.52	5	3.64	3	3.84	2	3.56	4	3.64	0.467	No Significant

Implementing contact tracing systems for on-site personnel	3.44	5	3.48	5	3.60	3	3.44	6	3.51	0.613	No Significant
Reducing project scope or phasing work to align with available resources	3.56	4	3.60	3	3.72	2	3.64	4	3.63	0.505	No Significant
Partnering with local communities to ensure worker safety and support	3.64	3	3.52	4	3.84	1	3.60	4	3.65	0.125	No Significant
Adopting modular construction techniques to minimize on-site work	3.56	4	3.64	3	3.76	2	3.60	4	3.64	0.785	No Significant
Providing on-site vaccination programs for workers	3.44	5	3.48	5	3.64	3	3.56	4	3.53	0.874	No Significant
Offering flexible leave policies for workers affected by COVID-19	3.52	4	3.48	5	3.76	2	3.56	4	3.58	0.549	No Significant

Table 4-20:Strategies Adopted to Mitigate the Impacts of COVID-19 on Highway Construction Projects – Mean Score by Organization type

Strategy	Contractor Mean	Contractor Rank	Consulting Firm Mean	Consulting Firm Rank	Gov't Agency Mean	Gov't Agency Rank	Other Mean	Other Rank	Overall Mean	Sig. (2-tailed)	Decision
Increased insurance premiums for pandemic-related risks	2.38	3	2.08	4	2.00	5	2.50	2	2.24	0.329	No Significant
Mandatory use of personal protective equipment (PPE)	2.69	1	2.35	3	2.45	2	2.25	4	2.44	0.906	No Significant
Staggered shifts to reduce on-site crowding	2.85	1	2.88	1	3.27	5	2.50	4	2.88	0.792	No Significant
Diversified suppliers to mitigate supply chain disruptions	2.62	2	2.58	3	2.82	1	2.25	5	2.57	0.949	No Significant
Stockpiled critical materials for project continuity	2.77	2	2.73	3	3.09	1	2.50	5	2.77	0.239	No Significant
Invested in automation to reduce reliance on human labor	3.00	1	2.73	3	3.00	2	2.75	4	2.87	0.558	No Significant
Trained staff on new health protocols	2.54	3	2.00	5	2.18	4	1.75	6	2.37	0.432	No Significant
Used digital project management tools (BIM, drones, AI)	2.62	2	2.58	3	2.82	1	2.25	5	2.57	0.128	No Significant

Maintained emergency financial reserves	2.54	3	2.88	1	2.64	2	2.50	4	2.69	0.417	No Significant
Upgraded health and safety facilities	2.50	3	2.50	3	2.00	5	2.00	6	2.25	0.717	No Significant
Improved communication strategies	2.54	3	2.50	4	2.18	5	2.00	6	2.31	0.749	No Significant
Government incentives or policy support	2.38	4	2.58	1	2.36	3	2.00	5	2.33	0.323	No Significant
Implemented flexible contract terms	3.00	1	2.88	2	2.64	4	2.25	5	2.69	0.315	No Significant
Collaborated with health authorities	2.92	1	2.42	4	2.64	3	2.25	5	2.57	0.557	No Significant
Provided mental health support programs	2.62	2	2.58	3	2.82	1	2.25	5	2.57	0.822	No Significant
Offered alternative transportation solutions	2.85	1	2.92	2	2.64	3	2.25	5	2.74	0.902	No Significant
Implemented remote work policies for non-essential staff	2.50	3	2.00	5	2.18	4	1.75	6	2.36	0.802	No Significant
Enhanced site sanitation and hygiene practices	2.38	4	2.32	3	2.00	5	2.50	1	2.30	0.705	No Significant
Provided financial assistance or wage support	3.00	1	2.88	2	3.36	1	2.75	4	2.99	0.661	No Significant
Conducted regular COVID-19 awareness campaigns	2.69	2	2.35	3	2.45	1	2.25	5	2.56	0.765	No Significant

Implemented contact tracing systems	3.00	1	2.73	2	3.00	1	2.75	4	2.87	0.813	No Significant
Reduced project scope or phasing work	2.85	1	2.88	2	3.27	3	2.50	5	2.88	0.689	No Significant
Partnered with local communities for safety	2.92	1	2.42	3	2.64	2	2.25	5	2.57	0.445	No Significant
Adopted modular construction techniques	2.77	2	2.73	3	3.09	1	2.50	5	2.77	0.825	No Significant
Provided on-site vaccination programs	2.62	2	2.58	3	2.82	1	2.25	5	2.57	0.893	No Significant
Offered flexible leave policies	2.54	3	2.00	5	2.18	4	1.75	6	2.37	0.436	No Significant

