Assessing the Climate-Related Disaster Resilience of Urban Transport Systems in Asian Cities

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ABSTRACT

Climate change is unquestionably associated with an increase in acute and chronic disasters such as flooding, sea level rise, and cyclones. Urban transport, where ageing infrastructure serves as the economic backbone to dense populations, is exceptionally vulnerable to these disasters. Throughout Asia, where the incidence of the aforementioned disasters is particularly alarming, cities have utilized innovative strategies to create resilience with their most salient climate events – most notably floods.

This paper, using a "focused comparison" methodology, examines the efforts of three Asian cities: Bangkok, Dhaka, and Manila, to reveal best practices for creating climate-related disaster resilience (CDR) in transport systems. To conduct the assessment, this paper develops the Climate-related Disaster Resilience Framework for Transport (CDRFT), a novel tool that allows researchers to assess the CDR of transport systems in cities globally. This paper illustrates that capital-intensive solutions such as building physical resilience is paramount for creating a resilient transport system, while lower-cost efforts, which improve the social and natural dimensions of transport resilience, are nonetheless still effective. The insights gained from the CDRFT can ultimately be used to develop CDR for transport globally, while contributing towards the achievement of several sustainable development goals.

Key Words: Climate Disaster Resilience, Sustainable Transport, Asian Cities, Floods

1. INTRODUCTION

As atmospheric temperatures rise due to the unprecedented increase in anthropogenic carbon emissions, so too does the incidence of natural disasters. Rising temperatures can be attributed to an intensification of flooding (tidal, glacial, or rainfall) and coastal erosion, and increases the severity of droughts, tropical cyclones, and wildfires (IPCC, 2014). Of the 10 countries globally with the highest disaster risk, seven are in the Asia-Pacific region, where 5.2 billion people were affected by natural disasters from 1989 – 2018 (ADB, 2020).

Asia suffers disproportionately from natural disasters, accounting for 89% of global disaster-related asset losses (OECD, 2018). This hinders economic growth, feeds poverty, and discourages development. Cities are particularly vulnerable to the risks associated with these disasters as they are often overcrowded with aging infrastructure and complex governance. Thus, for climate-related disasters, resilience, defined by the IPCC (2014) as

> *the capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation,*

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is key to ensuring economic prosperity and enhanced societal wellbeing. Of the dimensions that build urban climate-related disaster resilience (hereinafter CDR), transport, the focus of this paper, is perhaps the most critical. Transport is a truly cross cutting sector in terms of development: it is the backbone of supply chains and trade, promotes human productivity via mobility, and can aid in times of crisis – providing connectivity to crucial services (GFDRR, 2019). It is also eminently at risk from climate change-related disasters. Sea level rise and tidal floods are problematic for ports and other coastal transport infrastructure. Tropical cyclones and floods can inundate subways and roads, damage bridges, and disrupt mass rapid transit and logistics (Chakwizira, 2019). The need for urban transport resilience is therefore vital for achieving overall urban resilience.

A foundational step towards creating resilience in the transport sector is assessing the current state of resilience. An entry-level resilience assessment is beneficial to both the city in question and other cities aspiring to improve resilience, as it concisely highlights successful and unsuccessful resilience building practices. For general urban resilience, both the international community and academia have sought to create workable assessment indices. The Disaster Resilience Scorecard for Cities, for example, is a qualitative tool designed to measure urban resilience through a 1-2-day consultation with city officials. The Climate Disaster Risk Index (CDRI), developed by Kyoto University, utilizes quantitative indicators and five dimensions to capture a city's overall resilience (World Bank 2015). Yet, for the transport sector, tools for assessing urban CDR are limited (Koetse and Rietvield, 2012). To fill that gap, this paper makes a novel contribution by proposing a qualitative index entitled the Climate Disaster Resilience Framework for Transport (CDRFT), which serves two main purposes. First, to provide researchers, practitioners, professionals and policy makers with an entry-level tool to measure transport sector resiliency across cities, and second, to allow policymakers and planners to gain straightforward insights on the efforts similar cities are making to adapt their transport systems for climate change-related natural disasters.

