

AIRPORT PAVEMENTS RESILIENCE TO CLIMATE CHANGE

by

Rafeh Nasim

BSC Civil Engineering (Foundation and Association of Sciences and Technology, 2019)

A Report Submitted in Partial Fulfillment

of the Requirements for the Degree of

Master of Engineering

in the Graduate Academic Unit of Civil Engineering

Supervisor: Xiomara Sanchez, Ph.D., P. Eng., Department of Civil Engineering

Examining Board: Trevor Hanson, Ph.D., P.Eng., Department of Civil Engineering

Eric Hildebrand, Ph.D., P.Eng., Department of Civil Engineering

This report is accepted by the Dean of Graduate Studies

THE UNIVERSITY OF NEW BRUNSWICK

November 2022

©Rafeh Nasim, 2022

ABSTRACT

Since the industrial revolution, there have been greenhouse gas (GHG) emissions caused by the burning of fossil fuels. From that point onwards, the atmosphere started getting polluted with such gases causing the world to exhibit notable changes in the climate. The environment and infrastructure have been affected by this climate change, and airports are no exception. The aim of this research is to present the potential effects of climate change on airport pavements in Canada. Several factors, such as maximum and minimum temperatures, intensity and frequency of precipitation, number of freeze-thaw cycles and wind direction, were considered.

The research findings indicate that airports are also impacted by climate change, and the airport authorities should acknowledge the effect on pavement structures. A case study on the Fredericton International Airport (YFC) was examined to analyze climate change in the city and how it affects the airport infrastructure. YFC is experiencing an increase in days of maximum temperature and precipitation intensity and frequency. The number of freeze-thaw cycles is expected to decrease because of fewer cold days and longer summers. Hence, the airport could be susceptible to rutting due to high temperatures in the summer and cracking due to the weakening resulting from an increased moisture content of the supporting soils. Airport authorities should consider adaption strategies to prevent further damage to their pavement infrastructure.

DEDICATION

I would like to dedicate this report to my beloved parents as they always have been my foundation, providing me with the support, care and love required.

ACKNOWLEDGEMENTS

The research would not have been possible without the continuous support and contribution of:

- Professor Xiomara Sanchez for her guidance, support, and help in this entire research.
- Climate Atlas, Environment Canada and Meteoblue for providing a significant source of environmental data.
- The Fredericton International Airport Authority, in particular to Andrew Isbill, Director of Regulatory Affairs, for all the information provided.
- The Regional Community Airports of Canada for cooperating with this project's survey.

Table of Contents

ABSTRACT.....	ii
DEDICATION.....	iii
ACKNOWLEDGEMENTS.....	iv
Table of Contents.....	v
List of Figures.....	vii
1. Introduction.....	1
1.1 Problem Definition.....	2
1.2 Objectives.....	3
1.3 Project Methodology.....	3
1.3.1 Climate Change Prediction Method.....	4
2. Background.....	6
2.1 Climate Change Definition.....	6
2.2 Adaptation vs Mitigation Strategies.....	11
2.3 Effect of Climate Change on the Transportation Industry.....	11
2.4 Airport Infrastructure.....	13
2.5 Types of Airport Pavements.....	14
2.6 Climate Change Factors that Affect Airport Pavements.....	17
2.6.1 Temperature.....	19
2.6.2 Precipitation and Groundwater.....	20
2.6.3 Freeze-Thaw Cycles.....	21
2.6.4 Cloud Cover.....	21
2.6.5 Wind Speed.....	22
2.7 Distresses due to Climate Change in Pavements.....	22
2.7.1 Stripping.....	22
2.7.2 Thermal Cracking.....	23
2.7.3 Rutting.....	24
2.7.4 Frost Heaving.....	25
2.7.5 Shoving.....	26
2.7.6 Settlement.....	27
2.7.7 Fog and Loss of Skid Resistance.....	28
3. Case Study: Climate Change on Fredericton International Airport.....	29
3.1 Description of YFC.....	29

3.1.1 History.....	29
3.1.2 Layout	31
3.2 Pavements Description.....	32
3.2.1 Pavement Load Rating (PLR).....	33
3.2.2 Pavement Classification Number (PCN)	33
3.2.3 Type of Asphalt.....	36
3.3 YFC Susceptibility to Climate Change.....	36
3.3.1 Increase in Maximum Temperatures	37
3.3.2 Increase in Precipitation.....	38
3.3.3 Decreased Number of Freeze-thaw Cycles.....	39
3.3.4 Changes in Wind Speed and Direction	41
3.4 Potential Climate Change Adaption Strategies.....	42
3.4.1 Improve Asphalt.....	43
3.4.2 Increase Layer Thickness.....	46
3.4.3 Stabilize Subgrade Soils	47
3.4.4 Limitations	47
3.4.5 Strategies for Rigid Pavements.....	48
4. State of Climate Change Adaptation by Canadian Regional Airports.....	50
4.1 Types of Airfield Pavements	50
4.2 Pavement Condition of Airport Pavements	52
4.3 Climate Change Challenges in Airports Pavements	52
4.4 Changes in Practices due to Climate Change on Airfield Pavements.....	54
4.5 Barriers to Incorporating Climate Change Adaptation Strategies	57
4.6 Limitations	58
4.7 Recommendations.....	59
5. Conclusions.....	60
6. References.....	63
Appendix A (Survey Questions).....	71
Curriculum Vitae	

List of Figures

Figure 2.1 GHG Emissions in Canada by Sector.....	7
Figure 2.2 Global Land-Ocean Temperature Index Variation.....	8
Figure 2.3 Global Greenhouse Gas Emissions by Gas 1990-2015.....	9
Figure 2.4 Global Carbon Dioxide Emissions by Region, 1990-2018.....	10
Figure 2.5 Sample Layout of an Airport.....	13
Figure 2.6 Flexible vs Rigid Airport Pavements.....	15
Figure 2.7 Raveling on the Surface of Pavement.....	23
Figure 2.8 Thermal Cracking on Airports Pavement.....	24
Figure 2.9 Rutting on Pavement.....	25
Figure 2.10 Frost Heaving.....	26
Figure 2.11 Shoving in Pavement.....	27
Figure 2.12 Settlement on Pavement Surface.....	28
Figure 3.1 Fredericton International Airport in its Early Years.....	30
Figure 3.2 Runways, Taxiways, and Apron of the Fredericton International Airport.....	31
Figure 3.3 Fredericton International Airports Pavement PCN codes.....	35
Figure 3.4 Number of Days with Maximum Temperature in Fredericton (1950-2100)...	38
Figure 3.5 Precipitation Days Fredericton (1950-2095).....	39
Figure 3.6 Number of Freeze-Thaw Cycles Fredericton (1950-2095).....	40
Figure 3.7 Wind Rose for Fredericton.....	41
Figure 3.8 Wind Speed each Month in Fredericton.....	42
Figure 3.9 Change in Pavement Performance Parameters due to Climate Change.....	44
Figure 3.10 Adaptation Strategies recommended for Climate Change.....	46
Figure 4.1 Type of Runway Pavements.....	51
Figure 4.2 Types of Taxiway Pavements.....	51
Figure 4.3 Pavement Condition of Airport Pavements.....	52
Figure 4.4 Climate Change Phenomena.....	53
Figure 4.5 Climate Change Challenges.....	53
Figure 4.6 Perception of Changes in Practices.....	54
Figure 4.7 Changes in the Maintenance, Preservation, and Rehabilitation.....	55
Figure 4.8 Consequences of Climate Change.....	56
Figure 4.9 Airports Plan to Assess Climate Change on Airfield Pavements.....	56
Figure 4.10 Barriers to Incorporating Climate Change Adaptation Strategies.....	57
Figure 4.11 Best adaptation Techniques to Climate Change.....	58

1. INTRODUCTION

Economic development has seen a major rise over the past decade as technology growth has improved automation procedures (Palandrani, 2020). The trend can only be seen to go higher in the future. During this period, worldwide climatic conditions have been affected because of the higher concentration of greenhouse gases. Climate change is a matter that requires the attention and collaboration of all fields (Engineering, Politics, Environment, Economics, etc.) to find a solution to mitigate the impacts and implement adaptation techniques to help live with the changes affecting the present.

From an engineering perspective, climate change impacts all stages of an asset, i.e., planning, design, construction, and maintenance. Human impacts on climate change can be measured by the mathematical approach described in Equation 1 (Holdren, Ehrlich and Daily, 1995);

$$I = P \times A \times T \quad (1)$$

where;

I = impacts,

P = population,

A = affluence (production per person) &

T = technology (environmental impacts per unit of production)

Hence, engineers are responsible for the technology advancements that act to mitigate this global challenge.

1.1 Problem Definition

Canada is one of those countries which is getting affected by climate change. The changes observed depend on location as well as the severity of the weather events causing harsh winds, floods, and droughts. This can cause considerable damage to the infrastructure built in the country. The airports remain vulnerable to these extreme events, which involve flight cancellations. According to the Federal Aviation Administration (FAA), 70% of flight cancellations are recorded due to weather extremes, flooding and disruptions for travellers and workers (Baglin *et al.*, 2012). Airport authorities, hence, must understand the risk and make changes to their already built or new infrastructures to become more and more resilient to significant climate change every few years (Baglin *et al.*, 2012). The variations in climate are also affecting the airport pavements in Canada, provoking the authorities to plan, design, construct and modify in a way that provides resiliency to the infrastructure. These modifications can be a challenge as they must make the infrastructure more resistant to any future climate change, together with making sure the environmental and socio-economic impacts are being kept constant if not reduced.

The decision-making process can be made significantly easier by developing an understanding of how the climate is changing in terms of varying locations and severity. This report will study the trend of climatic changes and how drastic events could affect the pavement infrastructure of airports. Following the climatic trends, extremes in weather conditions, frequent rainfalls, and snowstorms, this study could help improve airport management systems to increase their pavement resilience when subjected to

these events. This report will focus on studies and research related to airports in Canada, specifically regional airports such as Fredericton International Airport.

1.2 Objectives

- Discuss how climate change could affect airport pavement and investigate the potential distresses.
- Evaluate temperature and precipitation changes along with the fluctuations in freeze-thaw cycles and wind analysis in Fredericton.
- Undertake a case study for the city of Fredericton, study its climate data and discuss and suggest mitigation strategies the Fredericton airport authority should take to dissipate the impacts of climate change.
- Analyze the protocols and measures taken by selected airport authorities for the effective operation and performance of the airport pavements amid climate change, with special attention to asphalt pavements.

1.3 Project Methodology

The first part of the research included gathering information derived from past research on the effect on airport infrastructure due to climatic change. Most of the literature review was extracted from journals and articles which explain how climate can harm high trafficking infrastructures like airports. A case study of the Fredericton International Airport was conducted to analyze how climate change could affect the infrastructure and what strategies could be implemented to deal with the issue.

1.3.1 Climate Change Prediction Method

The collection of climate data for Fredericton was extracted from the climate atlas and Environment Canada. Climate Atlas uses Global Climate Models (GCMs) to depict how the climate is likely to change in the future. A wide range of GCMs are used since there is no accurate model that can be relied upon. Furthermore, to increase the possibility of accurate climate modelling, GCMs capture the wide range of data produced from 24 different models for temperature and precipitation for all of Canada, but this research focuses on the data obtained for the City of Fredericton. The data are categorized into two major representative concentration pathways (RCP): RCP 8.5 and 4.5. RCP 8.5 depicts a high carbon scenario which assumes that the population will continue to emit large amounts of carbon dioxide from the burning of fossil fuels, whereas RCP 4.5 is an approach towards the safer end, which assumes that drastic reductions in emissions in the coming decades will stabilize the concentration of greenhouse gases in the atmosphere by the end of this century. This categorization is done to predict the concentration level of greenhouses in the future, and it is used as an input for the GCM simulations. There are three periods considered for each RCP. The first period includes the mean temperature and precipitation data for the years 1976-2005. Using the GCM, the data were predicted for the periods 2021-2050 and 2051-2080. Low, average, and high values are predicted for each season throughout the year.

Similarly, an analysis of precipitation, temperature changes and wind analysis were done to observe the variations in the number of freeze/thaw cycles. After the completion of the analyses, mitigation and adaptation strategies for Fredericton Airport were discussed.

The last part of the research includes a quantitative analysis, where a pilot survey was conducted to examine how the airport infrastructure gets affected by weather extremes and how necessary an update on the current measures being taken to adapt to climate change is. The survey comprised a total of 30 questions (open and close-ended), and it was distributed to several regional airports across Canada. Each question was asked to obtain information from the airport authorities about their current adaptation practices in pavements, their understanding of climate change and predictions of pavement conditions in the future. According to the knowledge, data and information of the airport authorities, the responses that were relevant and reflected important information were selected and discussed.

2. BACKGROUND

2.1 Climate Change Definition

A common misconception among people is that there is no difference between weather and climate. Weather can be described as a short-term atmosphere variation, whereas climate is the overall average of the weather (Prairie Climate Centre, 2019a). The varying statistical distribution caused by the change in weather patterns is called climate change.

It was Svante Arrhenius, a chemist and a physicist from Sweden, who first noticed in 1896 that the atmosphere could become warmer when subjected to the release of CO₂. Subsequently, Guy Stewart Callendar started to evaluate the changes in global temperature from 1880 to 1938. He revealed that it was the industrial processes of burning coal and oil that were causing the Earth to get warmer with time (Applegate, 2013). Earth's surface continues to get significantly warmer, with multiple records of the hottest global years since 2000 (NASA, 2021).

Environment Canada distributed the emission of greenhouse gases expressed in "CO₂ equivalents" by sector, as shown in Figure 2.1 (Government of Canada, 2020). It can be observed that 73% of the emissions are attributed to stationary combustion sources and transport.

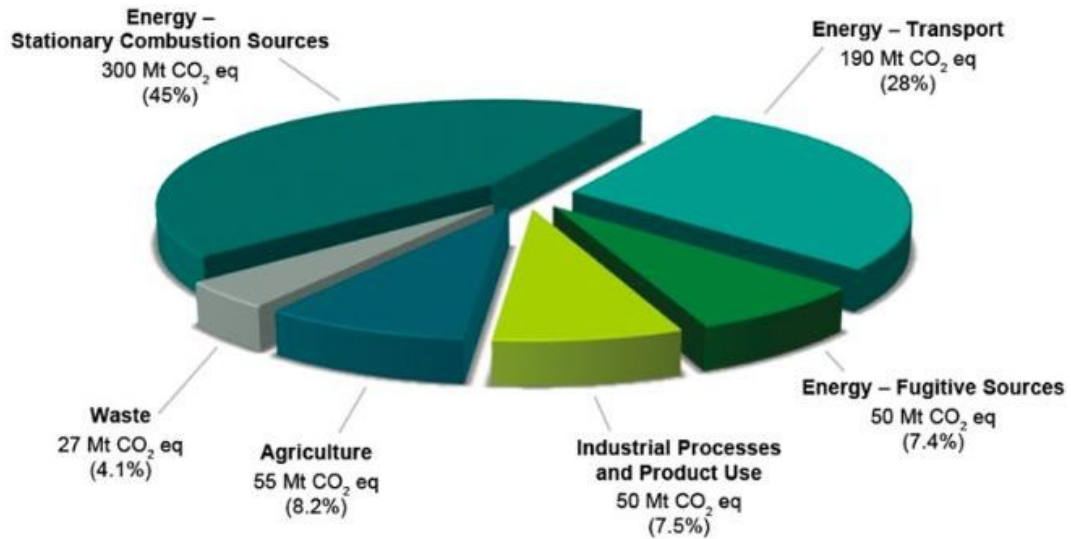
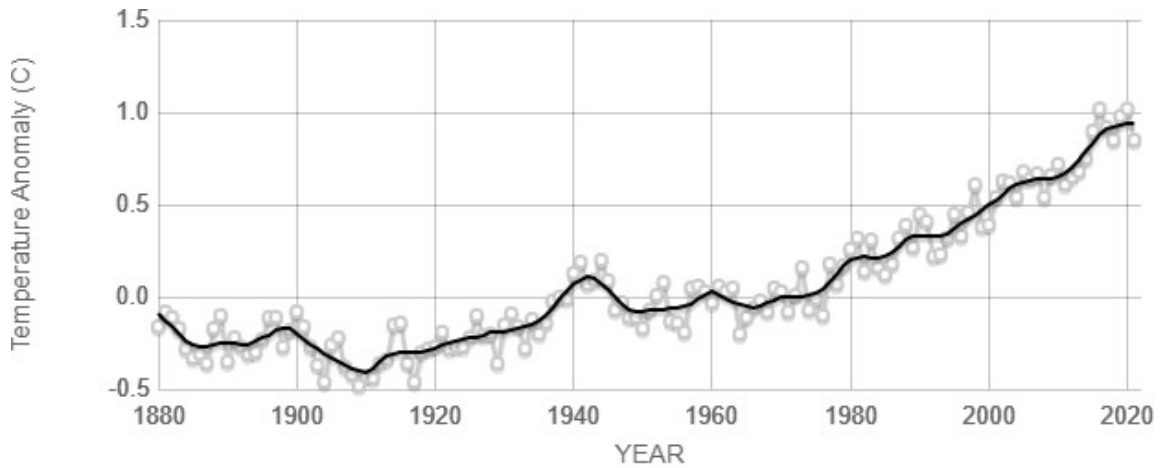


Figure 2.1 GHG Emissions in Canada by Sector

The majority of Canadians are now experiencing longer summers and milder winters. It does not mean that every place will experience the same temperature rise. Some places will heat up at a faster rate than others. The complex nature of air and ocean currents helps scientists predict the real danger of the phenomenon of "climate change" (Hartman, 1998). It can be inferred that the Canadian east coast, which includes the island of Newfoundland, Prince Edward Island, Nova Scotia, and the majority of New Brunswick, could face a harsher climate change than the other regions. This research later focuses on the area of New Brunswick and specifically the City of Fredericton and its airport.

