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# ON TRACK TO CLIMATE RESILIENCE? INSIGHTS FROM JAPANESE RAILWAYS

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**Abstract**: Japan has a long history of managing natural hazards due to its geography and geology. Simultaneously, it is known as a country with a railway system that is highly punctual, reliable, and safe. This research uses an exploratory approach to review climate change adaptation and disaster risk reduction practices in the Greater Tokyo Area. Unstructured interviews with various stakeholders and a literature review discuss how the climate is changing in Japan, what strategies are used amongst railway organisations to manage meteorological hazards, and how railway organisation acknowledge climate change adaptation alongside disaster risk reduction. Results indicate that disaster risk reduction practices still dominate within the railway sector however, more efforts of climate change adaptation set forth by the government may shift practices.

**Keywords**: Climate resilience; Climate adaptation; Disaster risk reduction; Railway

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## 1. INTRODUCTION

Railways play an important role in mitigating the negative effects of climate change by providing a low-carbon and energy-efficient mode of transportation. However, the global climate is already changing, bringing increases in the severity and frequency of extreme weather events (IPCC, 2021). This leads to adverse impacts on railways, including damage to infrastructure, delays, and increased safety concerns (Ochsner et al., 2024). To encourage a greater shift in rail usage, railways must be safe, efficient, and reliable. The shifts in and uncertainties regarding climate change and extreme weather events thus pose challenges to the operation and maintenance of railways.

Literature to date mainly focuses on the impacts of extreme weather and climate change on railway

operations (Greenham et al., 2020) and/or infrastructure (Ochsner et al., 2024). However, less research is focused on decision-making and how to ensure railway networks are more climate resilient. In addition, there is little academic literature focused on climate change adaptation (CCA) and disaster risk reduction (DRR) practices specific to the railway sector in the Japanese context. Japan has a long history of managing natural hazards, both meteorological and not. This has led to more DRR practices compared to other countries for whom dealing with natural hazards is a relatively new challenge and therefore is framed as CCA.

This study follows an exploratory approach with the aim to critically review CCA and DRR practices across Japanese railway networks. This approach allows to explore themes within the topic and emerging future research directions or policy developments. Specifically, this research aims to answer three research questions: (1) How is the climate changing in Japan? (2) What are the strategies used among Japanese railway organisations to manage meteorological hazards? And (3) Have Japanese railway organisations acknowledged CCA alongside DRR, and have they distinguished a difference between them? To answer these research questions, unstructured interviews were held with four organisations pertaining to railway operations and research. These interviews focused on topics related to CCA issues in Japan, DRR, and railway research. In addition, to support the unstructured interviews, grey literature published by various Japanese railway companies and government ministries was reviewed.

In this study, we define meteorological hazards as any natural hazards or disasters driven by weather and/or climate such as typhoons, heavy rainfall, or flooding, thus excluding natural hazards such as earthquakes, tsunamis, and volcanic eruptions. In addition, we define CCA as adjusting to climate change through planned or spontaneous interventions addressing its impacts on society, environment, and economy; while DRR focuses on minimising the effects of natural hazards by reducing vulnerability and acknowledging that each disaster can weaken future coping capacity (Schipper, 2009).

## 2. THE CASE OF TOKYO, JAPAN

Greater Tokyo is one of the most densely populated urban areas in the world, with a population of more than 30 million people (Schimkowsky, 2024). In addition, the railway network in Tokyo is one of the most extensive in the country with over 2,500 km of track, and approximately 15 billion passenger journeys are made annually (Schimkowsky, 2024), making Greater Tokyo one of the busiest railway networks in the world. A key feature of the Japanese railway system that differs to many other railway networks around the world is that Japanese passenger railways are vertically integrated as an outcome of the Japanese National Railways (JNR) reform in 1987. As a result, a majority of railway companies around Japan are private and therefore responsible for their own infrastructure, operation, and maintenance (Kurosaki, 2018). JNR was split into six passenger rail companies and one nationwide freight operator (JR Freight), of which JR Freight must apply for access to the tracks owned by the passenger railway companies (Kurosaki, 2018).