This paper contains five chapters, including this introduction. The second chapter reviews existing urban resiliency toolkits, international disaster risk mitigation guidelines, as well as current literature regarding adaptation actions for the transport sector specifically. The third chapter develops the CDRFT and outlines the methodology used to so. The fourth chapter applies the CDRFT checklist to Bangkok, Dhaka, and Manila, and discusses the implications of the results. The fifth and final chapter contemplates the usefulness of the insights learned from this analysis, suggesting the practical utility of the lessons learned beyond the cities studied.

2. LITERATURE REVIEW

Though climate change increases the severity of droughts, wildfires, and landslides, this paper focuses on flooding as it is the climate change-related disaster which poses the largest global risk to urban transport. Floods increase service disruptions, damage infrastructure, and exacerbate congestion, causing billions of dollars in damage annually (Ebinger and Vandycke, 2015). Though there is no specific mechanism for assessing the resilience of an urban area to flooding, the following section reviews relevant international initiatives for overall CDR.

2.1 Climate Resilience and Sustainable Development Goals

The Sendai Framework for Disaster Risk Reduction (hereafter SFDRR) is to date the most comprehensive international accord on disaster risk reduction, and specifically emphasizes the need for resilience (United Nations, 2015b, p. 15). Though the SFDRR encompasses all disasters, it pays attention to climate change, mentioning it 15 times in its 50 paragraphs (Ibid). Further, the SFDRR is fundamentally linked to the sustainable development goals. As the SDGs offer a holistic approach to development, the attainment of all 17 goals is hindered by ineffective responses to natural disasters. Transport is a cross-cutting sector affecting many of the domains covered by the goals. As a result, there is an inherent link between many aspects of the CDRFT and a city working towards achieving the SDGs. A sample of several relevant goals and targets can be seen in **Table 1**, below.

Table 1: Transport CDR and the SDGs:

Goal	Relevant Target	Link to Transport
1 No Poverty	1.5 Build resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events.	Many vulnerable populations lack access to climate resilient transport, a fact which exacerbates poverty following a disaster.
9. Industry, Innovation, and Infrastructure	9.1 Develop resilient infrastructure to support economic development and human well-being, with a focus on affordable and equitable access to all.	Transport is the backbone of economic development. Ensuring its continuity through disasters will improve overall socioeconomic development.
11. Sustainable Cities and Communities	11.B Increase the number of cities adopting and implementing integrated policies and plans towards mitigation and adaptation to climate change, resilience to disasters, and develop holistic disaster risk management at all levels.	Transport is foundational to city planning and should be included in all mitigation and adaptation plans.
	11.5 Significantly reduce the number of deaths, the number of people affected, and the direct economic losses relative to GDP caused by disasters, including water-related disasters.	Resilient transport can provide citizens with safe means of transport, saving lives. As a capital-intensive sector, planning for disasters will reduce losses directly while resilient systems can assist a city in reducing overall productivity loss following an event.
13. Climate Action	13.1 Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries.	Transport is foundational to national planning and is notably affected by natural disasters.
	13.3 Improve education, awareness raising and human and institutional capacity on climate change, mitigation, adaptation, impact reduction and early warning.	Transport is a large source of CO2 and it is therefore imperative that it is included in capacity building efforts with regards to climate change.

Source: Adapted from United Nations (United Nations, 2015a)

2.1.1 Existing Assessment Tools

To accompany the SFDRR, the United Nations Office for Disaster Risk Reduction developed a resilience assessment toolkit entitled the Disaster Resilience Scorecard for Cities (hereinafter Scorecard) (UNDRR, 2017). The Scorecard creates "Ten Essentials" which can assist cities in becoming resilient per the SFDRR. The Scorecard has two versions. The Preliminary Assessment, consisting of 47 qualitative questions / indicators, and the Detailed Assessment, with 117. The Preliminary Assessment formulates indicators by creating detailed questions answered on a scale from zero, indicating no resilience, to three, the highest level. The Scorecard employs an optimal number of questions to capture all relevant aspects of the Essential. The total number of questions depends on the breadth of the Essential itself. This form of assessment will be incorporated into the CDRFT as it does not rely heavily on expert consultation nor quantitative measurements.