Figure 2.2 (NASA, 2021) illustrates the change in global surface temperature relative to 1951-1980 average temperatures. Nineteen of the hottest years have occurred since 2000. The year 2020 is tied with 2016 for the hottest year on record since record-keeping began in 1880 (NASA, 2021).



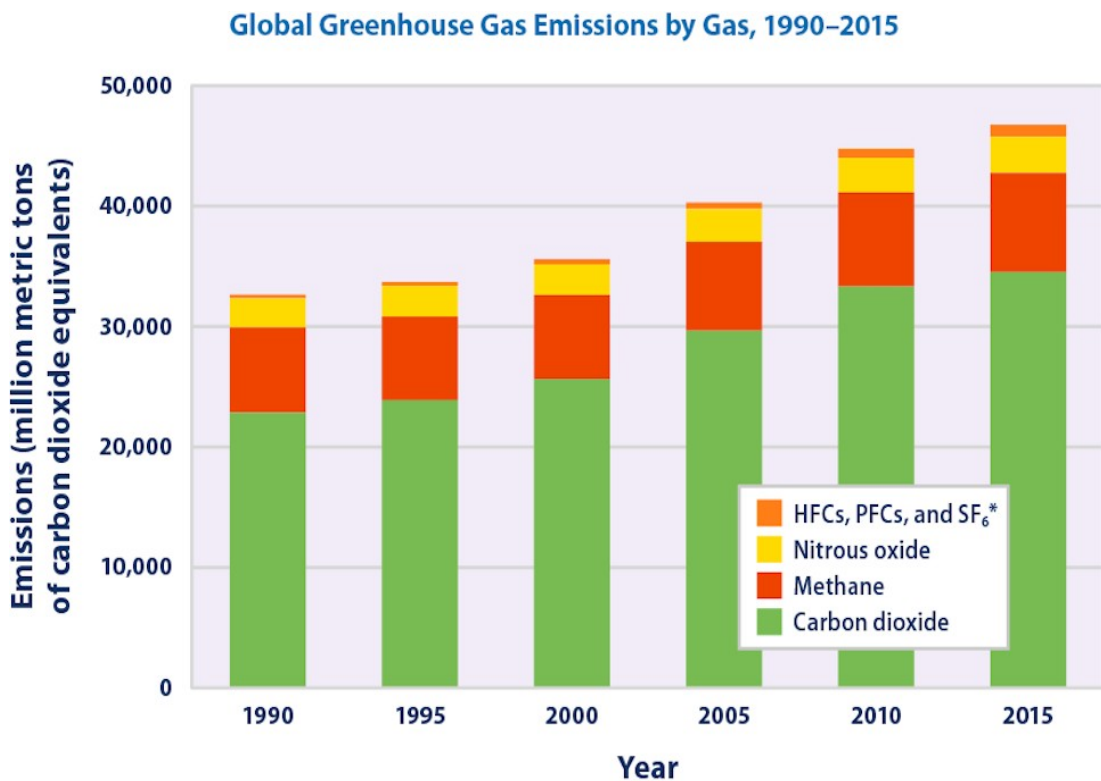
Source: climate.nasa.gov

Figure 2.2 Global Land-Ocean Temperature Index Variation

Since the industrial revolution, the concentration of greenhouse gases has grown significantly. The increase in the concentration of these gases has caused heat retention in the lower atmosphere of the Earth (Hartman, 1998). There has been a contribution by every country in the world to emit greenhouse gases into the atmosphere. Some produce far more greenhouse gases than others which may be subject to several factors such as population, economic activity, and climatic conditions. According to the US Environmental Protection Agency (EPA), each greenhouse gas has a different lifetime and a different ability to contribute to climate change. To compare the amount of greenhouse gases, all other emissions are converted into Carbon Dioxide equivalents (EPA, 2021). The World Resources Institute's Climate Analysis Indicators Tool (CAIT) compiled such data from peer-reviewed and internationally recognized greenhouse gas inventories developed by EPA and other government agencies worldwide. The inventories for gases other than carbon dioxide are limited to five-year intervals. This

data is represented in Figure 2.3 (EPA, 2021) and Figure 2.4 (EPA, 2021) which are described in detail below.

Figure 2.3 indicates the emissions of greenhouse gases, i.e., carbon dioxide, methane, nitrous oxide, and several fluorinated gases, worldwide from 1990 to 2015. It can be observed that the concentration of CO₂ has been increasing and plays a vital role in climate change. Between 1990 and 2015, global emissions of all major greenhouse gases increased. Net emissions of carbon dioxide increased by 51 percent, which is particularly important because carbon dioxide accounts for about three-fourths of total global emissions.



* HFCs are hydrofluorocarbons, PFCs are perfluorocarbons, and SF₆ is sulfur hexafluoride.

Figure 2.3 Global Greenhouse Gas Emissions by Gas 1990-2015

Figure 2.4 shows Carbon Dioxide emissions from 1990 to 2018 for different regions of the world. While Canada is observed to have the lowest amount of CO₂ emissions as compared to other regions, the concentration can be seen to be uniformly increasing, whereas the CO₂ emissions are increasing faster in some parts of the world, such as East Asia and the Pacific. The majority of emissions come from three regions: East Asia and Pacific, Europe and Central Asia, and the United States, which together accounted for 74 percent of total global emissions in 2018. As the major cause of climate change is the emission of Carbon Dioxide gas into the atmosphere, there must be mitigation measures that reduce the future impact on climate.

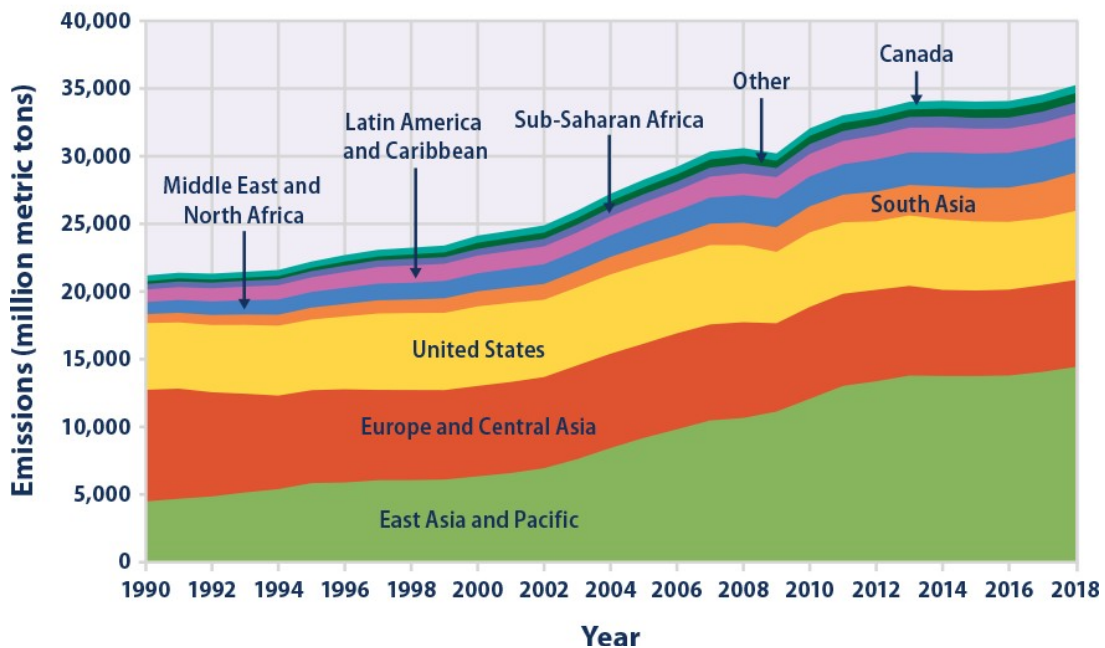


Figure 2.4 Global Carbon Dioxide Emissions by Region, 1990-2018

2.2 Adaptation vs Mitigation Strategies

Mitigation strategies are more inclined towards sustainability and reducing climate change by avoiding the emission of greenhouse gases (by reducing the burning of fossil fuels for electricity, heat, or transport). This is to avoid human intrusion into Earth's climate and stabilize the gases to control extreme weather events and temperatures. Mitigation also includes making the most of any potential beneficial opportunities related to climate change, for example, longer growing seasons or increased yields in some regions.

Adaptation strategies, however, are inclined towards adapting and adjusting to actual or expected future climate. The goal here is to avoid the risks and effects that come with climate change, such as sea-level rise or food scarcity. Alterations in systems and behaviours are made to ensure that a more sustainable environment is left for the future with the unavoidable changes in climate.

2.3 Effect of Climate Change on the Transportation Industry

Is indicated by the Intergovernmental Panel on Climate Change that climate change is a significant risk to nature, human life, and the built environment (Intergovernmental Panel on Climate Change, 2014). Out of the several components of the built environment getting affected by climate change, one of the major components is the physical network of roads, railroads, bridges, and hydraulic structures that ensure efficient, safe, and reliable movement of people, goods, and services, i.e., transportation infrastructure (Gudipudi, Underwood and Zalgout, 2017). Due to their constant exposure to the

elements, this system is highly prone to climate change. Its failure may cause substantial user productivity loss as its repair can often require days or months, depending upon the intensity of the disruption.

Climate change can affect the transportation industry in two ways; direct and indirect. The direct impacts rely upon changes in temperature, wind velocity, sunshine hours and other environmental factors, which can be a cause of variation in moisture, temperature, and infrastructure's structural response. In contrast, the indirect impacts are due to varying hydrogeological conditions because of climate change, including ground and seawater level rise. IPCC uses a scenario analysis tool to predict the possibilities of future GHG emissions and climate change (Intergovernmental Panel on Climate Change, 2014). The impacts of climate change vary depending upon the different regions of the world. For example, coastal areas are more prone to flooding due to nearby seas or rivers.

The vulnerability of transportation infrastructure depends on its location, design features and construction. For example, a pavement or a rail track built on permafrost will be a subject of settlement when the ground unfreezes. In regions with a higher amount of frozen water, warmer winters will result in more freeze-thaw cycles causing increasing damage to pavements. Whereas in rough terrain areas, intense precipitation may cause landslides that can negatively affect the infrastructure. Transportation agencies identify risks on a regional scale, which depends on the type and function of the infrastructure and address them accordingly.

Road infrastructure in Canada is considered a valuable asset to the economy as most of the goods are transported by trucks and numerous people travel around in cars. Similarly, airport infrastructure also represents a relevant transportation asset.

2.4 Airport Infrastructure

In general, an airport is defined as an infrastructure designed, built, and planned for the arrival, departure and or movement of aircraft, goods, and passengers. Airports can be divided into two main parts: landside and airside. While the landside is completely accessible to the public, the airside has limited access and is private for aircraft and authorized personnel. The airside infrastructure deals with pavements meant for aircraft traffic. The airside infrastructure can be further classified into three sections, namely, the runway, the apron, and the taxiway. A sample representation is shown in Figure 2.5 (Schmidt, 2017).

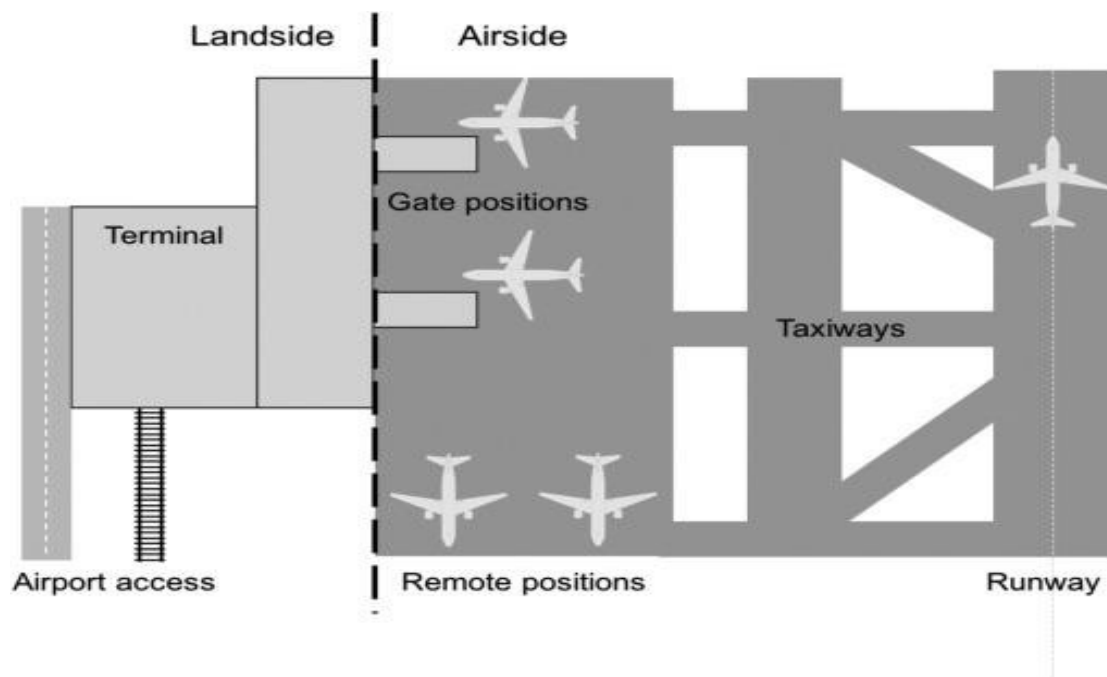


Figure 2.5 Sample Layout of an Airport

In terms of operations, airfield pavements, i.e., runways, aprons and taxiways, are an essential asset of airport infrastructure. In case of a prolonged delay or shut down in any one of these areas, it will cause delays on the ground as well as in the sky. Hence, pavement infrastructure and its resilience to climate change play an important role in airport operations.

Canada has 726 certified airports in total. Transport Canada owned 150 of those airports before the National Airport Policy (NAP) was introduced in 1994, which classified the airports into different categories, including the National Airport System (NAS), small airports, local/regional airports, remote airports, and arctic airports. 94% of all cargo and air passengers in Canada are transported by 26 airports in the NAS. Even though the federal government retained ownership of these airports, the operations were transferred over to either Canadian Airport Authorities (CAAs) or Local Airport Authorities (LAAs) by the introduction of NAP. The operations and ownership of local/regional, arctic, and small airports will eventually be transferred to regional stakeholders, including provincial, territorial, and local governments and private businesses (Whiteley, 2006).

2.5 Types of Airport Pavements

The design of airfield pavements is similar to highway pavements; however, airfield pavements sustain higher loads and lower repetitions than highway pavements and also receive higher tire pressures. Similar to highway pavement, airfield pavements can be classified into two major types essentially: flexible and rigid. Flexible pavements are also

known as asphalt pavements and have an asphalt surface layer with a base, subbase, and subgrade underneath it. In comparison, rigid pavements are also named concrete pavements, which consist of a Portland cement concrete (PCC) surface layer on top of an unbound or chemically treated base layer, a subbase layer and a subgrade. In Canadian airports, JPCP is the most used pavement type (Whiteley, 2006). Rigid pavements are designed by slab analysis and bending load, whereas flexible pavements are designed by layered analysis and shear load. Figure 2.6 (Pavement Tools Consortium, 2022b) below shows the difference between the type of pavements and how they carry the load.