Japan operates some of the most reliable and punctual railway services in the world. Simultaneously, Japan is located along the Pacific “Ring of Fire” and is frequently exposed to many natural disasters related to tectonic activity such earthquakes, volcanic activity, and tsunamis. Tokyo, and many other regions in Japan are located in the Cfa (humid subtropical) climate zone (Beck et al., 2018). This humid subtropical climate leads to Japan experiencing several meteorological hazards such as typhoons and heatwaves, which can lead to flooding, landslides, and damage to infrastructure. Previous research in Japan has focused on reducing the vulnerability of railway infrastructure and operations to various climate-related risks such as flooding (Xu et al., 2024), strong winds (JR East, 2014), and heat (Saito et

al., 2018). Although Japanese railway systems can broadly withstand or respond well to meteorological hazards and natural disasters compared to other countries around the world, there remains the added challenge of climate change increasing the intensity and severity of meteorological hazards (Suzuki, 2013). For instance, between 1980 and 2020 Japan has experienced an almost 1.7 times increase in the frequency of short-term rainfall and temperature increase (Xu et al., 2024). Majority of the railway networks across Japan still follow the path of the network built during the Meiji (1868-1912) and Taisho (1912-1926) periods, when civil engineering technology was developing. However, these lines are vulnerable as they are primarily constructed along rivers, the sea, and mountainsides (Xu et al., 2024), particularly in the case of Tokyo where the urban area is developed on a large alluvial plain.

In November 2015, the Cabinet of Japan approved its first Climate Change Adaptation Plan, which was updated in 2021 (Government of Japan, 2021). The plan recognises the growing need for society to adapt to the impacts of climate change, highlighting the transportation sector as particularly vulnerable (Government of Japan, 2021). The Climate Change Adaptation Act came into effect in December 2018, which "*expects private companies to strive to adapt to climate change in line with their business activities in order to smoothly carry out their own business activities and corporate with the measures of the national and local governments on climate change adaptation*" (Ministry of Environment, 2022). In response, the Ministry of Environment released a Climate Change Adaptation Guide for Private Companies (Ministry of Environment, 2022).

# 3. METHOD

## 3.1. Literature Review

First, grey literature was collected and reviewed on the status of CCA and DRR of railways in Japan. The literature was collected by searching news articles, government, and railway company websites. The grey literature collected included annual reports, news articles, national adaptation plans and climate change assessments, and operational guidelines for different natural hazards. These were included as grey literature can help address stakeholder concerns (Mahood et al., 2014). Additionally, since little academic research exists regarding CCA in the railway sector in Japan, grey literature assisted in understanding the current strategies to prepare and respond to meteorological hazards and how railway companies consider these issues. Some of the literature reviewed was also provided by the interviewees.

## 3.2. Unstructured Interviews

The interviews were conducted between July and August 2024 and lasted around 60 minutes each. Four interviews were conducted with organisations pertaining to railway operations and research. As many railway companies in Japan are privatised, the names of the railway companies are not disclosed. To keep consistency, all organisations are anonymised. The interviews helped to support the literature by eliciting expert knowledge and experience. In this study, the railway companies interviewed operate in the Greater Tokyo region. However, the results can be related to greater Japan wide context.

Unstructured interviews allow for a more flexible discussion and to delve more deeply into a social situation (Myers & Newman, 2007). The interviewees were selected through the authors' contacts, and expertise ranged from CCA, hydrology, risk mitigation, and transportation planning both from a railway perspective and more broadly. During the interviews, notes were taken for later analysis. Interviewees also provided academic or grey literature or further information, which was included in the literature review. After reviewing the literature and conducting the interviews, all material was coded into themes according to the research questions.