Along with the Scorecard, another widely used assessment method is the Climate Disaster Resilience Index (CDRI), developed by Kyoto University (Shaw, 2009). Though more complex than the Scorecard, it is also more inherently holistic, which is of use to the development of the CDRFT. It considers five dimensions: Physical, Social, Economic, Institutional, and Natural. Each dimension has five parameters, which in turn have five variables /indicators (Ibid). The final score for each dimension is the average of the parameter score. Operationalizing CDR into the above five components emphasizes the holistic nature of the transport sector and climate change altogether.

2.2 Operationalizing Climate-related Disaster Resilience for Urban Transport

There is no holistic, qualitative tool for assessing the resilience of an urban transport system to climate-related disasters. However, the Scorecard and the CDRI are two examples which can be used as templates. Urban transport resilience is a complex, multi-faceted concept, yet it too can be distilled into the five dimensions used by the CDRI. The following section describes urban transport resilience per the five dimension which forms the basis of the framework, presented in final tabular form in Table 3. Suggested actions for each dimension score, based on insights from the discussion below, can be found in Table 4.

2.2.1 Physical Dimension

Physically, the transport sector needs to be resilient on two levels: its infrastructure and its services. Per Ebinger and Vandycke (2015), resilient infrastructure means designing or retrofitting to deal with shocks. For example, subways stations in flood-prone areas should incorporate flood barriers, and future infrastructure should be located in less vulnerable areas (GFDRR, 2018, p. 5).

With regards to services, systems should incorporate redundancy to lessen the service loss from all scenarios. In dense, disaster-prone cities, this means investing in a multi-modal transport system, which includes public transit and active mobility. When multiple modes of transport are present, the system can rely an alternative mode should a given mode be damaged in a disaster, increasing the probability of service continuity and therefore resilience (Zakat, 2015, p. 35).

2.2.2 Social Dimension

As transport systems should provide equal services to all individuals, so should transport CDR (Zakat, 2015, p. 30). Community engagement on CDR will ensure that risks are mitigation for the entire population, ultimately saving more lives (GFDRR, 2018, p. 9). Should communities be included into overall municipal CDR, they can develop local initiatives which contribute to the preparedness of a region as a whole (World Bank, 2015). Yet, community resilience will be stunted if awareness efforts on behalf of the municipality are insufficient. The social dimension, though less applicable to transport directly, contributes greatly to a city's overall resiliency regardless. For example, should a community be included in CDR efforts, individuals will have greater awareness and will therefore possess sounder decision-making abilities in a disaster.

2.2.3 Economic Dimension

Funding is foundational for any CDR effort. For example, budgeting for contingency following an emergency is crucial for ensuring resilience. Yet, contingency is mainly concerned with reaction and not prevention. Ideally, municipalities should have climate plans, which allocate funding for CDR efforts specifically related to climate change, in addition to disaster contingency funds (Zakat, 2015, p. 17). Should a city have a comprehensive climate change funding action plan and contingency budgeting without including the transport sector specifically, the city will attain a score of 1, as overall financial resiliency would likely be reflected in the transport sector (Ebinger and Vandycke, 2015, p. 20).

2.2.4 Institutional Dimension

Successful transport CDR depends on an enabling environment for both pre- and post – disaster efforts. A cornerstone of such an enabling environment are policies and plans that are designed to reduce the impact of current and future climate risks on transport. At its most comprehensive, this means city CDR plans that acknowledge climate risk and clearly state the role and resiliency actions for the transport sector, both prior to and after a disaster (Ebinger and Vandycke, 2015, p. 17). An effective plan clarifies transport governance in case of an emergency, delegating a single point of contact for all stakeholders (Ibid). In terms of post-disaster recovery, transport lifelines, essential to regional and national mobility, should be clearly identified and prioritized (Zakat, 2015, p. 11). Finally, a repair and reconstruction scheme should exist with the aims of returning service as fast as possible while Building Back Better (GFDRR, 2018, p. 3).