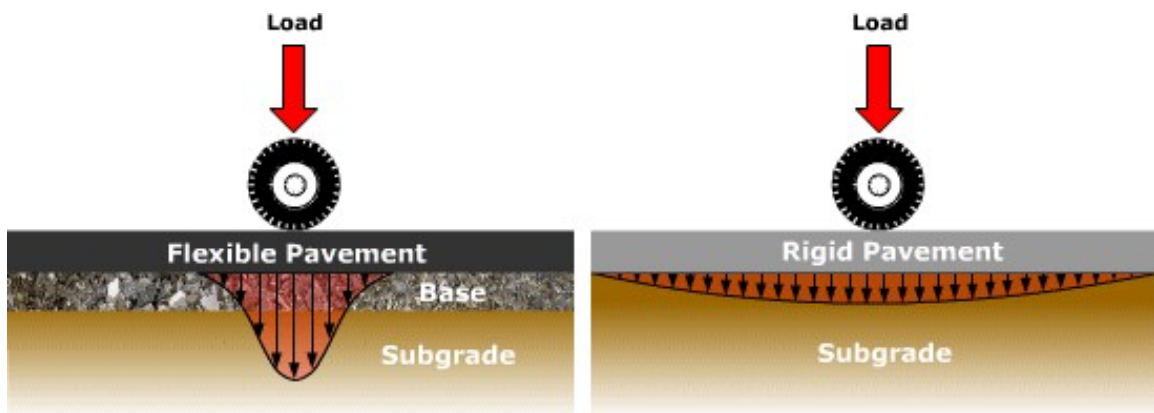


Figure 2.6 Flexible vs Rigid Airport Pavements

Each layer of the pavement has its own purpose within the pavement structure. The surface layer helps provide stability and durability for the pavement structure, whether it is Asphalt or Portland cement concrete. The purpose of the base layer is to provide stability under high aircraft tire pressures. There are non-frost susceptible, lower quality, granular aggregates in the subbase, which help increase pavement strength and reduce the effects of frost action on the subgrade. The last layer of the pavement structure is the

subgrade which is considered the foundation of the structure. It is assumed of infinite in thickness and provides stability to the overlying structure.

Each of the sections of the airfield pavements requires a distinct design depending upon the type of loads it is intended to receive. The runway is the section where the airplanes are seen to take off and land, which means that it experiences massive loads due to the first impact point for aircraft. Besides the main traffic load, the runway undergoes high shear stresses due to the braking action of the aircrafts and is subject to strong winds due to the turbines. The apron is the area where planes are loaded and unloaded, inducing heavy static loads. Lastly, the taxiway is the pavement which connects the apron to the runway, having slow-moving and heavy static loads. The apron requires an infrastructure which bears stationary loads and high temperatures, in this case, Portland cement concrete pavements. Whereas for taxiways and runways, the pavement type can vary between concrete, asphalt, gravel, or composite pavement.

Transport Canada Civil Aviation (TCCA) is the main institution in Canada to develop the standards and design specifications for the pavement infrastructure in airports. The design method adopted by Transport Canada shows no specific adaptation of climate and traffic, which are the two main significant factors. It only considers the freezing index, which gives an approximate idea about climate change, while the traffic input is based on the aircraft loadings design. Canadian airport authorities also consider other international design methods, but none of them combine calculated stress, strains, and deflections with

measured response and field observation of the performance of other airports given the location, hence these methods cannot be considered mechanistic-empirical (Abreu, 2019). Additionally, none of the methods examine the statistical distribution of climate patterns.

2.6 Climate Change Factors that Affect Airport Pavements

Climate change can directly affect environmental conditions leaving an impact on pavement performance. Climate change indirectly impacts the population in certain regions and causes a change in the local traffic demand (Black *et al.*, 2008). Airport flexible pavements are expected to have similar issues to those experienced by highway pavement, which are described in the following paragraphs.

Research has been held to find out the future necessary maintenance and rehabilitation of pavements. According to a southern Canada investigation, the variables measuring changes in the timing of maintenance requirements because of both the individual and combined influences of climate change and traffic growth proved that the number of years needed to reach the 2.7 m/km IRI maintenance threshold evidently declined because of the climate change and traffic growth in two provinces (Mills B.N. *et al.*, 2009). In Quebec, however, the number of years to reach the maintenance threshold went to a rise because of climate change, but the number reduced when traffic growth was regarded. In relevance to the findings, Qiao *et al.* predicted the change in pavement service life because of climate change and inquired that it radically declined. With relevance to the climate change conditions, pavement maintenance was triggered 8–16% earlier in today's time (Qiao, Santos, *et al.*, 2020).

An investigation was done on the impacts on flexible pavements between 2050 to 2070 using two climate change models, Hadley Climate Model 3 (HadCM3B21) and Coupled Global Climate Model 2 (CGCM2S2x). It revealed that the future prediction of variation in temperature, rainfall and traffic growth are essential factors that will influence pavement performance (Mills B.N. *et al.*, 2009). Another study investigated the consequences of climate change on pavement deterioration processes, which found that the effects of temperature rise on permanent deformation are significant (Meagher *et al.*, 2012).

A study forecasted climate change and introduced this data into the Highway Development & Management (HDM) road maintenance software to assess the impacts of climate change on pavement performance. Increased temperatures impacted the pavements with asphalt aging embrittlement and cracking. An increment in precipitation frequency and intensity would also alter moisture conditions and further deteriorate pavements (Shao, Jenkins and Oh, 2017). All these studies highlight the importance of incorporating climate change effects in pavement design early in the process.

Climate stressors affect long-term pavement performance by disturbing the moisture balance and energy of a pavement. Pavement performance is the most affected by temperature and moisture from increases in precipitations (Qiao, Dawson, *et al.*, 2020). Some common climate stressors are temperature, precipitation, groundwater, cloud water and wind speed.

2.6.1 Temperature

The pavement temperature on the surface is dependent upon the energy balance. Throughout the service life of a pavement, the heat absorbed is from solar energy. A certain amount of energy is lost from the pavement by radiation and convection, and the amount of heat loss is dependent on wind speed and air temperature. Through the asphalt layers, heat is conducted to the layers beneath. Hence, thermal conductivity is an aspect that determines the temperature profile of a pavement.

The pavement research field has accepted that asphalt layers are significantly impacted by temperature. An increase in temperature will reduce the asphalt materials' stiffness, resulting in a limiting stress-strain pavement response and then leading to the pavement's reduced ability to spread loads (AASHTO, 2009). In some cases, if the change in stiffness is not noticed in a day, it is possible that the load-spreading ability deteriorates over a period resulting in accelerated load-related deterioration. According to sustainability and pavements research done in Germany, the asphalt materials' ability to resist permanent deformation decreases with the increase in temperature. Hence, in cases where the pavement experiences a significant daily temperature increase, permanent deformation can be expected (Dawson *et al.*, 2014). The increase in the range of temperature due to climate change can cause a spike in thermal stresses in asphalt layers, expecting more thermal cracking. Furthermore, higher temperatures can make pavements age faster, making them more prone to cracking.

2.6.2 Precipitation and Groundwater

Moisture can enter and exit from a pavement in various ways, causing a change in its moisture levels. The drainage infrastructures, such as pipes and drains, help the rainfall to drain away from the pavement; however, surface runoff can enter through any cracks or potholes. The groundwater level is different depending upon the season and can be impacted by precipitation, flooding or sea-level rise. In regions with a higher groundwater level, moisture content can affect the pavement's unbound granular layer and subgrade. In the events of heavy rain or flooding, the subgrade may sometimes be submerged, causing an increase in moisture level. Temperature rise can cause water to travel in the form of vapours in the capillaries of a pavement. Moisture targets the soil particles and adhesion between asphalt and bituminous material present in the pavement. The resilient modulus of subgrade materials can decrease if the degree of saturation is increased. Moisture also has an impact on the rutting resilience and shear strength of the subgrade, and permanent deformation can happen under extreme circumstances. To summarize, moisture damage targets unbound subgrade materials where the proportion of fine particles is high.

Moisture also has an impact on asphalt concrete materials at the surface of a pavement. Stripping is a phenomenon occurred on the asphalt surface due to various factors, such as poor construction, materials, environmental factors, traffic, or a combination of one or more. Previous research found that stripping can be accelerated by higher moisture levels (Apegyei, Grenfell and Airey, 2015).

2.6.3 Freeze-Thaw Cycles

Freeze-thaw is a phenomenon caused by both temperature and moisture levels in colder regions. Low temperature causes the moisture in the pavement layers to freeze and then later defrost in the spring season. In some cases, extra water coming from the pavement layers below freezes and during thawing, an extra amount of moisture is trapped in the pavement until thawing is complete. This causes the resilient modulus and the rutting resistance to decrease significantly. In the latest research, it was found that the resilient modulus in a pavement experiencing spring thaw was decreased to between 48% and 63% (Salour, 2015).

A pavement experience distresses during the thaw period, which is in spring. Climate change can increase the period of thaw. This means that the pavement will have a longer period of excess moisture content, causing distresses such as rutting and stripping. A spring load restriction will have to be applied in such cases, which may not be economically feasible, also causing limited accessibility.

2.6.4 Cloud Cover

Cloud cover influences the amount of solar energy absorbed or reflected by a pavement. An increase or decrease in the amount of cloud cover can impact air and pavement temperature. However, back radiation may occur due to cloud cover reflecting the surface radiation down to the earth's surface. Pavements will tend to cool down if the cloud cover increases in the future, but the cooling process will also be slowed down.

2.6.5 Wind Speed

Wind speed has an impact on the pavement surface heat convection. An increase in wind speed will reduce the temperature of a pavement's surface, which is beneficial for pavements. It was found by Qin and Hiller that wind speed can affect the temperature of a pavement by 2 to 10 degrees Celsius (Qin and Hiller, 2013). The variation also depends on the time and type of day (i.e. rainy, sunny, cloudy, etc.).

2.7 Distresses due to Climate Change in Pavements

According to research in the transportation industry, airport pavements experience several types of distress, such as early crack propagation, stripping, rutting, shoving, settlement, and frost heaving. Besides them, there are several minor distresses that have no effect on the airport pavements but rather affect their operation, such as the loss of skid resistance due to the presence of ice in the pavement and the fog. Each of the distresses is described below with their relationship to the changing climate.

2.7.1 Stripping

This distress generally starts from the bottom of the pavement and occurs when there is a loss of bonding between aggregates and asphalt cement. The loss of bonding leads to moisture damage in the asphalt mix. As it starts from the bottom, it can deprive the pavement of strong structural support and lead to deep cracks and potholes if not treated. If a pavement is exposed to constant moisture by intense precipitation and has a weak aggregate/asphalt bond, stripping can be intensified. Raveling occurs when stripping starts from the surface, as shown in Figure 2.7 (Pavement Tools Consortium, 2022a).



Figure 2.7 Raveling on the Surface of Pavement

2.7.2 Thermal Cracking

When a pavement experiences expansions and contractions due to hot and cold temperature variations, thermal cracking may appear on the pavement surface. During the winter season, pavements become stiffer and shrink, which makes them more prone to cracking. Thermal cracking is of two types, one is due to low temperatures, and the other one is because of fatigue which is mainly due to aging and degradation after cumulative thermal cycles (Mills *et al.*, 2007).

The cracks start to develop during shrinking in the perpendicular direction of the runway in airports, as shown in Figure 2.8 (Nguyen, Tang and Huynh, 2020). In the spring season, the pavement goes back to its normal position, but the cracks are much more visible.



Figure 2.8 Thermal Cracking on Airports Pavement

2.7.3 Rutting

Rutting occurs when the softening of the pavement surface is combined with excessive traffic loading causing permanent deformation in the longitudinal direction, as shown in Figure 2.9 (Lidia Sarah et al., 2017). It can also be caused by various other reasons; notable variations in the groundwater table, the loss of support due to the weakening of the soils or the melting of permafrost in the layers. Canada has a colder climate which makes rutting not a major problem; however, the south of Canada is experiencing climate change, and an increase in temperature can make this distress a potential threat (White, 2018).



Figure 2.9 Rutting on Pavement

2.7.4 Frost Heaving

This type of pavement distresses occurs due to the presence of ice lenses in the base, subbase, or subgrade of pavement in winter periods. A visual representation of the distress is shown in Figure 2.10 (Pavement Tools Consortium, 2022a). Even though the pavement compresses because of low temperatures, the water present in the soil still expands by 9%, causing heaving (Abreu, 2019). The permanent deformation a pavement experiences after each winter depends on temperature differences, the length of the winter season, and the resiliency of the pavement structure.



Figure 2.10 Frost Heaving

2.7.5 Shoving

This type of pavement distress normally occurs when the asphalt is against a rigid object which causes pushing forces. The forces caused by car brakes originate shear stresses and, thus, the softening of the asphalt when there is a temperature increase generating a permanent deformation as shown in Figure 2.11 (Ahmad and Khawaja, 2018). Shoving is mostly seen in airfield pavements where the pavements are subject to excessive forces and shear stresses, high temperatures and torsion.



Figure 2.11 Shoving in Pavement

2.7.6 Settlement

Settlement occurs when the ground, or the structure above it, sinks. Figure 2.12 (Vaniček and Herza, 2021) is an example of how the settlement will appear. It can happen at any layer of pavement, but sooner or later, it affects the layers above. This occurs either when the subgrade's bearing capacity is significantly reduced or when there is a difference in the internal stresses of the soil. The pavements in northern Canada experience the difference in internal stresses of the soil due to the thawing of permafrost. As the climate warms, the permafrost will discontinue and may cause future settlement.



Figure 2.12 Settlement on Pavement Surface

2.7.7 Fog and Loss of Skid Resistance

In Northern Canada, fog plays a critical role along with other distresses that occur due to the change in environmental conditions. The ice in rivers is being reduced, which creates fog as the temperature or the number of precipitation events increases. The fog then condenses and freezes the surface of the pavement, which significantly reduces its skid resistance. In airports, it raises the need for maintenance as it can put the user's safety at risk. Thus, airport operations need to carefully maintain their pavements, especially in the winter season.

3. CASE STUDY: CLIMATE CHANGE ON FREDERICTON INTERNATIONAL AIRPORT

This chapter will study the case of the Fredericton International Airport (YFC) and analyze the potential impact of climate change on its pavement infrastructure. In the end, potential suitable adaption strategies specifically for asphalt pavements are proposed.

3.1 Description of YFC

3.1.1 History

The Fredericton airport is located on 447.5 hectares of land within the local district of Lincoln and began operations in 1951. During the early years, Fredericton airport was using the aircraft 'Lockheed 10', which could only carry ten passengers, but it kept replacing it afterwards, increasing the capacity. Currently, the aircraft regularly operating at the airport is Bombardier Q-400, which can carry 90 passengers.

In 1959, the Department of Transportation took over the ownership after the airport had started to take a financial toll on the city with the increasing expansions and construction demands. The Department expanded the primary runway length and installed lights and an Instrument Landing System. They also added a second taxiway with an extension to the aircraft ramp, a maintenance garage, a new terminal building, a pump-house, water, sewage, and fire hydrant system, roads, and a car parking lot. Figure 3.1 (Fredericton International Airport, 2022d) is a graphic presentation of the Fredericton International Airport in its early days.



Figure 3.1 Fredericton International Airport in its Early Years

The airport is owned by Transport Canada, but in 2001, the operations, management and maintenance of the airport were transferred to the Fredericton Airport Authority (FAA). Fredericton International Airport kept expanding time by time and raised business by servicing aircrafts for companies; Delta, WestJet, Air Canada, etc.

The airport authority renamed it to Fredericton International Airport Authority (FIAA) in 2009 to recognize its international designation. Since then, the airport has seen major improvements and record-breaking passenger numbers each year. In 2016, 377,977 passengers travelled through the airport, which was an 8 percent increase from 2015. A record 427,085 travellers used the airport in 2019. FIAA completed a terminal expansion in 2021. Since the city of Fredericton, like every other in Canada, is facing a climate change setback, it becomes very necessary to introduce mitigation and adaptation strategies in their updated designs (Fredericton International Airport, 2022d).

3.1.2 Layout

Figure 3.2 (Fredericton International Airport, 2022a) highlights the airport pavements present in the Fredericton International Airport.