# 4. RESULTS

## 4.1. How the climate is changing in Japan

Japan is experiencing the effects of climate change, with rising average temperatures and an increase in heavy rainfall occurring more frequently in recent years (Government of Japan, 2021). The Japan Meteorological Agency (2024) has estimated that the annual mean surface temperature in Japan has risen at a rate of 1.35°C per century and is expected to continue increasing. The Assessment Report on Climate Change Impacts in Japan released by the Ministry of Environment (2020) estimated the following:

- The increase in mean annual temperature at the national level is expected to be 1.4°C or 4.5°C under a low emission scenario (RCP 2.6) and high emission scenario (RCP 8.5) respectively, which is 1.2 to 1.4 times the global average rate of warming.
- The annual number of days with a maximum temperature over 35°C is expected to continue increasing while the annual number of days with a minimum temperature below 0°C is expected to decrease.
- The annual frequency of precipitation events reaching 50 mm and 80 mm or more per hour are increasing. The number of dry days with no precipitation in expected to also increase, but the number of short, torrential rainfall events are expected to increase. An increase in the frequency and severity of typhoons hitting Japan is also expected to increase.

The assessment report has also included the significance and urgency of action against climate action for a number of different sectors. The transportation sector is listed as having high significant impacts and urgency. Transportation in Japan is deemed as a critical infrastructure and the impacts of climate change can have significant impacts on disruptions to the network. Railway infrastructure also plays a vital role during natural disasters to transport relief goods and people. During the Great East Japan Earthquake and Tsunami in 2011, the damage to the railway greatly prohibited this function (Okumura & Kim, 2018). All interviewees stated that the increase in localised torrential rainfall (known as "guerrilla heavy rainfall" in Japan (Suzuki, 2018)) is one of the biggest challenges associated with a changing climate on their railway networks.

## 4.2. Measures against meteorological hazards and natural disasters

### 4.2.1 Weather monitoring

The majority of railway companies operating in the Greater Tokyo Area use sensors to actively monitor the weather conditions along their networks. These include rainfall gauges, wind anemometers, track thermometers, river water level gauges, and snow depth gauges. Additionally, while not explicitly related to climate change, seismometers are used to monitor earthquake activity. If railway companies do not have all sensors to monitor all types of weather and seismic activity they receive weather forecasting information from the Japan Meteorological Agency. Each company has different thresholds for how they operate their network. For example, a certain wind speed will lead to speed restrictions or even suspended services (Keikyu, n.d.). Often there are lower thresholds for bridges or other more vulnerable areas. Some larger railway companies use a radar rainfall system, which can more accurately assess landslide risk by monitoring how the amount of water in soil changes over time. Interviewee B mentioned that the suspension of services due to heavy rainfall has increased and is becoming more common in recent years. In addition, they aim to give their customers 48 hours' notice in the event of a planned suspension to allow their customers to make alternative arrangements, a common practice among railway companies in Greater Tokyo.

### 4.2.2 Precipitation

Due to the strong history of natural disasters in Japan many risks are effectively engineered out. For example, fences are used to protect slopes and embankments from landslides. Many underground railway networks feature flood gates and doors to prevent water from entering stations and tunnels. After Typhoon 19 in 2019 flooded the Nagano Train Depot, 120 Shinkansen rolling stock wagons were decommissioned, resulting in increased focus on rolling stock evacuation (Okumura & Moriai, 2024). Traditionally, most railway companies prioritise the safety of passengers. However, increasing heavy rainfall and changing typhoon patterns has increased considerations to include protecting infrastructure assets such as rolling stock. In 2017, the Task Force on Climate-related Financial Disclosures (TCFD) released a framework for companies internationally to disclose climate-related risks and opportunities, including those associated with transitioning to a low-carbon economy and those related to the physical effects of climate change (Ministry of Land, Infrastructure, Transport and Tourism, 2023). In Japan, 94% of companies listed on the Tokyo Stock Exchange have been assessing physical risks related to water-related hazards (Ministry of Land, Infrastructure, Transport and Tourism, 2023).