Understanding the nature of the hazards facing a city will allow for optimal planning. Thus, the nature of hazards a city can expect to face in the future need to be understood, which involves knowledge of the effect climate change will have on the disasters a city has historically faced. For this to be done most effectively, a city should utilize data and modern technology to provide up-to-date information on the hazard probability and city infrastructure vulnerability (Zakat, 2015).

2.2.5 Natural Dimension

Natural ecosystems have values and benefits that can assist in improving urban resilience (UNDRR, 2017, p. 27). With regards to transport, green and blue infrastructure (GBI) such as natural drainage systems alongside roads or canal rehabilitation are methods of increasing natural resiliency. Often, the effects of climate change on cities are exacerbated by the degradation of local ecosystems such as wetlands, greenspace, and canal systems. With regards to floods, these systems provide natural drainage which, when eliminated, reduces the ability of an urban area to effectively remove water during intense rainfall or flooding (Zakat et al, 2015). GBI can assist in rehabilitating these natural mechanisms which can aid in flood prevention, while improving overall transport quality (World Bank, 2010, p. 89).

3. METHOD AND DATA

3.1 Methodology

The CDRFT blends both the format of the CDRI and the Scorecard. Therefore, it contains five dimensions – physical, social, economic, institutional, and natural, each described by qualitative questions as shown in Table 3. More than one question will be needed to capture the breadth of certain dimensions. However, for a simplified aggregation per the CDRI, all dimensions should have the same weight. Therefore, the dimension score will be described by the equation below where *Q* is the question score and *i* is the number questions per dimension.

$$Dimension\ \ Score\ (DS)\frac{\sum_{i=1}^{n} Q_1}{\sum_{i=1}^{n} w_1} = \frac{Q_i + Q_i + \cdots}{Maximum\ score * i}$$

Further, an aggregate score will be presented out of a total score of 100, per the equation below.

$$Aggregate\ = \frac{D_1 + D_2 + D_3 + D_4 + D_5}{Maximum\ total\ score} * 10$$

3.2 Data Collection and Analysis

The data used for this framework is qualitative by nature and will vary depending on the city. Four main categories of documents should be used, illustrated in the table below. These documents will span a temporal period pre-dating the assessment, which should be indicated in future assessments, and most-recent data should be used.

Table 2: Data sources

Document	Dimensions	Notes
Adaptation Strategy	Physical	National or municipal.
Disaster Risk Management Plans	Physical, Institutional, Economic	National or municipal.
Third-party Assessment	All	Including assessments by IGOs, Development Agencies, and Academia
Urban Development Plans	Natural, Physical	Municipal

Each dimension is defined by one or two qualitative questions, as seen in Table 3, below. The possible scores, 0 – 3, reflect varying levels of sufficiency with regards to the urban transport resilience of the dimension under consideration. To employ this framework effectively, the data collection and analysis process is as follows. To start, one must gather all the relevant documents for the municipality as described in table 2, above. If these documents are only available at the national level, the governance structure should be examined to ensure the national government has the power to enact effectively any prescribed initiatives or policies. Next, the user should attempt to answer each of the seven question by analyzing aforementioned documents. Third-party assessments can be particularly useful should the city lack cohesive plans. Should there be a lack of data with regards to CDR efforts for the transport sector specifically, the user can use their best judgement to ascertain whether other resilience efforts contribute to transport resilience. Ultimately, the value of the CDRFT lies in its ability to present key questions concisely across five comprehensive dimensions in order to describe a city's transport resilience.

3.3 Case Selection

This paper uses a "focused comparison" methodology, using the earlier developed CDRFT to ask the same questions for Bangkok, Dhaka, and Manila in order to gain valuable lessons. Although there is an inherent subjectivity to the framework, it nonetheless offers a baseline measurement of transport CDR. For the purposes of this paper, this is used to highlight innovative technologies, policies, and practices that each city has used to mitigate the risks associated with climate change-related disasters on transport. Bangkok, Dhaka, and Manila have been chosen for three specific reasons. First, all three are megacities, whereby the metropolitan regions have populations of over 10 million inhabitants. Similarities in the scale of efforts based on population size will lead to an easier comparison. Second, all three cities are significantly impacted by the same climate-changed induced natural disaster – flooding. While Bangkok is not exposed to tropical cyclones like Dhaka or Manila, each city faces widespread annual flooding which will allow for a more streamlined comparison with regards to the checklist. Finally, Bangkok, Dhaka, and Manila have distinct transport systems based on modal distribution, governance, and infrastructure. This will decrease the potential for overlap between resilience initiatives and will create unique findings from each city.