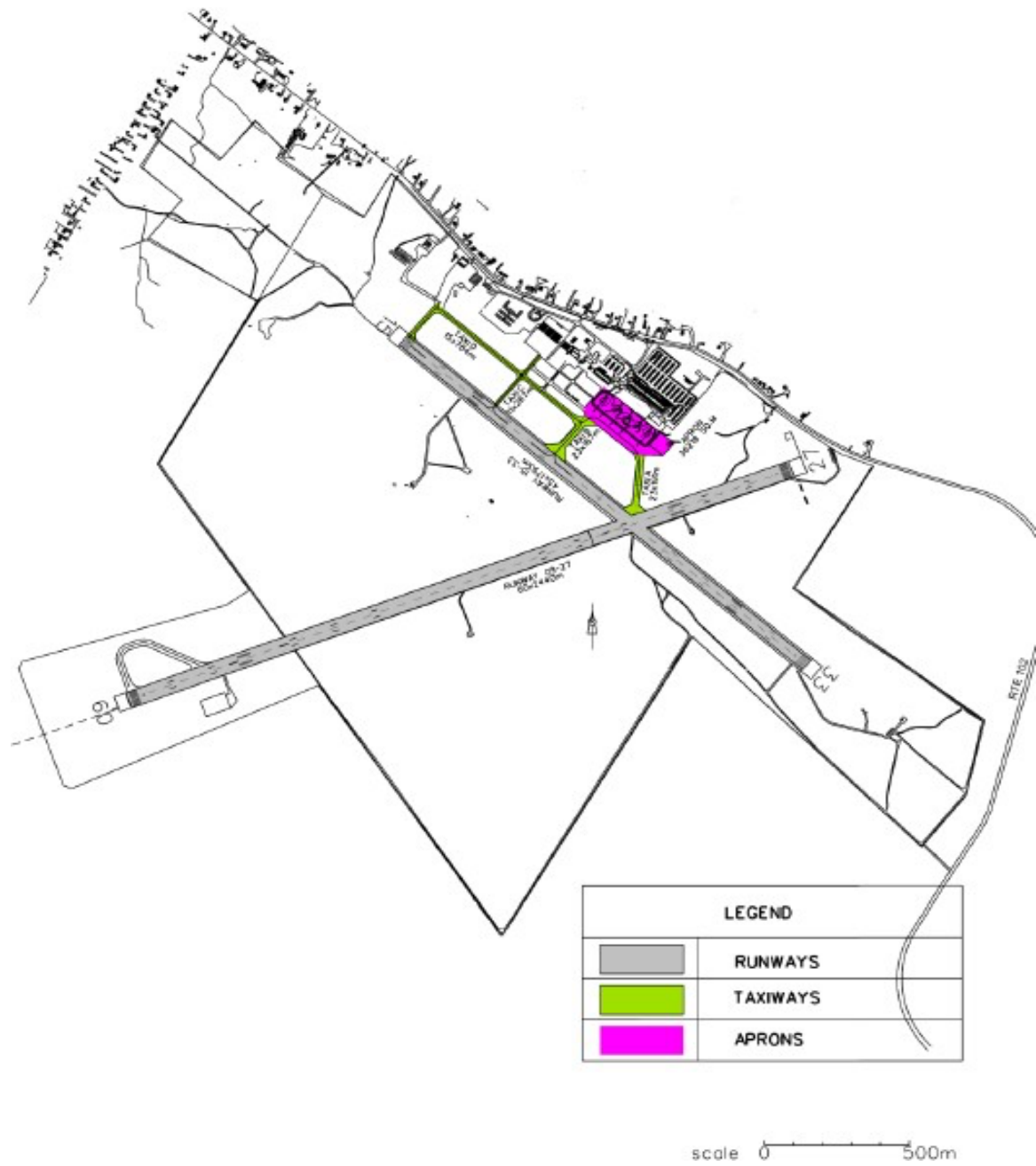


Figure 3.2 Runways, Taxiways, and Apron of the Fredericton International Airport

The Fredericton International Airport has two runways. The primary runway is labelled 09/27, which has a length of 2440m, and it is 61m wide. It has a longitude slope of 0.13% down and a crown of 1.4% on the transverse slope. The airport also has a secondary runway 15/33, which is 1829m in length and 45m wide. It has a longitudinal slope of 0.19% down and a 1% crown as the transversal slope. Both runways are paved with an asphalt surface type, whereas the runway safety area surface type is grass. They provide adequate drainage as per the Operations Manual and have ditches outside the runway safety area.

There are four taxiways in the airport which connect to the two runways. The four runways are labelled as A, B, C and D, and all of them are flexible pavements with different lengths and widths. Taxiways A, B, C and D have 191m, 167m, 267m, and 784m lengths and 23m, 23m, 11m, and 15m widths, respectively.

The apron, however, has a Portland cement concrete layer at the aircraft stands and the rest is paved by asphalt. It has an area of approximately 36218 square metres (Fredericton International Airport, 2022a). The airport also has two helicopter-parking spots located on the south side of the apron.

3.2 Pavements Description

Airport authorities require the strength data to make observations of the pavements' suitability to safely support aircraft loads without causing structural damage to either the

aircraft or the pavement. The pavement bearing strengths are reported using both Transport Canada's Pavement Load Rating (PLR) system and the International Civil Aviation Organisation (ICAO) Pavement Classification Number (PCN) (Transport Canada, 2001). Unfortunately, YFC did not provide details on the cross-section of the pavement structures, but instead, they shared their PCN.

3.2.1 Pavement Load Rating (PLR)

An Engineering Reference Document (ERD) published by Transport Canada recorded pavement-bearing strengths for 150 runways at National Airport System (NAS) and regional/local airports in Canada. PLR is a number expressing the bearing strength of pavement for unrestricted aircraft operations. It is expressed on a scale of 1 (weakest pavements) to 12 (strongest pavements). Fredericton International airport's two runways have a Pavement Load Rating of 11, which can be considered fairly strong (Transport Canada, 2001).

3.2.2 Pavement Classification Number (PCN)

The PCN system was adopted by ICAO as the standard of reporting internationally the airfield pavement bearing strengths. The Pavement Classification Number (PCN) is a five-digit strength code, with each digit providing the following information.

1. Pavement Classification Number

The number expresses the bearing strength of a pavement. The higher the number, the stronger the pavement is for aircraft operations.

2. Pavement Characteristics

Typically, Rigid Pavements are indicated by the Code "R," whereas Flexible Pavements are indicated by the letter "F."

3. Category of Subgrade Strength

High strength, medium strength, low strength, and ultra-low strength are indicated by A, B, C, and D, respectively.

4. Maximum Allowable Tire Pressure

It is usually a number to indicate the maximum aircraft pressure allowed on a pavement in megapascals (MPa), but the tire pressure limitations are generally only applied to flexible pavement structures. The letter "W" is used when no pressure limit is applied to a pavement.

5. Strength Evaluation Method

Strength is either evaluated technically, represented by the letter "T," or evaluated using aircraft experience indicated by "U."

For an airport to be certified by the Transportation industry, it must meet specific standards that apply to the airport and the immediate surrounding area. The bearing strength of the runways of the Fredericton International Airport is 61F/B/W/T each. The taxiways also have the same bearing strength; however, taxiway C has not yet been evaluated as per the updated version of the Airport manual (Fredericton International Airport, 2022a). The aprons have a bearing strength of 63F/B/W/T and 48 and 58R/B/W/T. Figure 3.3 (Fredericton International Airport, 2022a) shows the Fredericton Airport's pavements highlighted differently with respect to their PCN numbers.

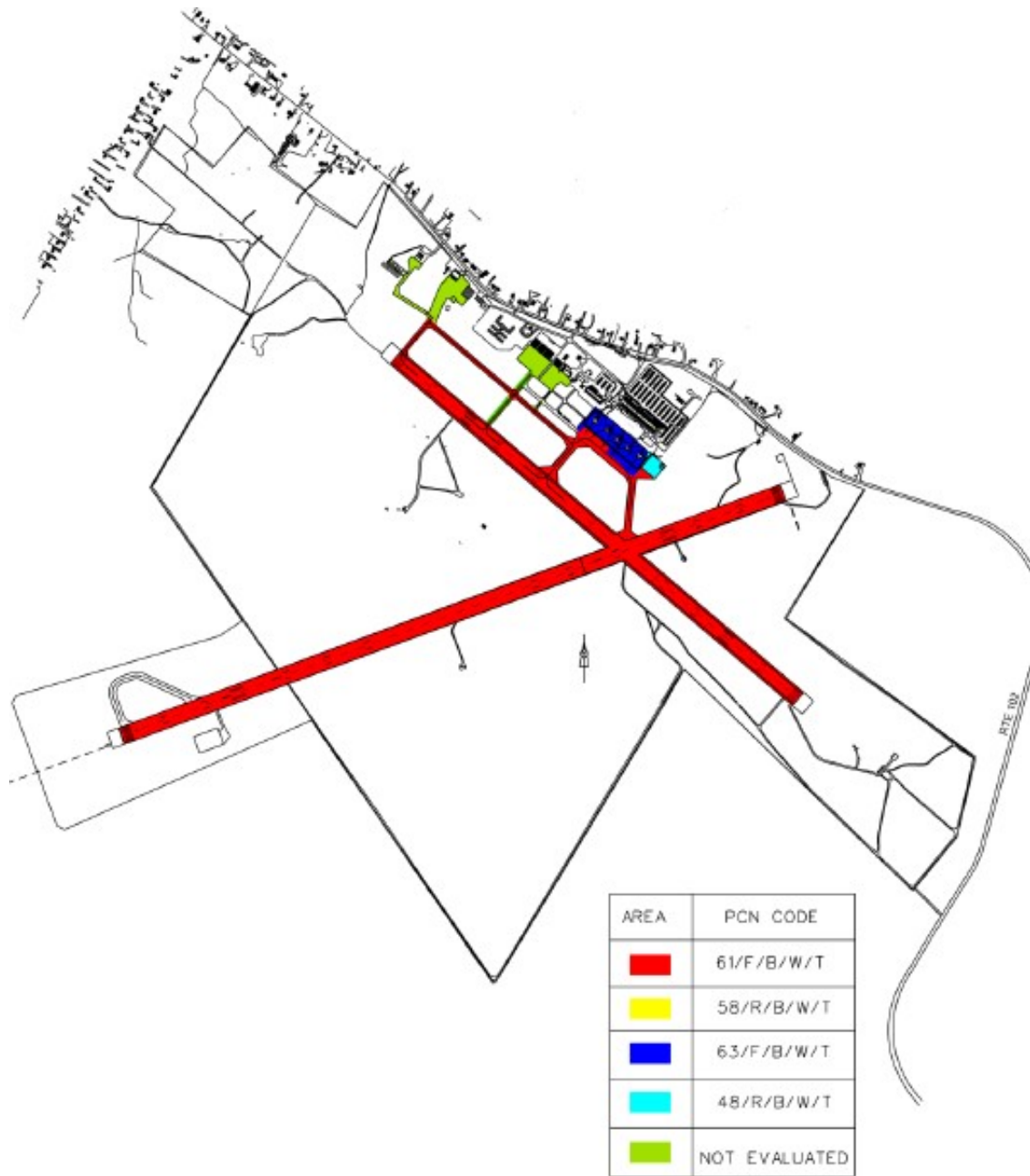


Figure 3.3 Fredericton International Airports Pavement PCN codes

3.2.3 Type of Asphalt

Based on a conversation with the FIAA Director of Regulatory Affairs, historically, Transport Canada specifies asphalt cement by penetration grades such as 80-100, 120-150 or 150-200, depending on the site's average freezing index. For Fredericton, it would be 120-150 penetration-grade cement. However, grading the asphalt cement by penetration was replaced by grading based on performance, in which binders are graded based on fundamental engineering properties to predict the pavement performance accurately and to provide an asphalt material that is tough enough to resist rutting yet resilient enough to resist thermal cracking and fatigue. For example, the specified asphalt cement for the primary 09/27 runway rehabilitation in 2002 was a PG 58-28 binder. The asphalt mix designed followed the Marshall method with 50 blows compaction effort to improve stability. Utilizing a local industry mix design allows the contractors and suppliers to use a mix they are familiar with and minimizes overall construction and supply costs. There are Polymer Modified Asphalts (PMA) on the market that improve stability and resistance to rutting; however, there is a significant premium on these asphalts, and there is no proof that this material was beneficial to the FIAA for the runway rehabilitation.

3.3 YFC Susceptibility to Climate Change

The province has already said to be experiencing the impacts of climate change. According to the Government of New Brunswick, in the last 30 years, the mean annual temperature has increased by 1.1 degrees Celsius (Government of New Brunswick,

2022). There has been an increased risk of flooding as an effect of the rise in sea levels. In the past ten years, there have been extreme weather events in the province, such as the back-to-back flooding in 2018 and 2019 along the St. John River and the post-tropical storm in 2019, which caused extensive damage to infrastructure, property, and shoreline. Climate projections predict that the province is expected to become warmer and stormier and experience fewer freeze-thaw cycles, challenging various sectors and communities of New Brunswick.

Fredericton is one of the cities of New Brunswick that has already been impacted by climate change. The impacts have been experienced by all the infrastructure, assets and service levels and operations in the city, such as the Fredericton International Airport. An increase in the mean annual temperature was observed over the past century in the city. Besides the temperature rise, there have been other significant impacts of climate change also explained in the following sections.

3.3.1 Increase in Maximum Temperatures

The history of climate has shown an increase of 1.1 degrees Celsius in the past decade. The higher mean temperatures are projected to be increased by 2.2 to 3 degrees Celsius by the 2050s and even 2.8 to 5.1 degrees Celsius by the 2080s. There has been an increase in hot nights that didn't go below 20 degrees Celsius and intense heat waves in terms of length and frequency.

Figure 3.4 (Climate Data, 2022) illustrates that hot days will become more frequent in the city by 2050. According to the projection, the number of days when the temperature is more than 30 degrees Celsius will be approximately three times in 2050, depending on the RCP (Representative Concentration Pathway). As the city is expected to get warmer, the increase in winter temperature is expected to rise between 3.4 to 6.1 degrees Celsius.

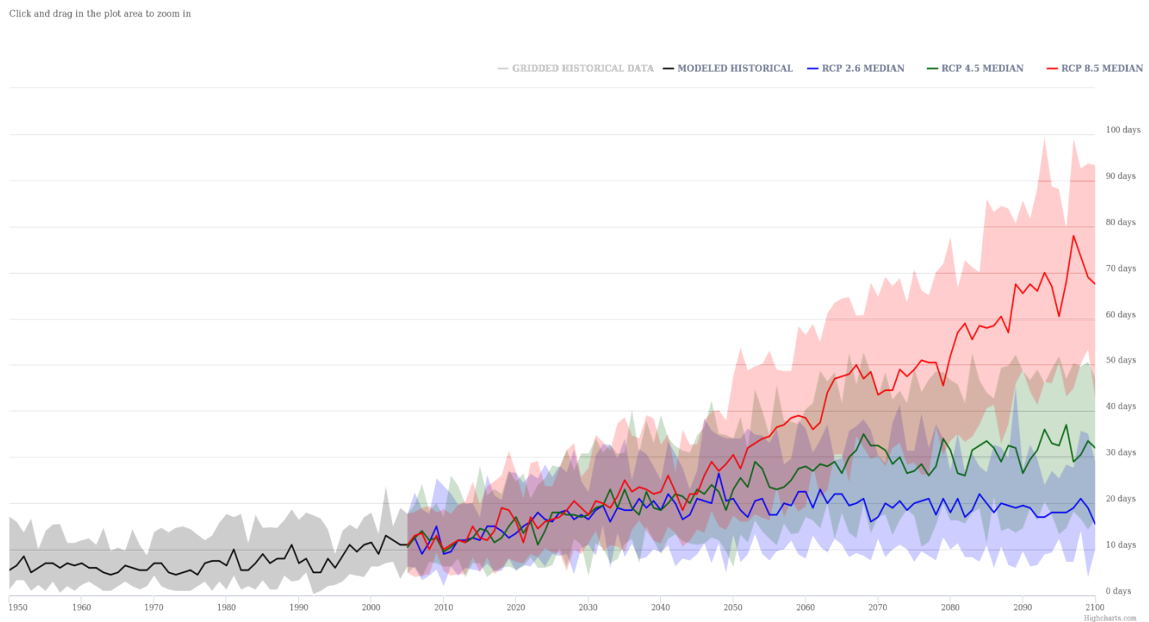


Figure 3.4 Number of Days with Maximum Temperature in Fredericton (1950-2100)

3.3.2 Increase in Precipitation

The City of Fredericton is predicted to experience an increase in the average annual precipitation in the future. An increase in the rain, along with a higher temperature in the spring, will lead to a higher risk of flooding, such as what occurred in 2018 and 2019 in the province. Figure 3.5 (Prairie Climate Centre, 2019b) depicts that there will be an

increase in annual precipitation; 3.6 to 4.5 percent by the 2020s, 6.3 to 8.5 percent by the 2050s and approximately 8.6 to 12.5 percent by the 2080s. The increase in the days of heavy precipitation will be 3.2 days between 2021 to 2050. The graph visualizes the range of values, the lower line being the 10th percentile and the higher one being the 90th percentile. The city will also be at potential risk for heavy rainfall events and flood events.