### 4.2.3 Wind, Snow, and High Temperatures

Interviewee A has stated that they have increased the amount of wind anemometers to monitor windspeed along their network as well as the amount of windbreak fences. Interviewee B mentioned their efforts in maintaining vegetation along their railway network to prevent debris from falling onto their tracks or other important assets.

Regarding snowfall, several railway companies use snow ploughs to remove snow from their tracks. In addition, many switches have heaters or devices that blow air to blast ice or snow that block switches. Finally, regarding high temperatures, Interviewee C mentioned the use of sprinklers to cool down switches and rail temperature. Greater Tokyo is primarily focused on preventing disasters related to heavy rainfall, compared to snowfall, extreme low and extreme high temperatures.

## 4.3. History of Disaster Risk Reduction in Civil Engineering and Lessons from the Past

### 4.3.1 Lessons from the past:

Given the geography and geology of Japan, natural hazards and disasters are a common part of everyday life throughout history. DRR measures to protect the lives of people have been invested in for a long time, and the ones applied to the safety of railways has been no exception (Interviewee A). Due to the mountainous topography, when railway infrastructure was planned and developed, most was built on flatter land along rivers and the sea. This means the railway can be particularly vulnerable to flood events. The number of natural hazards impacting the railway has greatly reduced over the last 60 years. Historically, JNR experienced impacts of almost 10,000 natural hazards per year (Suzuki, 2018). The number of impacts was halved in the 1980s as a result of physical countermeasures to prevent damage from natural hazards (excluding earthquakes), reducing to about a few hundred per year (Suzuki, 2018). However, due to climate change, this decline in natural hazards begins to cease (Suzuki, 2018). The engineering research approach in Japan has been empirical, based on learning from past experiences, rather than using a more theoretical approach.

### 4.3.2 Safety and customer service as a priority:

Safety and customer service are a top priority for railway companies operating in the Greater Tokyo Area. This most likely stems from majority of the railway companies being privately owned, meaning

that they own all infrastructure in their network and therefore are also responsible for protecting their assets from natural hazards to protect their profits. As previously mentioned, there is an emphasis on providing information to help assist passengers to plan their journeys. Many of the interviewees mentioned how suspended operations is the easiest way to save people's lives. All interviewees discussed the challenges due to the increasing amount of localised torrential rainfall, and the increase in speed restrictions and planned suspensions due to this. However, due to Covid-19 there has been a shift in office working practices. Interviewee D mentioned how a few decades ago, people were expected to go to work despite the weather, and normal operation was important. However, the shift in people working remotely has allowed more flexibility in planned suspensions. It was also mentioned that planned service suspensions were first introduced in 2014, and since have become more accepted in Japan.

Finally, there is a strong presence of research institutions and universities across Japan to research management of natural disasters and how to protect people's lives. This is not exclusive to the railway sector, but more generally research in natural hazard management is strong in Japan due to the history of natural disaster in Japan.

### 4.3.3 Towards climate change adaptation?

CCA is a fairly new term and concept according to most interviewees. Interviewee D mentioned that the general public is used to meteorological and other natural hazards and do not have a general sense of climate change. However, some effort by the government has progressed to highlight the potential impacts of climate change.

Within railway companies, many of the interviewees mentioned that climate adaptation is a less familiar concept. In addition, Interviewee C mentioned that they feel they are prepared to handle natural disasters currently, but potentially need to reconsider and adapt in the future due to climate change. Interviewee D mentioned that the majority of railway companies in Japan are private businesses who think more in the short-term. However, since the introduction of the Climate Change Adaptation Act in 2018, there are more long-term considerations being put forth by the government. Therefore, there is a potential for the mindset to shift in order to consider more long-term impacts of climate change.