3.4 Relation between Dimensions, Scores

The dimensions, though collectively representing the holistic approach needed to assess an urban transport system's disaster resilience, are independent of one another for the purposes of this framework. The CDRFT is meant to be deployed as a high-level assessment tool for researchers and policymakers, providing direction for future research and policies in the transport disaster resilience space. Therefore, viewing the status of each dimension independently is crucial for determining next steps. Though in practice, a degree of interdependence may exist between some or all of the five dimensions, this is difficult to operationalize accurately and doing so would be detrimental to the clear assessment the CDRFT intends to create. Consequently, it would be plausible for a city to score perfectly on four dimensions and zero on one, should the assessment reveal large deficiencies a particular dimension. The independent nature of the dimensions mirrors the approach taken by Shaw (2009) in the development of the CDRI.

Table 4, below, highlights suggested high-level actions that can be taken by a city for a given score on each dimension / question. Assuming the scores are reflective of domestic capacity issues, the actions should be taken as guidance for achieving an incrementally higher score in a subsequent assessment. Thus, for a city receiving a score of *0* on the natural dimension, following the guidance should result in a score of *1* during its next assessment. Cities should therefore evaluate all suggested actions for a given dimension to gain an understand of the collective actions needed to receive a perfect score of *3.* For lower scores, partnerships with organization that cover capacity building, such as the Green Climate Fund (GCF) with its Readiness Program, have been suggested.

3.5 Limitations

The CDRFT, despite its demonstrated utility, has several limitations. As a rudimentary research tool, it provides a solid framework one can employ to analyze cities globally. However, it remains subjective and functions with limited resources. As a result, the CDRFT provides directionality for policies, yet lacks substance. Assessing the vulnerability of a city's transport system to climate change-related events is a complex task that would be best completed using more data rather than less. Future iterations of the CDRFT should include a more detailed version which involves guidelines for government consultation. Depth, in terms of increasing the number of questions per dimension, can be combined with primary data to provide a more substantive report which can provide solid policy advice, similar to the Preliminary Disaster Resilience Scorecard.

Dimension	Physical	Social		Economic	Institutional		Natural
Score	**Question 1:** Is current and future transport infrastructure well designed to reduce the impacts of current and future climate risks?	**Question 2:** Would a significant loss of service and transport infrastructure be expected during a natural disaster?	**Question 3:** Is CDR inclusive to all communities?	**Question 4:** Does the city have a sufficient financial plan for transport CDR?	**Question 5:** Does the city have adequate pre- and post-disaster planning and governance?	**Question 6:** Does the city have knowledge of key hazards that the city face and the likelihood of their occurrence, with regards to transport?	**Question 7:** Is GBI being promoted on major urban transport projects?
3	Future infrastructure plans adapt for climate change and disaster effects. Diversified modal usage, all vulnerable infrastructure protected from foreseeable hazards.	No loss of service or infrastructure from most severe scenario.	Extensive community awareness CDR campaigns. Transport and climate change included. Strong local CDR initiatives exist.	The city has transport included into their climate change funding plan as well as their disaster contingency budget.	Transport included in CDR plan, CDR plan includes comprehensive response and recovery efforts. Governance is clear and streamlined.	Modern technology used to monitor infrastructure vulnerability and hazard probability, updated regularly.	GBI exists and is being further promoted on major urban transport projects through policy
2	Most assets and services are prepared for hazards. Future assets are planned in lower risk areas. Some modal diversity.	Some loss of service from most severe scenario.	Widespread community disaster engagement, local initiatives exist.	Transport included in disaster contingency budget but lacking from climate adaptation plan.	Transport efforts are clearly defined in pre-disaster planning. Role in response and recovery has deficiencies.	Climate change incorporated into hazard assessment, vulnerable infrastructure noted, lack of modern technology utilized.	GBI is being promoted for transport projects through policy, but there is little supporting guidance for practitioners.
1	No evidence of multi-modal transport. Systems in place to protect some vulnerable assets and services.	Some loss of service from most probable scenario.	Local initiatives exist with little municipal support or engagement.	Plans exists among different organizations but are not coordinated. Transport role is existent but vague.	Transport loosely incorporated into municipal disaster plan. Governance is complex.	Data exists on main hazards, lack of acknowledgment on climate change. Critical infrastructure highlighted.	No current usage of GBI, some evidence of planned implementation.
0	No promotion of resilience in current and future transport infrastructure.	Loss of service predicted from most probable scenarios.	No community engagement.	No clear plan	Transport omitted from plans / no plans exist.	The effects of hazards on transport are not understood.	No usage of GBI.