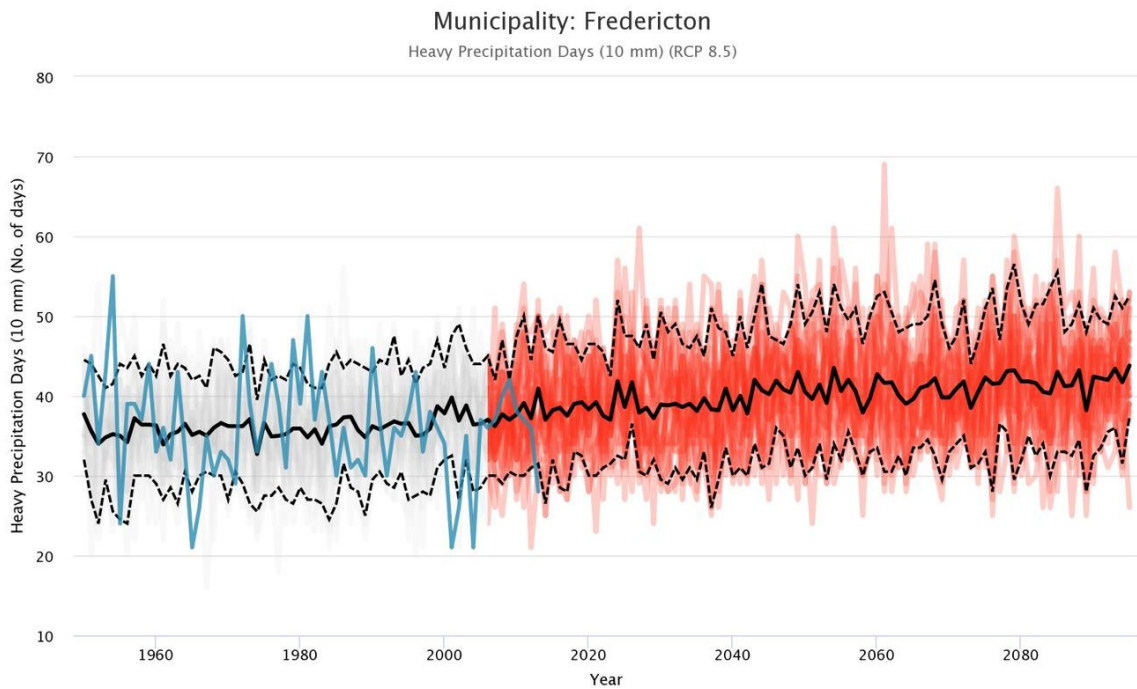


Figure 3.5 Precipitation Days Fredericton (1950-2095)

3.3.3 Decreased Number of Freeze-thaw Cycles

Due to climate change, the number of frost days has significantly decreased and is projected to see a further reduction as well. The days with a maximum below -10 degrees

Celsius will be as few as two by the 2080s, compared to 12 in the current year, with fewer snow days. The relationship between the mean annual temperature and the number of freeze-thaw cycles is inversely proportional. Hence, the City of Fredericton is expected to see a decrease in the number of freeze-thaw cycles, according to the data presented in Figure 3.6 (Prairie Climate Centre, 2019b). The number of freeze-thaw cycles was observed to be 81.9 from 1976-2005, and it is expected to drop to 76.4 in the period 2021-2050.

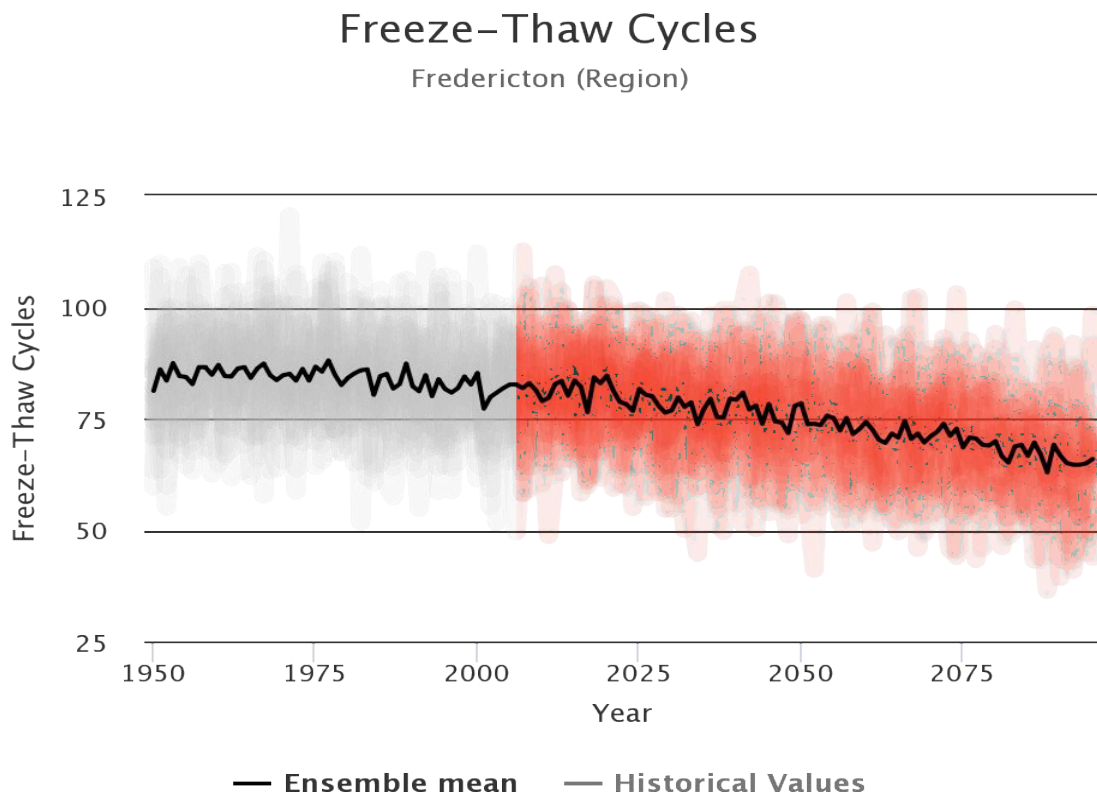


Figure 3.6 Number of Freeze-Thaw Cycles Fredericton (1950-2095)

3.3.4 Changes in Wind Speed and Direction

Even though wind speed and direction do not directly impact the pavement infrastructure, it is relevant to mention the changes in it since this could impact airport operations. In Fredericton, winds mostly blow from the west direction. Figure 3.7 (Meteoblue, 2022) is a wind rose which shows the number of hours the wind blows from an indicated direction. The strong winds coming from the west make it very difficult for airplanes that travel from East to West.

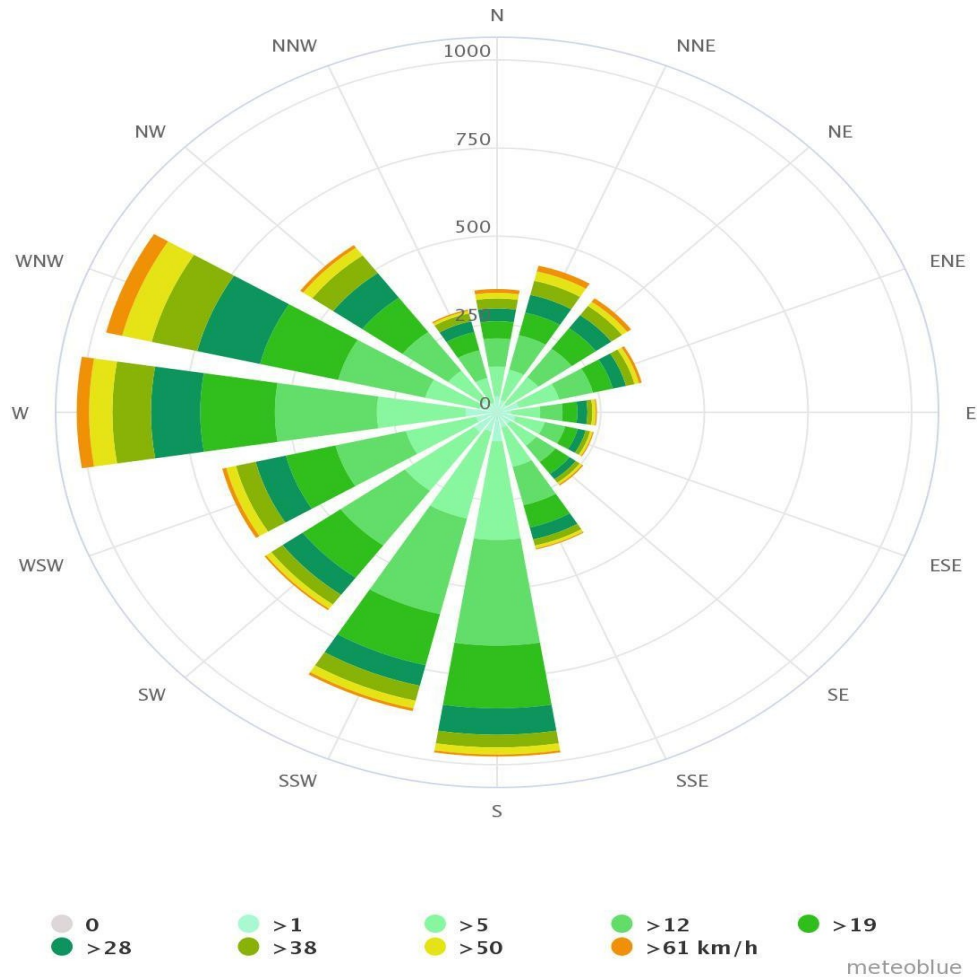


Figure 3.7 Wind Rose for Fredericton

Moreover, Figure 3.8 (Meteoblue, 2022) shows the number of days in a month when the wind reaches a certain speed throughout the year.

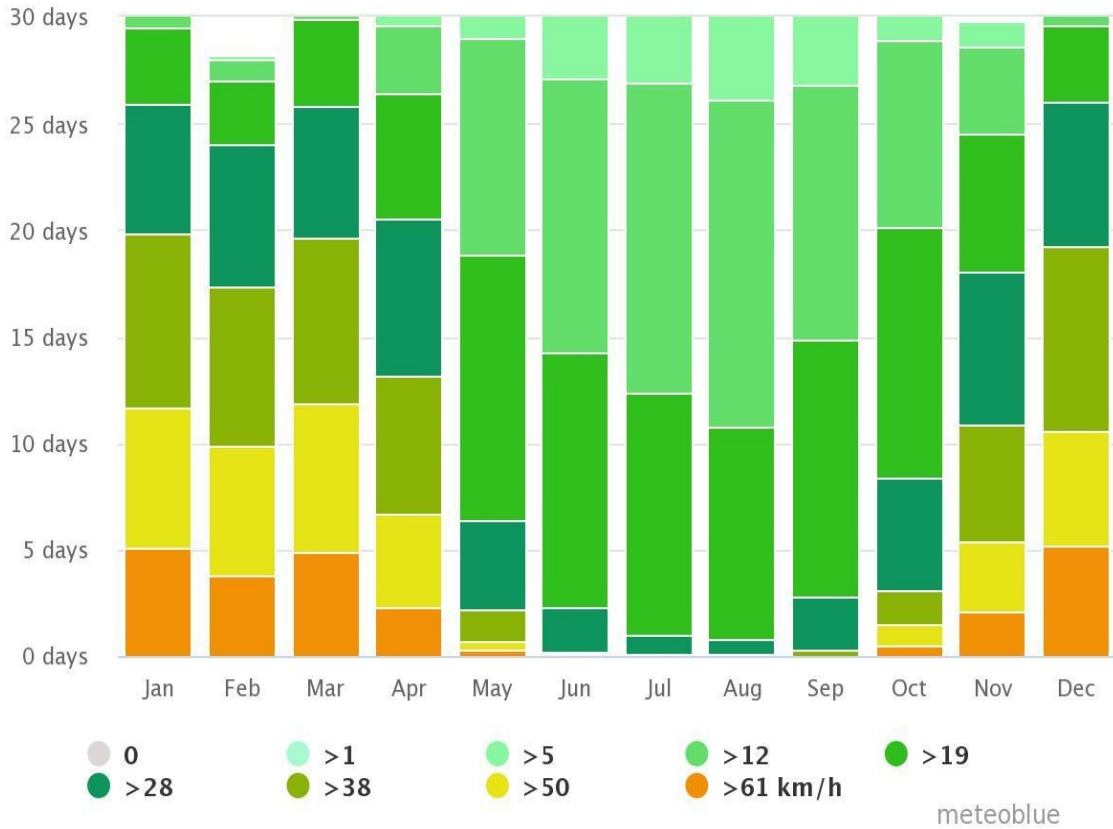


Figure 3.8 Wind Speed each Month in Fredericton

Due to the impact of climate change, the wind speed is predicted to decrease in the future; however, there could be a potential increase in the number of winter ice storms, post-tropical storms, and hurricanes. All these changes are of consequence to YFC.

3.4 Potential Climate Change Adaption Strategies

YFC could be susceptible to multiple significant distresses; hence adaption strategies must be considered accordingly. Although the airport does not cater to a large amount of

traffic as compared to other airports, the temperature rise could make the airfield pavement prone to distresses, such as rutting and shoving. The increase in maximum and minimum temperature and precipitation combined with fewer snowy days and slower winds should make the authorities suggest adaptation strategies for future rehabilitation projects that are more focused on summer conditions.

Also, since precipitation is projected to increase in the future, the Fredericton Airport Authority could also consider enhancing the maintenance of drainage systems to deal with surface runoff optimally and avoid water penetration into the layers, considering that the pavement could experience settlement and cracking as a result of the weakening of the soils due to water infiltration. As YFC has runways and taxiways that are flexible pavements, the authorities could use similar adaption strategies to the ones suggested for highway pavements, which are described in the following sections.

3.4.1 Improve Asphalt

A recently published study suggested climate change adaption strategies for Canada (Swarna *et al.*, 2022), using asphalt concrete layers and taking into consideration data inputs such as material properties, traffic loading, and climate data. The AASHTOWare mechanistic-empirical pavement design tool was used to predict the performance of selected cities in 30 years' time. The reliability level taken was 50%. Asphalt rutting, fatigue cracking, total rutting, and International Roughness Index (IRI) were the main parameters of interest. Figure 3.9 (Swarna *et al.*, 2022) illustrates the percent change in performance parameters for upcoming years with respect to historical climate. The study

suggested that if the rutting in any city was worse under the climate change scenario, an adaptation strategy was necessary.