## 4.4. Challenges in Japan

Despite many railway companies in Japan having a history of dealing with natural disasters and stating that they are equipped to handle the current situation, some challenges remain. Since most railway companies are privately owned this means they rely on profits from ridership to successfully run their business. This is particularly a challenge in rural areas of Japan where profits are lower, infrastructure is older, and investments to protect infrastructure from natural hazards is a lower priority compared to urban areas like Tokyo. In general, smaller railway operators in rural areas of Japan often receive less investments (JSCE, 2021). The Act on Improvement of Railroads and Rail Tracks is a major act about railway construction and maintenance, which states the railway operator is responsible for restoring the railway after a natural disaster (Yoshioka & Kamiko, 2021). This indicates that sometimes a railway company is forced to close a line if they cannot afford the restoration costs. Although there are some special circumstances to receive government support (Yoshioka & Kamiko, 2021), this remains a challenge and could be increase in light of climate change and a rapidly declining population in Japan.

The state of infrastructure is another major challenge in Japan. Much of the infrastructure was built prior to the present-day knowledge of climate change. Additionally, Japan faces issues with rapidly aging infrastructure. The infrastructure always deteriorates but the external forces, such as heavy rainfall, keep

increasing in frequency and severity. This leads to challenges with maintenance and how to adapt to changing design standards.

All interviewees identified an increase in speed restrictions and operation suspensions due to hazards such as localised torrential rainfall and typhoons. Localised torrential rainfall is more challenging to forecast, and many companies are working towards testing new technologies to forecast and increase the safety of operations. Additionally, the increase of heavy rainfall has led to an increase in speed restrictions and planned suspensions which leads to challenges in profit when railway companies cannot operate according to plan.

# 5. CONCLUDING DISCUSSION

This study aimed to review CCA and DRR practices across Japanese railway networks in Greater Tokyo. Due to climate change, Japan is expected to experience an increase in temperature and precipitation. Increasing localised torrential rainfall events in particular pose many operational and infrastructural challenges across railway networks in Greater Tokyo. There are various structural measures used by railway companies to reduce the risk of meteorological hazards as discussed in this paper.

DRR is deeply rooted in the organisational culture of infrastructure management in Japan, including in the railway sector. The history of natural disasters has led to efficient engineering research and practice to engineer out natural disasters from impacting railways, learning from past events to improve infrastructure in the future. This stems from the frequency of natural disasters Japan has experienced since urbanisation begun. Railway companies tend to prioritise earthquakes over meteorological hazards. This is most likely because earthquakes are always guaranteed to occur and are difficult to predict. Compared to meteorological hazards, there is uncertainty connected to climate change. However, due to the knowledge Japan has with dealing with natural hazards, the current DRR practices could underpin future CCA. DRR today tends to consider a more short-term perspective while CCA considers a more long-term perspective and how to handle the uncertainties associated with climate change. In addition, CCA could also be used to equip more compound events associated with climate change that traditional DRR may not consider. Despite the history of natural hazards striking the country, Japan is still experiencing the effects of climate change. The introduction of CCA into government acts may lead to a shift towards more CCA strategies and long-term perspectives. Still, DRR provides many lessons how to adapt to climate change in the future.

This research provides a broad overview of CCA in the railway sector in the Greater Tokyo Area. Future research directions may focus on a deeper investigation into the posed research questions. Particularly in regard to furthering understanding a CCA DRR nexus. As Japan is a country with a strong history of managing natural hazards, the political and financial incentives may lag countries in, for example Europe, who are new to managing extreme weather and therefore mobilise climate adaptation through policy and finances. Additionally, future research directions may include more comparison of climate change perceptions and impacts across Japan to understand the variation of challenges throughout the country. A greater comparison of CCA perceptions and strategies across Japan, especially in low profit areas could lead to insights on how Japanese railways consider climate change in their future planning.

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