Table 3: The Climate-related Disaster Resilience Framework for Transport (CDRFT**)**

Dimension	Physical		Social	Economic	Institutional		Natural
Score	**Question 1:** Is current and future transport infrastructure well designed to reduce the impacts of current and future climate risks?	**Question 2:** Would a significant loss of service and transport infrastructure be expected during a natural disaster?	**Question 3:** Is CDR inclusive to all communities?	**Question 4:** Does the city have a sufficient financial plan for transport CDR?	**Question 5:** Does the city have adequate pre- and post-disaster planning and governance?	**Question 6:** Does the city have knowledge of key hazards that the city face and the likelihood of their occurrence, with regards to transport?	**Question 7:** Is GBI being promoted on major urban transport projects?
3	**No actions needed**						
2	Focus on increasing resilience through shift to diverse transport modes.	Evaluate efforts needed to ensure minimal loss of service from most severe scenario.	Focus on incorporating transport into existing municipal and grassroots initiatives.	Mainstream transport into both disaster relief funding and climate planning.	Focus on identifying a role for transport in response and recovery.	Research and seek partnerships to ensuring the utilization of the most state-of-the-art technologies.	Mainstream GBI into climate and development policies.
1	Bolster resilience of most vulnerable and crucial assets; mainstream resilience into future transport planning.	Focus efforts on preparing necessary infrastructure vulnerable to most probable scenario.	Identify and address barriers to city-wide community-based initiatives. Seek external assistance if necessary.	Consolidate disaster funding into a streamlined, central plan.	Mainstream transport into disaster planning; identify areas where governance can be streamlined.	Mainstream hazard assessment into climate policymaking.	Identify and address barriers to implementation; seek external assistance if necessary, such as GCF Readiness.
0	Create a roadmap for increasing physical transport resilience; Seek assistance from organizations such as GCF (Readiness), ADB.	Focus efforts on preparing necessary infrastructure vulnerable to most probably scenario.	Create a roadmap for future community engagement - seek assistance from regional NGOs are city based IOs.	Create a roadmap for developing an adequate disaster funding strategy. Seek partnership with organizations such as the GCF (Readiness).	Create a roadmap for establishing preliminary transport – related disaster plan - seek assistance from organizations such as GCF (Readiness), ADB.	Partner with relevant organizations (WB, ADB, academia) to conduct hazard assessment.	Create a roadmap for future GBI developments; seek assistance from organizations such as GCF (Readiness), ADB.

Table 4: Suggested actions for CDRFT dimension scores

4. RESULTS AND DISCUSSION

The below results for Bangkok (Table 5), Manila (Table 6), and Dhaka (Table 7) have been derived from a qualitative analysis of municipal and country-level documents relating to climate change adaptation and transport for the cities in question. Scores are given with reference to the framework outlined in table 3, above.