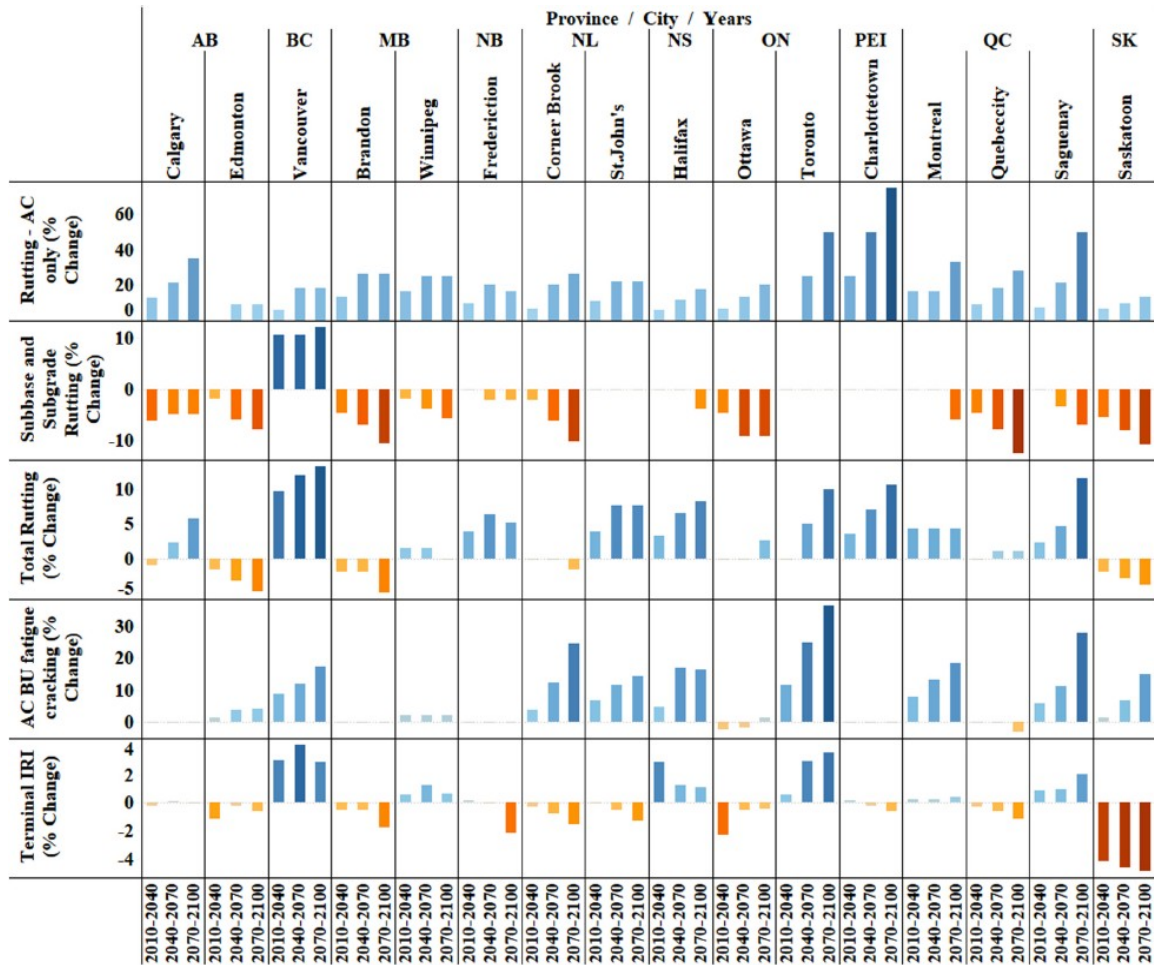


Figure 3.9 Change in Pavement Performance Parameters due to Climate Change

AC= Asphaltic Concrete, BU= Bottom-Up, IRI= International Roughness Index

The first step to cater to the rutting problem was to upgrade the asphalt binder. If the rutting problem decreased from the baseline scenario, the binder was upgraded. If not, a Stone Matrix Asphalt (SMA) gradation was considered. If rutting remained a problem, it was suggested to increase the asphalt layer thickness in 1 cm steps until climate changes

were encountered. This necessary change in thickness was performed at each location. The same strategy was directed to improve rutting in subgrade and subbase (Swarna *et al.*, 2022).

According to this study, in Fredericton, the Asphalt Concrete (AC) rutting increased by 10% for 2010-2040 when compared to 1980-2010. Similarly, the AC rutting is increasing by 25% and 20% for 2040-2070 and 2070-2100, respectively. A negative IRI change is predicted to happen in 2070-2100. Subgrade and subbase rutting is also seen to be slightly decreasing (Swarna *et al.*, 2022).

Figure 3.10 (Swarna *et al.*, 2022) is the result of the study to recommend an adaptation strategy according to the selected cities' data and pavement performance in the upcoming years. This study only recommends Fredericton's flexible pavements change the asphalt binder grade in every stage, but not the asphalt mixture gradation since rutting is not that big of a problem as compared to other cities (Swarna *et al.*, 2022).

City ID	Province	City	Adaptation Strategy		
			2010–2040	2040–2070	2070–2100
BC_00	BC	Vancouver	BG + BT	BG + MG + BT	BG + BT
AB_01	AB	Calgary	BG	BG	BG
AB_02	AB	Edmonton	BG	BG	BG
SK_03	SK	Saskatoon	BG	BG	BG
MB_04	MB	Brandon	BG	BG	BG
MB_05	MB	Winnipeg	MG	BG + MG	BG
ON_06	ON	Toronto	MG	BG + MG	BG + MG
ON_07	ON	Ottawa	BG	BG	BG + MG
QC_08	QC	Montreal	MG	MG	BG
QC_09	QC	Quebec City	MG	BG	BG + MG
QC_10	QC	Saguenay	MG	MG	BG + MG
NB_11	NB	Fredericton	BG	BG	BG
PEI_12	PEI	Charlottetown	BG + MG	BG + MG	BG + MG + CT
NS_13	NS	Halifax	BG	BG	BG
NL_14	NL	Corner Brook	MG	MG	BG + MG
NL_15	NL	St. John's	BG	BG + CT	BG + MG

Figure 3.10 Adaptation Strategies recommended for Climate Change

BG= change in asphalt binder grade, BT= change in the base type, CT= change in asphalt layer thickness, MG= change in asphalt mixture gradation.

3.4.2 Increase Layer Thickness

As a climate change adaptation strategy, the thickening of pavement layers might be an effective course of action (Knott *et al.*, 2019). Research probed factors like seasonal average temperature, change in season length, and temperature-dependent resilient modulus to simulate the pavement response regarding climate change. It was clearly observed that, with 85% reliability, the current base layers are working effectively, but if the thickness is increased by 7-32%, it will be more adaptable to climate change. The research also covers what the threshold is for the increase in the base layer and the

thickness of the hot mix asphalt because of another problem faced due to climate change; groundwater rise (Knott *et al.*, 2019). Primarily in the coastal regions, temperature and groundwater rise will decrease the pavement service life, and to avoid this outcome, more resistant pavements are made with increased asphalt and base layer thicknesses (Knott *et al.*, 2019).

3.4.3 Stabilize Subgrade Soils

Alternatively, stabilized subgrades can be used as another adaptation measure. Mallick *et al.* opted for a Monte Carlo simulation to calculate what percentage of roads would need restoration in the coming 50 and 100 years. The three variables studied were: no climate change, climate change and climate change with different mitigation scenarios, which also included the use of stabilized subgrade. The results showed that using stabilized subgrades would require a lesser number of roads needed restoration than any other option under climate change conditions (Mallick *et al.*, 2018). With the results in his favour, Mallick *et al.* extended the investigation to the effects of using a stabilized subgrade with a modified Hot Mixed Asphalt (HMA). This resulted in a further decrease in the percentage of the roads that needed restoration in both 50- and 100 years' time.

3.4.4 Limitations

Pavements get affected by the changing climate all around the world. As studied in earlier research, stabilized base layers, asphalt binder grade upgrades, and increased asphaltic concrete thicknesses also help in decreasing pavement distresses related to climate change.

However, these studies were limited to one or two climate change models to examine their pavement performance. There is a heightened uncertainty due to the restricted use of climate change models (Gudipudi, Underwood and Zalghout, 2017). The majority of research used the Long-Term Pavement Performance program (LTPP) or Strategic Highway Research Program (SHRP) pavement temperature models to convert climate data to pavement temperatures. Prior research inquired about these strategies and how these models have restricted geographical applications and may be less accurate for northern climates (Swarna *et al.*, 2021).

While many adaptation strategies have been studied, only a few have explored the effects of combining them (Mallick *et al.*, 2018). Also, probing just one pavement temperature, one climatic region, or one location may limit the results from being generalized to wider applications (Gudipudi, Underwood and Zalghout, 2017).

3.4.5 Strategies for Rigid Pavements

Although this report has an emphasis on asphalt pavement, it is also deemed important to mention some potential strategies for concrete pavement. While climate change impacts could exacerbate distresses such as rutting, cracking, stripping, etc., in flexible pavements, for rigid pavements, the distresses include blow-ups, slab cracking, joint spalling, faulting, corner breaking, slab warping and punch-outs. The most concerning parameter is the annual increase in average temperature each year. In rigid pavements, this change will increase the potential for concrete temperature-related curling and moisture warping. However, if the concrete coefficient of thermal expansion and drying

shrinkage are considered, this problem can be solved over time. The incorporation of design elements such as shorter joint spacing, less rigid support, and enhanced load transfer may also reduce damage from thermal effects. There is also a risk of excessive slab expansion when the slabs experience an increase in the maximum temperature. Using shorter joint spacing in new designs and expansion joints in existing pavements will help overcome this impact.

As the city of Fredericton is safe from increased freeze-thaw cycles, YFC does not need to adapt strategies for it. However, considering extreme rainfall events, surface friction and surface texture need to be maintained. Keeping a positive cross slope will facilitate water flow from the surface. A better understanding of how submergence affects pavement layer stiffness will help develop strategies to address it and maintain the structural capacity of pavements (US Department of Transportation, 2015).

Most climate change impacts, such as increases in average temperature, precipitation patterns and sea level rise, occur over a long period of time. For long-term pavement strategies, the first step is to identify and monitor key pavement performance parameters and search for trends that develop over longer periods of time to reveal slow shifts in these parameters. The identified climate impacts must be addressed by making the necessary changes in pavement materials, design, and management.

4. STATE OF CLIMATE CHANGE ADAPTATION BY CANADIAN REGIONAL AIRPORTS

As part of this project, a survey with 30 questions was created to assess the awareness and concerns that regional airports have regarding climate change. Regional airports were the focus of this investigation in order to identify the level of awareness of the operators to climate change effects on pavement infrastructure. The survey was created using the Google Forms utility, and the questionnaire is presented in Appendix A (Survey Questions). These questions were adapted from a survey developed in 2016 by the Centre for Pavement Transportation and Technology (CPATT) at the University of Waterloo, designed for Canadian airport authorities to express their perspective on climate change (Vanheule *et al.*, 2017). In April 2022, Dr. Xiomara Sanchez approached the Regional Community Airports of Canada (RCAC) administration and requested the organization to distribute the survey to its members. The survey was available for two weeks; however, of RCAC 50+ members, only 9 (~18%) completed the anonymous survey. This chapter summarizes the analysis of the responses which were deemed more relevant for the purpose of the report.

4.1 Types of Airfield Pavements

The survey, distributed amongst regional airports in Canada, started by asking about the type of runway and taxiway being used in their respective airports. For this question, the respondents could choose more than one option.

Figure 4.1 (responses to question 2) and Figure 4.2 (responses to question 3) suggest that almost all the taxiway and runway pavements built in the surveyed airports are asphaltic concrete. Since most airports have multiple taxiways and runways, it is possible that they have different pavement types. The x-axis represents the number of respondents voting for an option.

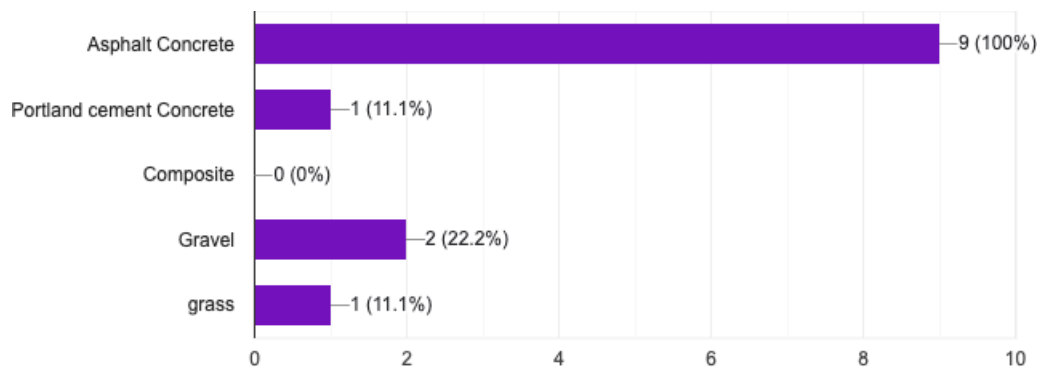


Figure 4.1 Type of Runway Pavements

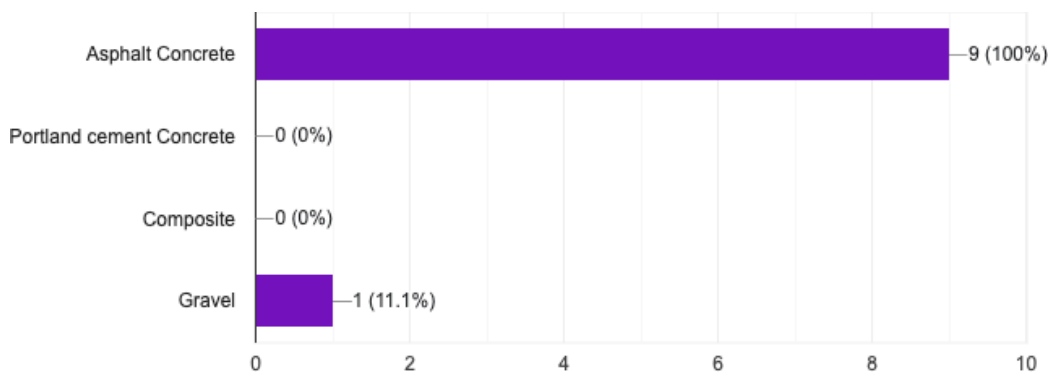


Figure 4.2 Types of Taxiway Pavements

4.2 Pavement Condition of Airport Pavements

In the current state of regional airports in Canada, represented in Figure 4.3 (responses to question 4), the vertical axis indicates the number of respondents, and the horizontal axis indicates the condition, 0 being poor and 5 being excellent. The survey conducted indicated that mostly the pavements are in neutral condition and can be improved.

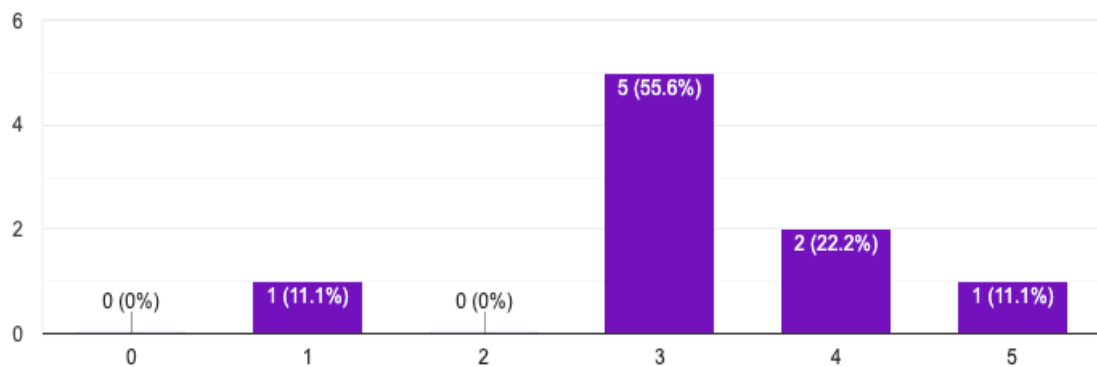


Figure 4.3 Pavement Condition of Airport Pavements

4.3 Climate Change Challenges in Airports Pavements

Figure 4.4 (responses to question 5) shows that airport authorities agree on the fact that there has been a clear slight increase in the precipitation intensity and the number of freeze/thaw cycles over the years. These changes can have a negative impact on infrastructures and pavements.

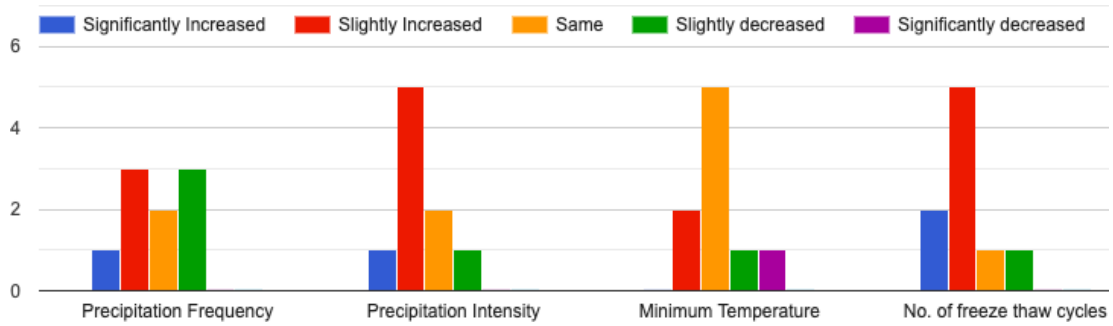


Figure 4.4 Climate Change Phenomena

The surveyed airports highlighted the challenges in climate change shown in Figure 4.5 (responses to question 6). Freeze/thaw cycles and precipitation frequency and intensity were the top responses.