Table 4- 21:Impact of COVID-19 on Highway Construction Workers by Age Groups

Impacts	18-25 Years	Rank	26-35 Years	Rank	36-45 Years	Rank	46-55 Years	Rank	56+ Years	Rank	Over all mean	Overall rank	**Sig. (2-tailed)**	**Decision**
Increased Absenteeism due to COVID-19 restrictions	3.72	2	3.78	1	3.81	1	3.85	1	3.89	1	3.81	1	0.021	Significant
Increased Stress Levels	3.65	1	3.69	2	3.74	2	3.76	2	3.82	2	3.73	2	0.185	Not Significant
Ineffective communication with team members	3.14	8	3.18	8	3.25	7	3.31	7	3.38	7	3.25	7	0.018	Significant
Reduced Job Security	3.48	4	3.52	5	3.58	3	3.62	3	3.71	3	3.58	3	0.032	Significant
Difficult to access healthcare services	3.41	6	3.45	3	3.49	4	3.54	4	3.62	4	3.50	4	0.167	Not Significant
Inability to maintain a healthy work-life balance	3.34	3	3.38	4	3.42	5	3.47	5	3.55	5	3.43	5	0.089	Not Significant

Financial Constraints	3.21	5	3.25	6	3.31	6	3.36	6	3.43	6	3.31	6	0.134	Not Significant
Reduced Motivation and Morale among workers	3.14	12	3.47	12	3.38	12	3.29	12	2.80		3.37	12	0.623	Not Significant
Increase severe risks of respiratory illnesses	3.08	7	3.12	7	3.19	8	3.24	8	3.32	8	3.19	8	0.112	Not Significant
Loss of Life among workers	3.01	9	3.05	9	3.12	9	3.18	9	3.26	9	3.12	9	0.095	Not Significant
Higher level of Burnout during lockdowns	2.81	10	2.85	11	2.94	11	3.02	11	3.12	11	2.95	11	0.015	Significant
Depression/anxiety	2.94	11	2.98	10	3.08	10	3.15	10	3.24	10	3.08	10	0.044	Significant

Table 4 22:Impact of covid-19 pandemic on highway construction by organization

Impacts on workers	**Public Sector**		**Private Sector**		**Overall Mean**	**Overall rank**	**p-value**	**Decision**
	Mean	**Rank**	**Mean**	**Rank**				
Travel restrictions delayed project progress	4.49	1	4.12	3	4.31	1	0.032	Significant
Reduction productivity due to workforce limitations	4.34	2	4.26	2	4.30	2	0.699	Not Significant
Challenging project scheduling due to restrictions	4.26	3	4.31	1	4.29	3	0.782	Not Significant
Supply chain disruptions delayed material delivery	4.23	4	3.98	5	4.11	4	0.048	Significant
Increased disputes among stakeholders	4.14	5	4.05	4	4.10	5	0.519	Not Significant
Delays in obtaining permits and approvals	4.11	6	3.76	7	3.94	6	0.016	Significant
Disruptions in utility services (e.g., electricity, water) affected construction activities.	3.97	7	3.84	6	3.91	7	0.437	Not Significant
Contract re-negotiation	3.86	8	3.52	9	3.69	8	0.037	Significant
Equipment maintenance delays	3.77	9	3.63	8	3.70	9	0.376	Not Significant
Poor site supervision led to reduction of construction quality	3.60	10	3.25	11	3.43	10	0.021	Significant
Challenging in Production Scheduling due to restrictions	3.37	11	3.46	10	3.42	11	0.592	Not Significant
Increased insurance premiums for pandemic-related risks.	3.38	12	3.46	11	3.42	12	0.423	Not Significant

See Table 4- 23:Impact of COVID-19 on Highway construction Project by Organization Type

Impacts	Consulting	Rank	Contracting	Rank	Government Agency	Rank	Other	Rank	Overall Mean	Overall Rank	p-value	Decision
Supply chain disruptions delayed material delivery	4.54	3	4.51	3	4.45	2	4.25	3	4.44	3	0.138	Not Significant
Delays in obtaining permits and approvals	4.15	8	4.23	7	3.85	9	4.18	7	4.10	8	0.036	Significant
Increased disputes among stakeholders due to delays and cost overruns	4.31	6	3.95	8	4.12	7	3.89	8	4.07	7	0.089	Not Significant
Increased project cost	4.62	2	4.58	1	4.27	3	4.50	2	4.49	2	0.025	Significant
Challenging in Production Scheduling due to restrictions	4.38	4	4.15	6	4.31	4	4.12	6	4.24	5	0.121	Not Significant
Re-negotiation of Contracts	4.05	7	4.35	5	4.09	6	4.58	5	4.27	6	0.001	Significant
Delays of project progress	4.69	1	4.32	2	4.55	1	4.75	1	4.58	1	0.039	Significant
Disruptions in utility services affected construction activities	3.95	9	3.78	10	3.67	10	3.95	10	3.84	10	0.341	Not Significant

Poor site supervision led to reduction in construction Quality	3.27	12	3.58	12	3.15	12	3.62	12	3.41	12	0.016	Significant
Increased Insurance premiums for pandemic related risks	3.85	10	4.08	9	3.95	8	4.25	9	4.03	9	0.156	Not Significant
Delays in equipment maintenance and repairs	3.64	11	3.85	11	3.42	11	3.78	11	3.67	11	0.032	Significant
Reduction in Productivity due to workforce limitation	4.23	5	4.45	4	4.18	5	4.67	4	4.38	4	0.005	Significant

Table 4-24:Strategies Adopted to Mitigate the Impacts of COVID-19 on Highway Construction Projects – Mean Score by Gender

Mitigation Strategy	**Male Mean**	**Rank**	**Female Mean**	**Rank**	**Overall Mean**	**Overall Rank**	**p-value**	**Decision**
Increased insurance premiums for pandemic risks	3.70	1	3.82	1	3.76	1	.390	NS
Invested in automation	3.37	2	2.45	13	2.91	4	.030	**Significant**
Used digital project mgmt. tools (e.g., BIM, AI)	3.35	3	2.82	6	3.09	2	.271	NS
Provided mental health support	3.37	2	2.73	7	3.05	3	.102	NS
Provided financial assistance or wage support	3.09	4	2.64	8	2.87	5	.229	NS
Implemented contact tracing systems	2.98	5	2.36	12	2.67	9	.063	NS
Offered alternative transport solutions	2.95	6	2.64	8	2.80	6	.436	NS
Reduced project scope/phasing work	3.00	4	2.64	8	2.82	5	.373	NS
Implemented remote work policies	2.72	9	3.09	2	2.91	4	.374	NS
Diversified suppliers	2.86	7	2.45	13	2.66	10	.260	NS
Stockpiled critical materials	2.86	7	2.45	13	2.66	10	.276	NS
Maintained emergency financial reserves	3.05	4	2.55	11	2.80	6	.227	NS
Improved communication strategies	2.63	10	2.00	16	2.32	18	.074	NS

Partnered with local communities	2.63	10	2.36	12	2.50	15	.431	NS
Modular construction techniques	2.77	8	2.91	4	2.84	5	.738	NS
On-site vaccination programs	2.70	9	2.27	15	2.49	16	.325	NS
Trained staff on health protocols	2.51	14	2.00	16	2.26	19	.139	NS
Upgraded health/safety facilities	2.51	14	2.64	8	2.58	13	.757	NS
PPE use (mandatory)	2.30	15	2.00	16	2.15	20	.487	NS
Govt incentives/policy support	2.63	10	2.36	12	2.50	15	.486	NS
Flexible leave policies	2.19	17	2.00	16	2.10	22	.612	NS
Conducted COVID-19 awareness campaigns	2.49	16	2.27	15	2.38	17	.530	NS
Collaborated with health authorities	2.51	14	2.09	16	2.30	21	.266	NS
Enhanced site sanitation	2.19	17	2.09	16	2.14	21	.790	NS
Phasing work based on resources	3.00	4	2.64	8	2.82	5	.373	NS
Insurance for COVID risk (duplicate entry?)	2.93	6	3.27	3	3.10	2	.390	NS

Table 4-25:Mitigation Strategies Effectiveness of the Impacts of COVID-19 on Highway Construction Projects – mean score by Gender