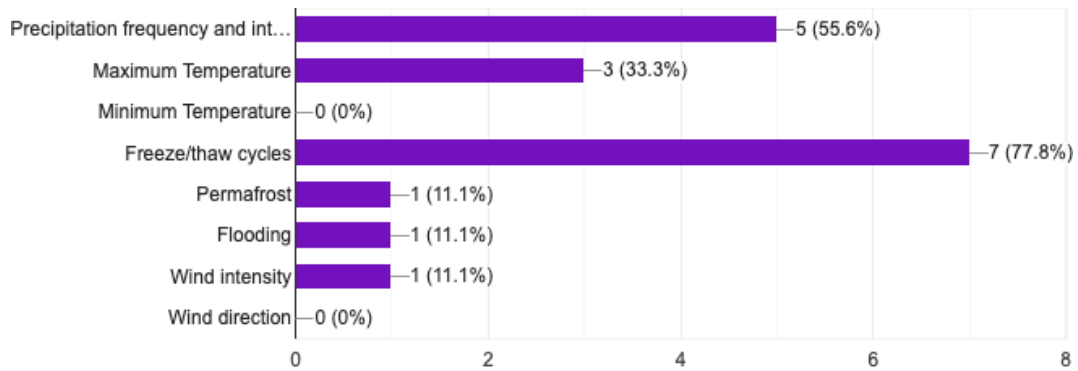


Figure 4.5 Climate Change Challenges

4.4 Changes in Practices due to Climate Change on Airfield Pavements

Airside pavement infrastructure could show superior performance if the factors mentioned above were to be considered in the design, preparing it for any future loads and hazards.

Several airport authorities agree that climate change has a meaningful effect on their practices. However, Figure 4.6 (responses to question 7) show an even split between the perceived changes in the maintenance, preservation, and rehabilitation in the past ten years.

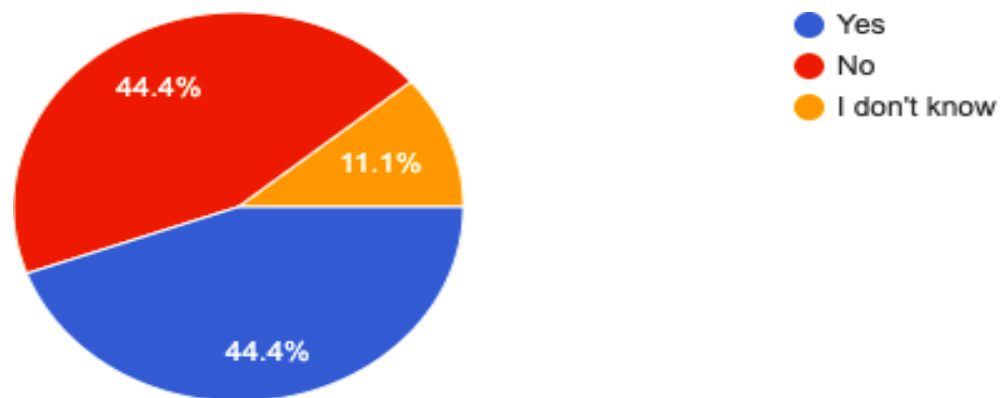


Figure 4.6 Perception of Changes in Practices

Several possible changes in practices were mentioned in the survey to which airports responded, as shown in Figure 4.7 (responses to question 8). Y-axis represents the number of respondents that vote on the particular practice. According to most airport

authorities, crack sealing is the maintenance practice that has changed due to climate change, followed by runway sweeping and snow removal from the airport pavements.

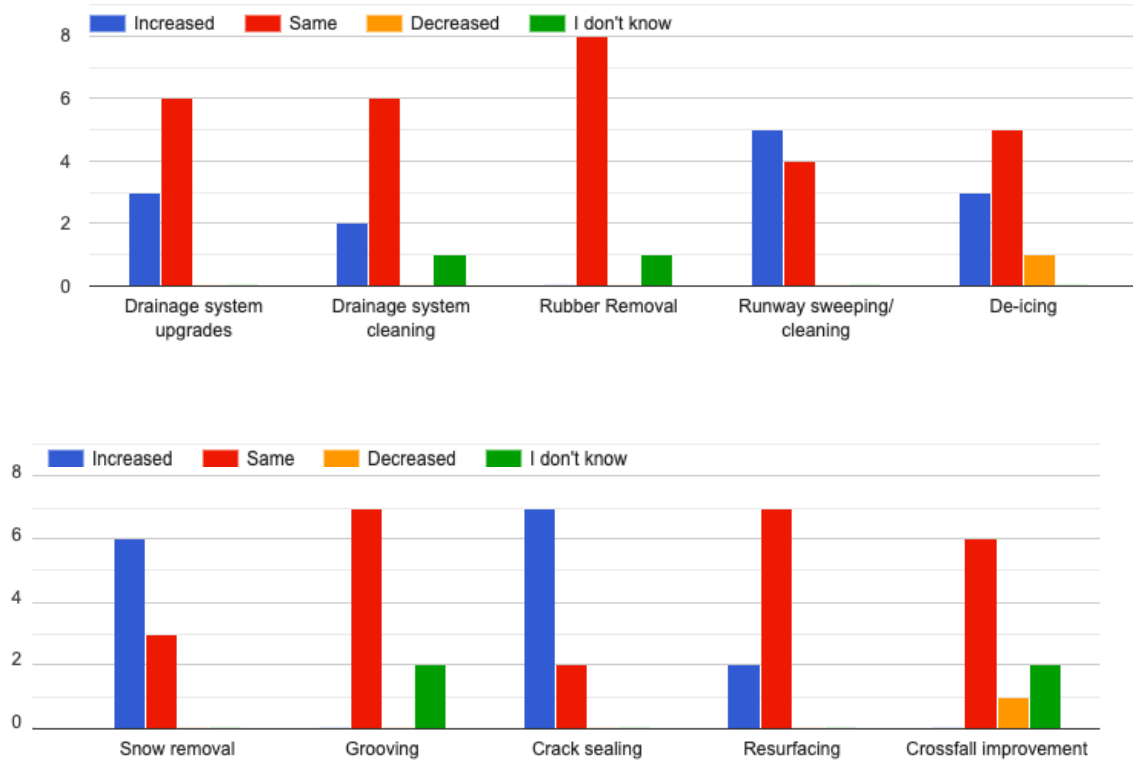


Figure 4.7 Changes in the Maintenance, Preservation, and Rehabilitation

A pavement can experience many distresses as a result of constant extreme weather exposure, as mentioned in Chapter 2.7 Distresses due to Climate Change in Pavements.

Figure 4.8 (responses to question 9) shows the surveyed airport authorities' perspective of the consequences on the airfield pavement structures under climate change. Evidently, the major distress impacting all of the surveyed regional airports in Canada is early cracking and crack severity.

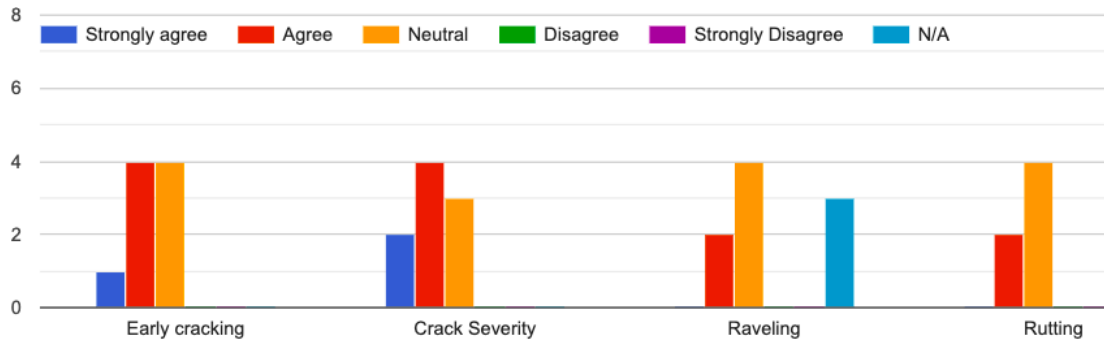


Figure 4.8 Consequences of Climate Change

Figure 4.9 (responses to question 13) shows how more than half of the surveyed regional airports, do not have plans to introduce tools or research activities for assessing climate change on airfield pavements.

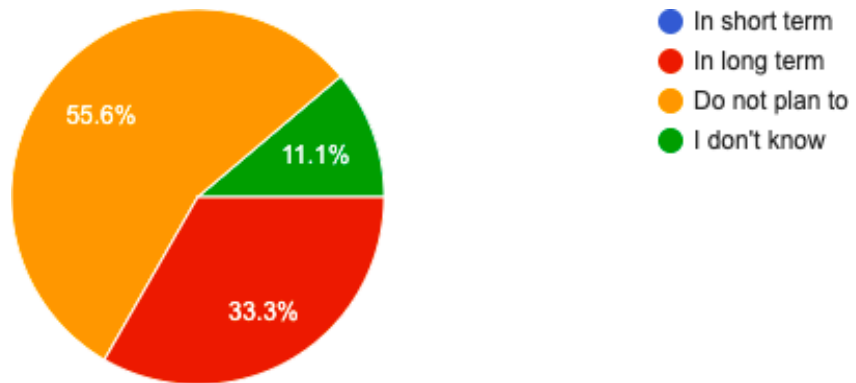


Figure 4.9 Airports Plan to Assess Climate Change on Airfield Pavements

4.5 Barriers to Incorporating Climate Change Adaptation Strategies

There can be various reasons why airports are unable to incorporate climate change adaptation strategies. The data in Figure 4.10 (responses to question 15) suggest that the main barrier to making the surveyed airports' pavements more resilient against climate change is insufficient funds, followed by the lack of related research and data required to suggest possible mitigation barriers. Without access to such data, it is very difficult to make future climate projections and strategies accordingly.

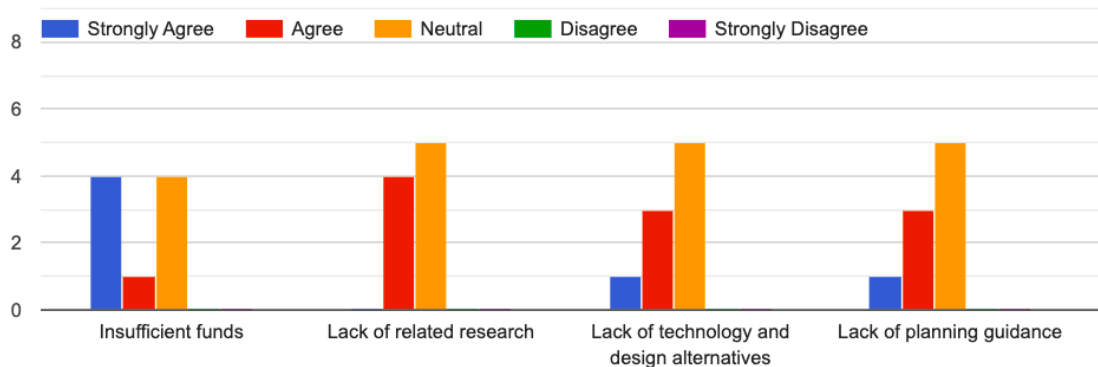


Figure 4.10 Barriers to Incorporating Climate Change Adaptation Strategies

According to the surveyed airport authorities, as shown in Figure 4.11 (responses to question 16), after solving the funding problems, new technology and design appear to be the best option. Several respondents selected more than one option.

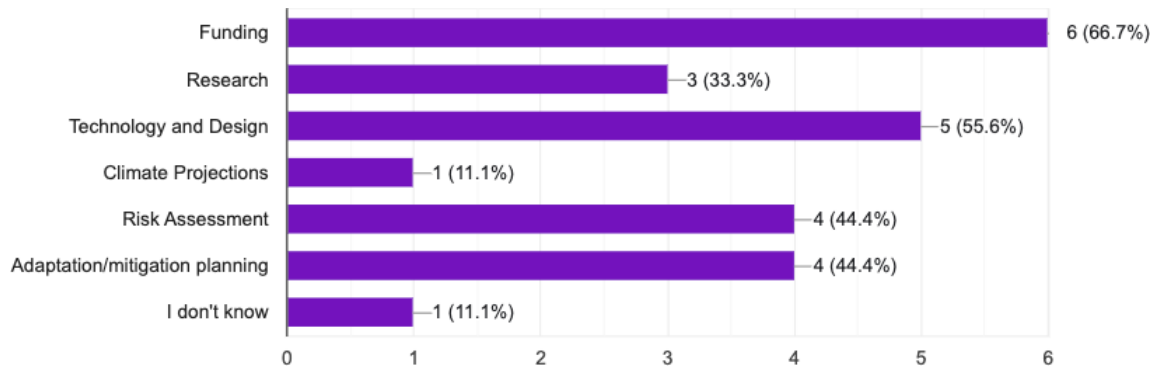


Figure 4.11 Best adaptation Techniques to Climate Change

4.6 Limitations

The survey consisted of 30 questions, a combination of open-ended questions and Likert scale questions which target the area of research. The survey started with general pavement questions but moved to specific questions later. It is important to mention that the number of survey responses was not enough to reach statistical significance; a similar issue was experienced with the survey created by the University of Waterloo (Abreau, 2019). The reasons behind the low response rate must be taken into consideration to avoid similar mistakes in any upcoming research. One of the key reasons would be the extensive survey and the wrong selection of agreement scales for most of the questions, which might have given the respondent a fair chance to provide generalized or unreliable answers, which was against the goal of this survey.

Moreover, the airports were not categorized by size or estimated passenger traffic, which is a variable to consider since this could affect the survey responses. Also, a better

analysis could be made if the locations of the respondents were known by studying how the climate change situation relates to the specific regional conditions.

4.7 Recommendations

Although the respondents were briefed about the aim of the research and the rationale of the survey, the survey itself could have been more precise and shorter. The reliability and validity of the survey could have been put in check better, for instance, by including reverse code questions and using the appropriate agreement scales. A survey of this nature should also be piloted to detect any issue and make further improvements before distributing it to a broader study group. Contextual and categorical information can be incorporated into the research for future reference. The survey can be revised by not including general questions but by asking more specific questions that address the issue at hand, which is to establish the state of airport pavement practices in response to climate change.

5. CONCLUSIONS

It is expected that the global climate will continue to change at an increasing rate in the upcoming century or so. While mitigation strategies are necessary, adaptation to the already changed environment is also significantly important. Climate change adaptation deals with making sustainable future decisions according to the projections for upcoming climatic conditions. It is comparatively easier, cost-effective, and efficient to adapt to climate change rather than to deal with the impacts of extreme weather conditions after they have occurred.

It can be said that the investigation of the impacts of climate change on pavements is still in its infancy and the adaptation strategies need more development. Most of the research to date only provides general guidance about climate change impacts, mostly precipitation and temperature changes, and its effects on pavement performance and materials. The gap in the research can be because the effect of climate change on pavements is a slow process taking around 20-40 years; hence it can be difficult to guarantee immediate adaptation responses.

Pavement climate adaptation is a new research area. This report summarizes the climate change impacts and adaptation strategies for pavements that have been suggested to date and broad general strategies that are yet to be investigated. The strategies suggested in this report can only be considered as a starting point for necessary future work. Future

work is expected to introduce more adaptation strategies and identify the ones that have the most potential.

Like other countries globally, Canada is experiencing climate change on an increased level every year. With the increase in the number of days with the maximum temperature, increased precipitation intensity and frequency and extended thaw period, it becomes a challenge for the airport industry to make sure the pavements adapt to the change that has arrived and is yet to come. The case study for the Fredericton International Airport presented in this research shows similar trends of increased wind speed, precipitation intensity and maximum temperature that are affecting the infrastructure. The airport authority has a policy in place to mitigate carbon emissions coming from the infrastructure. However, there are no adaptation strategies that the airport has in place to increase the pavements' resilience to climate change yet. According to the trend of climate change in the city, the adaptation strategies recommended in the report are not tested to be impactful but provide a starting point for the future.

There is a knowledge gap that exists between climate change and greenhouse gas emissions at a regional level. The gap is because of the unavailability of long-term weather and climatological data, which makes it difficult to connect climate factors and hydrogeological conditions. It is important to observe the effects on the infrastructure's response and performance and assess risks.