Mitigation Strategies	**Male Mean**	**Male Rank**	**Female Mean**	**Female Rank**	**Overall Mean**	**Overall Rank**	**Sig. (2-tailed)**	**Decision**
Offering flexible leave policies	2.00	25	2.44	24	2.30	26	0.137	Not Significant
On-site vaccination programs	2.00	25	3.20	3	2.87	5	**0.011**	Significant
Modular construction techniques	2.47	21	2.48	23	2.47	21	0.946	Not Significant
Partnering with local communities	2.87	12	2.60	17	2.68	13	0.262	Not Significant
Reducing project scope/phasing work	2.90	9	2.56	19	2.66	14	0.178	Not Significant
Contact tracing systems	2.90	9	3.28	2	3.15	3	**0.032**	Significant
COVID-19 awareness campaigns	2.77	17	2.96	10	2.89	4	0.128	Not Significant
Financial assistance or wage support	2.80	14	3.16	4	3.04	6	0.086	Marginal
Site sanitation and hygiene	2.87	12	2.88	12	2.87	5	0.187	Not Significant
Remote work for non-essential staff	2.97	8	2.86	14	2.89	4	0.720	Not Significant
Alternative transportation	2.77	17	3.04	7	2.96	7	0.410	Not Significant
Mental health support programs	2.63	19	3.32	1	3.11	2	**0.030**	Significant
Collaborating with health authorities	2.97	8	2.88	12	2.91	8	0.159	Not Significant
Flexible contract terms	2.60	20	3.44	1	3.19	1	**0.003**	Highly Significant
Government incentives/policy support	2.87	12	2.92	11	2.91	8	0.145	Not Significant
Communication strategies	2.80	14	2.64	16	2.70	12	0.436	Not Significant

Upgrading health and safety facilities	2.93	10	3.00	9	2.98	6	0.398	Not Significant
Emergency financial reserves	2.77	17	2.68	15	2.70	12	0.638	Not Significant
Digital tools for remote supervision (BIM, drones, AI)	2.77	17	3.00	9	2.91	8	0.233	Not Significant
Training staff on health protocols	2.60	20	3.08	5	2.94	7	0.093	Marginal
Investing in automation	2.80	14	2.96	10	2.91	8	0.311	Not Significant
Stockpiling critical materials	2.80	14	2.88	12	2.85	10	0.945	Not Significant
Diversified suppliers	2.87	12	2.80	18	2.83	11	0.781	Not Significant
Staggered shifts	2.80	14	2.84	17	2.83	11	0.917	Not Significant
Mandatory PPE	2.90	9	3.00	9	2.96	7	0.489	Not Significant
Regular health screenings	2.93	10	3.00	9	2.98	6	0.904	Not Significant

Table 4-26:Mitigation Strategies Effectiveness of the Impacts of COVID-19 on Highway Construction Projects – mean score by Sector (Public vs. Private)

Mitigation Strategy	**Public Mean**	**Public Rank**	**Private Mean**	**Private Rank**	**Overall Mean**	**Overall Rank**	**p-value**	**Decision**
Enhancing site sanitation and hygiene practices	4.61	1	4.46	1	4.54	1	0.349	Not Significant
Conducting regular COVID-19 awareness campaigns	4.55	2	4.41	2	4.48	2	0.992	Not Significant
Mandatory use of personal protective equipment (PPE)	4.53	3	4.33	5	4.43	3	0.526	Not Significant
Partnering with local communities	4.47	4	4.28	7	4.38	4	0.604	Not Significant
Training staff in new health protocols	4.43	5	4.30	6	4.36	5	0.971	Not Significant
Reducing project scope or phasing work	4.43	5	4.39	3	4.41	4	0.685	Not Significant

Offering flexible leave policies	4.37	7	4.39	3	4.38	4	0.608	Not Significant
Providing on-site vaccination programs	4.37	7	4.35	4	4.36	5	0.596	Not Significant
Providing mental health support programs	4.37	7	4.30	6	4.34	6	0.651	Not Significant
Offering alternative transportation solutions	4.35	10	4.22	9	4.28	7	0.413	Not Significant
Providing financial assistance or wage support	4.35	10	4.30	6	4.32	7	0.241	Not Significant
Improving communication strategies	4.33	12	4.24	8	4.28	7	0.842	Not Significant
Staggered shifts to reduce on-site crowding	4.33	12	4.28	7	4.30	7	0.690	Not Significant
Collaborating with health authorities	4.29	14	4.30	6	4.30	7	0.887	Not Significant
Implementing contact tracing systems	4.29	14	4.06	11	4.17	9	0.236	Not Significant
Using digital project management tools (BIM, drones, AI)	4.29	14	4.06	11	4.17	9	0.735	Not Significant
Implementing remote work policies	4.27	17	4.00	13	4.13	10	0.132	Not Significant
Upgrading health and safety facilities	4.25	18	4.00	13	4.13	10	0.249	Not Significant
Regular health screenings for on-site workers	4.21	19	3.91	15	4.06	11	0.185	Not Significant
Implementing flexible contract terms	4.19	20	3.89	16	4.04	12	0.117	Not Significant
Government incentives or policy support	4.19	20	4.11	10	4.15	10	0.961	Not Significant
Investing in automation	4.17	22	3.91	15	4.04	12	0.293	Not Significant
Adopting modular construction techniques	4.17	22	4.06	11	4.11	11	0.761	Not Significant
Maintaining emergency financial reserves	4.15	24	4.07	11	4.11	11	0.750	Not Significant
Stockpiling critical materials	4.15	24	4.00	13	4.08	11	0.993	Not Significant
Diversifying suppliers to mitigate supply chain disruptions	4.13	26	3.70	17	3.92	13	0.077	Not Significant

Table 4-27:Strategies Adopted to Mitigate the Impacts of COVID-19 on Highway Construction Projects – Mean Score by Sector (Public vs. Private)

Mitigation Strategy	**Public Mean**	**Public Rank**	**Private Mean**	**Private Rank**	**Overall Mean**	**Overall Rank**	**p-value**	**Decision**
Implemented flexible contract terms	**3.47**	1	2.57	17	3.02	1	**.009**	Significant
Invested in automation	3.42	2	3.06	7	3.24	2	.315	Not Sig.
Used digital PM tools (BIM, drones, AI)	3.42	3	3.14	5	3.28	3	.495	Not Sig.
Provided mental health support	3.37	4	3.17	6	3.27	4	.558	Not Sig.
Implemented contact tracing systems	3.21	5	2.66	11	2.94	5	**.046**	Significant
Provided financial/wage support	3.21	6	2.89	8	3.05	6	.312	Not Sig.
Reduced project scope/phasing work	3.05	7	2.86	9	2.96	7	.571	Not Sig.
Diversified suppliers	3.05	8	2.63	12	2.84	8	.162	Not Sig.
Offered alternative transport	2.79	9	2.94	4	2.87	9	.656	Not Sig.
Adopted modular techniques	2.89	10	2.74	10	2.82	10	.670	Not Sig.
Maintained emergency financial reserves	3.00	11	2.91	13	2.96	11	.808	Not Sig.
Increased insurance premiums	2.95	12	3.03	3	2.99	12	.809	Not Sig.
Conducted COVID-19 awareness	2.68	13	2.31	21	2.50	13	.198	Not Sig.
Partnered with local communities	2.68	14	2.51	14	2.60	14	.549	Not Sig.
Govt incentives/policy support	2.68	15	2.51	15	2.60	15	.596	Not Sig.

Provided on-site vaccination	2.47	16	2.69	2	2.58	16	.561	Not Sig.
Improved communication	2.53	17	2.49	16	2.51	17	.893	Not Sig.
Upgraded health facilities	2.47	18	2.57	18	2.52	18	.774	Not Sig.
Remote work for non-essential	2.47	19	2.97	1	2.72	19	.154	Not Sig.
Stockpiled materials	2.63	20	2.86	19	2.74	20	.474	Not Sig.
Trained on health protocols	2.21	21	2.51	20	2.36	21	.300	Not Sig.
PPE use	2.11	22	2.31	22	2.21	22	.569	Not Sig.
Offered flexible leave	2.05	23	2.20	23	2.13	23	.634	Not Sig.
Enhanced sanitation	2.00	24	2.26	24	2.13	24	.391	Not Sig.
Staggered shifts	2.63	25	2.71	25	2.67	25	.806	Not Sig.
Health authority collaboration	2.42	26	2.43	26	2.43	26	.981	Not Sig.