The survey conducted in this report indicated that climate change could be associated with some airfield pavement infrastructure distresses, mainly cracking. However, there is a lack of funding, related data, and risk assessment to plan for more resilient infrastructures in the airfield industry. The collection of data and experiments with new technology can not only improve pavement engineering but also help open new doors for research and introduce best practices.

6. REFERENCES

- AASHTO (2009) 'Mechanistic-Empirical Pavement Design Guide (MEPDG)', *AASHTO*, 1.1.
- Abreu, E.Alexander. (2019) *Impacts of Climate Change on Canadian Airport Pavements*. University of Waterloo. Available at: <http://hdl.handle.net/10012/15359>.
- Ahmad, T. and Khawaja, H. (2018)' Review of Low-Temperature Crack (LTC) Developments in Asphalt Pavements', *International Journal of Multiphysics*, 12, pp. 169–187. Available at: <https://doi.org/10.21152/1750-9548.12.2.169>.
- Apeageyi, A.K., Grenfell, J.R. and Airey, G.D. (2015) 'Influence of aggregate absorption and diffusion properties on moisture damage in asphalt mixtures', *Road Materials and Pavement Design*, 16(sup1), pp. 404–422.
- Applegate, Z. (2013) 'Global warming discovery marked', *BBC*, 26 April. Available at: <https://www.bbc.com/news/uk-england-norfolk-22283372>.
- Baglin, Chris. *et al.* (2012) *Airport climate adaptation and resilience*. Washington, DC: Transportation Research Board (ACRP synthesis, 1935-9187; 33). Available at: http://onlinepubs.trb.org/onlinepubs/acrp/acrp_syn_033.pdf.

Black, R. *et al.* (2008) 'Demographics and climate change: Future trends and their policy implications for migration', *Development Research Centre on Migration, Globalisation and Poverty*. Brighton: University of Sussex [Preprint].

Climate Data (2022) 'Physical and mental health impacts of climate change in New Brunswick'. Available at: <https://climatedata.ca/case-study/physical-and-mental-health-impacts-of-climate-change-in-new-brunswick/>.

Dawson, A. *et al.* (2014) 'Energy harvesting from pavements', in *Climate Change, Energy, Sustainability and Pavements*. Springer, pp. 481–517.

EPA (2021) 'Climate Change Indicators: Global Greenhouse Gas Emissions', *United States Environmental Protection Agency*. Available at: <https://www.epa.gov/climate-indicators/climate-change-indicators-global-greenhouse-gas-emissions>.

Fredericton International Airport (2022a) 'Airport Operations Manual'.

Fredericton International Airport (2022b) 'Airside Winter Operations 2022/2023'.
Fredericton International Airport.

Fredericton International Airport (2022c) 'FIAA Greenhouse Gas Reduction Commitment Policy'. Available at: <https://yfcfredericton.ca/our-airport/fiaa-greenhouse-gas-reduction-commitment-policy/>.

Fredericton International Airport (2022d) 'History of the Airport'. Available at: <https://yfcfredericton.ca/an-active-authority/history-of-the-airport/>.

Government of Canada (2020) *Greenhouse gas sources and sinks in Canada: executive summary 2022*. Available at: canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/sources-sinks-executive-summary-2022.html.

Government of New Brunswick (2022) 'Climate Change in New Brunswick'.

Gudipudi, P.P., Underwood, BS and Zalghout, A. (2017) 'Impact of climate change on pavement structural performance in the United States', *Transportation Research. Part D, Transport and Environment*, 57(C). Available at: <https://doi.org/10.1016/j.trd.2017.09.022>.

Hartman, J. (1998) 'A Primer on Urban Transportation and Global Climate Change', *Transportation Association of Canada*, p. 8.

Holdren, J.P., Ehrlich, P.R. and Daily, GC (1995) 'The meaning of Sustainability: Biogeophysical Aspects', in *Defining and Measuring Sustainability*. Washington, DC: The World Bank, pp. 3–17.

Intergovernmental Panel on Climate Change (2014) *Climate Change 2014 – Impacts, Adaptation and Vulnerability: Part B: Regional Aspects: Working Group II Contribution to the IPCC Fifth Assessment Report: Volume 2: Regional Aspects*. Cambridge: Cambridge University Press. Available at: <https://doi.org/10.1017/CBO9781107415386>.

Knott, J.F. *et al.* (2019) 'A Framework for Introducing Climate-Change Adaptation in Pavement Management', *sustainability*, 11(16), p. 4382. Available at: <https://doi.org/10.3390/su11164382>.

Lidia Sarah, C. *et al.* (2017) '3D-FEM Analysis on Geogrid Reinforced Flexible Pavement Roads', *IOP Conference Series: Earth and Environmental Science*, 95, p. 022024. Available at: <https://doi.org/10.1088/1755-1315/95/2/022024>.

Mallick, R.B. *et al.* (2018) 'Understanding the impact of climate change on pavements with CMIP5, system dynamics and simulation', *International Journal of Pavement Engineering*, 19(8), pp. 697–705. Available at: <https://doi.org/10.1080/10298436.2016.1199880>.

Meagher, W. *et al.* (2012) 'Method for Evaluating Implications of Climate Change for Design and Performance of Flexible Pavements', *TRANSPORTATION RESEARCH RECORD*, (2305), pp. 111–120.

Meteoblue (2022) 'Simulated historical climate & weather data for Fredericton'.

Available at:

https://www.meteoblue.com/en/weather/historyclimate/climatemodelled/fredericton_canada_5957776.

Mills, B.N. *et al.* (2007) 'Road well-traveled: Implications of climate change for pavement infrastructure in southern Canada'.

Mills B.N. *et al.* (2009) 'Climate change implications for flexible pavement design and performance in Southern Canada', *Journal of Transportation Engineering*, 135(10), pp. 773–782. Available at: [https://doi.org/10.1061/\(ASCE\)0733-947X\(2009\)135:10\(773\)](https://doi.org/10.1061/(ASCE)0733-947X(2009)135:10(773)).

NASA (2021) 'Global Temperature'. Available at: <https://climate.nasa.gov/vital-signs/global-temperature/>.

Nguyen, T.-C., Tang, V.L. and Huynh, T.-P. (2020) 'An Early-age Evaluation of Thermal Cracking Index of Heavy Concrete Applying for Airport Pavement', *Periodica Polytechnica-civil Engineering* [Preprint].

Palandrani, P. (2020) 'A Decade of Change: How Tech Evolved in the 2010s and What's In Store for the 2020s.' Available at: <https://www.globalxetfs.com/a-decade-of-change-how-tech-evolved-in-the-2010s-and-whats-in-store-for-the-2020s/>.

Pavement Tools Consortium (2022a) 'Frost Action'. Available at: <https://pavementinteractive.org/reference-desk/design/design-parameters/frost-action/>.

Pavement Tools Consortium (2022b) 'Pavement types'. Available at: <https://pavementinteractive.org/reference-desk/pavement-types-and-history/pavement-types/>.

Prairie Climate Centre (2019a) 'Climate vs. Weather', *Climate Atlas of Canada* [Preprint]. Available at: <https://climateatlas.ca/climate-vs-weather>.

Prairie Climate Centre (2019b) 'Municipality: Fredericton'. Available at: https://climateatlas.ca/data/city/461/precip10_2030_85/line.

Qiao, Y., Santos, J., *et al.* (2020) 'Climate change impacts on asphalt road pavement construction and maintenance: An economic life cycle assessment of adaptation measures in the State of Virginia, United States', *Journal of Industrial Ecology*, 24(2), pp. 342–355. Available at: <https://doi.org/10.1111/jiec.12936>.

Qiao, Y., Dawson, A.R., *et al.* (2020) 'Flexible Pavements and Climate Change: A Comprehensive Review and Implications', *sustainability*, 12(3), p. 1057. Available at: <https://doi.org/10.3390/su12031057>.

Qin, Y. and Hiller, J.E. (2013) 'Ways of formulating wind speed in heat convection significantly influencing pavement temperature prediction', *Heat and Mass Transfer*, 49(5), pp. 745–752.

Salour, F. (2015) *Moisture influence on structural behaviour of pavements: Field and Laboratory Investigations*. KTH Royal Institute of Technology.

Schmidt, M. (2017) 'A review of aircraft turnaround operations and simulations', *Progress in Aerospace Sciences*, 92, pp. 25–38. Available at: <https://doi.org/10.1016/j.paerosci.2017.05.002>.

Shao, Z., Jenkins, G. and Oh, E. (2017) 'Assessing the impacts of climate change on road infrastructure', *International Journal of GEOMATE*, 13, pp. 120–128. Available at: <https://doi.org/10.21660/2017.38.72099>.

Swarna, ST *et al.* (2021) 'Assessing Climate Change Impact on Asphalt Binder Grade Selection and its Implications', *Transportation Research Record: Journal of the Transportation Research Board*, 2675(10), pp. 786–799. Available at: <https://doi.org/10.1177/03611981211013026>.

Swarna, ST *et al.* (2022) 'Climate Change Adaptation Strategies for Canadian Asphalt Pavements; Part 1: Adaptation strategies', *Journal of Cleaner Production*, 363. Available at: <https://doi.org/10.1016/j.jclepro.2022.132313>.

Transport Canada (2001) 'Canadian Airport Pavements Bearing Strength'. Transport Canada. Available at: <https://www.flightops.ca/docs/TP2162E.pdf>.

US Department of Transportation (2015) 'Climate change adaptation for Pavements', *Federal Highway Administration*, FHWA-HIF-15-015. Available at: <https://www.fhwa.dot.gov/pavement/sustainability/hif15015.pdf>.

Vanheule, H. *et al.* (2017) 'Summary of Climate Change and Airfield Pavements Survey', September. Available at: <http://www.captg.ca/docs/pdf/17Presentations/Tuesday%20PM/Summary%20of%20Climate%20Change%20and%20Airfield%20Pavements%20Survey.pdf>.

Vaníček, I. and Herza, J. (2021) 'Geotechnical engineering and alternative aggregates, tailings', *Journal of Physics: Conference Series*, 1928, p. 012002. Available at: <https://doi.org/10.1088/1742-6596/1928/1/012002>.

White, G. (2018) 'State of the art: Asphalt for airport pavement surfacing', *International journal of pavement research and technology*, 11(1), pp. 77–98.

Whiteley, L. (2006) *Pavement thickness design for airports in Canada*. Waterloo, ON.

APPENDIX A (SURVEY QUESTIONS)

- 1) Identify your current role at the airport. Identify all that apply:
 - Engineering
 - Operations and Maintenance
 - Executive Management
 - Planning
 - Risk Management
 - Accounting and Finance
 - Emergency Operations
 - Sustainability, Environment and Resilience
 - Other (please explain)

- 2) What are the runway pavement types at your airport? Select all that apply
 - Asphalt Concrete
 - Portland Cement Concrete
 - Composite
 - Gravel

- 3) What are the taxiway pavement types at your airport? Select all that apply
 - Asphalt Concrete
 - Portland Cement Concrete
 - Composite
 - Gravel

- 4) In general, how would you consider your airfield pavement condition to be in?
 - Excellent
 - Very good
 - Good
 - Fair
 - Poor
 - I don't know

To what extent do you think the following phenomenon associated with climate change are occurring?						
	Significantly increased	Slightly increased	Same	Slightly decreased	Significantly decreased	N/A
Precipitation Frequency						
Precipitation Intensity						
Minimum temperature						
Maximum Temperature						
No. of freeze thaw cycles						
Permafrost Depth						

- 5) In your opinion, indicate the current major climate change challenges your airport is facing related to airfield pavements. (Select all that apply)
- Precipitation frequency and intensity
 - Maximum Temperature
 - Minimum Temperature
 - Freeze/thaw cycles
 - Permafrost
 - Flooding
 - Wind intensity
 - Wind direction
- 6) In the past 10 years, have your maintenance, preservation and rehabilitation practices changed due to climate change?
- Yes
 - No
 - I don't know

7) How have these maintenance, preservation and rehabilitation practices changed?				
	Increased	Same	Decreased	I don't know
Drainage system upgrades				
Drainage system cleaning				
Rubber removal				
Runway sweeping/cleaning				
De-icing				
Snow removal				
Grooving				
Crack sealing				
Resurfacing				
Crossfall improvement				

8) To what extent do you agree or disagree with the following climate change consequences on airfield pavements?						
	Strongly agree	Agree	Neutral	Disagree	Strongly Disagree	N/A
Early cracking						
Crack severity						
Raveling						
Rutting						
Bleeding						
Shoving						
Settlement						
Pumping						
Soft spots						
Heaving						

9) Indicate the extent to which you consider the impacts of a changing climate in your current pavement management decisions.

- Always
- Mostly
- Sometimes
- Never
- I don't know

10) Has your airport implemented any mitigation strategies for preserving airfield pavements?

- Yes
 - No
 - I don't know
- 11) Has your airport assessed the risk of climate change on airfield pavements or the vulnerability of pavements when exposed to extreme weather?
- Yes
 - No
 - I don't know
- 12) Do you plan to introduce tools or research activities for assessing the risk of climate change on airfield pavements?
- In short term
 - In long term
 - Do not plan to
 - I don't know
- 13) Identify the tools and techniques your airport is currently using to respond to the Impacts of a changing climate on airfield pavements. Select all that apply.
- Increase the magnitude of design parameters or safety factors
 - Consider replacing existing practices with entirely new solutions
 - Review and adopt best practices
 - Develop contingency plans for infrastructure failure
 - Perform risk assessment, identify infrastructure at risk, and retrofit priority assets.
 - Consider increased deterioration rates in design and maintenance plans
 - Consider different climate change scenarios or models for design, maintenance or planning
 - Design infrastructure that can be modified over time as the impacts of the changing climate occur
 - I don't know

14) Indicate, in terms of agreement/disagreement, the main barriers to considering climate change risk and adaptation in your daily activity for pavements.					
	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Insufficient funds					
Lack of related research					
Lack of technology and design alternatives					
Lack of planning guidance					
Lack of best practices					
Lack of adequate climate data					
Lack of adequate climate data analysis					
Lack of information and resources					
Lack of support from clients/owners/management					
Skeptical attitude towards climate change					
Lack of requirements in codes, standards, or policy					
Cost cannot be justified					
Lack of available time					
A changing climate has no effect on my practice					

15) How can your airport best adapt to climate change risk for airfield pavements?

Select all that apply.

- Funding
- Research
- Technology and design
- Climate projections
- Risk assessment
- Adaptation/mitigation planning
- I don't know

16) Have your airfield pavements experienced flood events in the last 10 years?

- Yes
- No
- I don't know

17) Could you briefly describe the impact on your pavement?

18) How you think your airfield pavements are at risk from flooding in the next 30 years?

- Strong agree
- Agree
- Neutral
- Disagree
- Strongly disagree

19) To what extent do you agree/disagree that you should buy flooding risk coverage for your airfield pavements and other infrastructure?

- Strongly agree
- Agree
- Neutral
- Disagree
- Strongly disagree

20) Have you experienced an increase in sustained high temperatures at your airport in the last 10 years?

- Yes
- No
- I don't know

21) Could you briefly explain the effects that high temperature has had on operations and/or maintenance for pavements at your airports?

22) Have you experienced an increase in sustained low temperatures at your airport in the last 10 years?

- Yes
- No
- I don't know

23) Could you briefly explain the effects that low temperature has had on operations and/or maintenance for pavements at your airports?

24) What changes are you considering making, if any, to your pavements as a result of changes to high and/or low temperatures? Select all that apply.

- Asphalt concrete layer thickness
- Asphalt concrete binder type
- Portland cement concrete layer thickness
- Portland cement concrete admixtures
- Base type
- Base thickness
- Sub-base type
- Sub-base thickness
- Sub-base treatments
- I don't know

25) Is your airport built on permafrost?

- Yes
- No
- Formerly
- I am not sure

26) Have you noticed an increase in permafrost active layer depth?

- Yes
- No
- I don't know

27) How do you think that frequency and/or severity of permafrost-related damage to your pavements will increase?

- Strongly agree
- Agree
- Neutral
- Disagree
- Strongly disagree

28) How do you try to fix permafrost-related damage to your pavements?

29) Have you noticed an increase in ice formation on your pavement surfaces?

- Yes
- No
- I don't know

30) Do you have any queries, comments or concerns?

Curriculum Vitae

Candidate's full name: Rafeh Nasim

Universities attended (with dates and degrees obtained):

- Bachelor of Science: Civil Engineering August 2015 – June 2019

Foundation and Association of Sciences & Technology (Lahore, Pakistan)

Publications: N/A

Conference Presentations: N/A