4.1 Bangkok

The Bangkok Metropolitan Area (BMA) has a complex urban transport system which includes electric-powered overhead and underground trains as well as an ageing fleet of busses, boats, and an increasing number of private vehicles which has doubled in the last 10 years (CEDMHA, 2018). The BMA's most salient natural disaster is floods. Bangkok lies in the Chao Phraya Delta, and has consequently received flooding yearly during the rainy season, which last from October to July (Ibid). Although some years are mild, Bangkok has suffered catastrophic floods, most recently in 2011, which caused an estimated US $ 45 billion in property damages and took 815 lives. (Promchote, 2015).

Bangkok							
Dimension	**Physical**		**Social**	**Economic**	**Institutional**		**Natural**
Score	**Question 1:** Is current and future transport infrastructure well designed to reduce the impacts of current and future climate risks?	**Question 2:** Would a significant loss of service and transport infrastructure be expected during a natural disaster?	**Question 3:** Is CDR inclusive to all communities?	**Question 4:** Does the city have a sufficient financial plan for transport CDR?	**Question 5:** Does the city have adequate pre- and post-disaster planning and governance?	**Question 6:** Does the city have knowledge of key hazards that the city face and the likelihood of their occurrence, with regards to transport?	**Question 7:** Is GBI being promoted on major urban transport projects?
3	**3**						
2		**2**	**2**			**2**	**2**
1				**1**	**1**		
0		.					
Total	**2.5**		**2**	**1**	**1.5**		**2**
Aggregate (out of 15)	**9**						
Data Source	World Bank Study - Climate Risks and Adaptation in Asian Coastal Megacities (2010) 100 Resilient Cities - Resilient Bangkok (2017)	World Bank Study - Climate Risks and Adaptation in Asian Coastal Megacities (2010)	100 Resilient Cities: Resilient Bangkok (2017)	National Disaster Risk Management Plan (2015) 100 Resilient Cities - Resilient Bangkok (2017)	National Disaster Risk Management Plan (2015)	Resilient Bangkok (2017)	100 Resilient Cities - Resilient Bangkok (2017)
Data Range	**2010-2017**						

Table 5: Bangkok CDRFT results

In Bangkok's urban development plan, there is a clear impetus to create resilient transport with flooding in mind, which is reflected by numerous initiatives. To start, there is a large-scale effort to improve public transit. Bangkok seeks to double the percentage of public transit users, eliminate incentives for private vehicle ownership, and ultimately reduce congestion (100 Resilient Cities, 2017). Other initiatives, such as the expansion of the water transport network, provide further mobility, and create needed redundancy in the system. Based on a World Bank Study (2010, p. 15), there are unlikely to be large damages and service disruptions from flooding to public transit, as the MRT system is protected from flood overflow. Moreover, there is a citywide initiative to improve drainage systems along main roads, which will ultimately reduce road service outages during major rainfalls (100 Resilient Cities, 2017, p. 76). Nevertheless, as seen in the 2011 floods, many roads were inundated which led to large-scale congestion, delays, and a loss of productivity (Promchote, 2015)

In its development plan and resilient strategy, Bangkok has emphasized a pan-community approach to capitalize on the insights each district and sub-district has to offer (100 Resilient Cities, 2017). The Community-Based Disaster Risk Management Pilot and the Community Flood Preparedness Communication are inclusivity initiatives that significantly contribute to overall urban resilience and therefore transport resilience (100 Resilient Cities, 2017). Though none of these initiatives mention transport specifically, they drastically improve social resiliency.

With regards to the economic dimension, the NDRMP clearly indicates that the BMA should budget for disaster preparedness, as well as create a contingency fund in case of a disaster. Yet, it fails to specify transport specifically. Though funds are ring-fenced for a disaster, the lack of clarity regarding the nature of the funding for the transport sector creates uncertainty with regards to financial resilience (NDPMC, 2015, p. 21).

Bangkok's low institutional resilience is reflective of Thailand's centralized governance structure. National Disaster Risk Management Plan (NDRMP), created in 2015, is comprehensive on a national level, and acknowledges the effect of climate change on disasters. Yet, there is scarcely a plan for the BMA, and the Bangkok Municipal Transit Authority lacks a cohesive disaster risk management plan. In the NDRMP, the Thai Ministry of Transport has designated roles for a disaster response, including evacuating those in vulnerable areas, ensuring continuity for logistics routes, and guaranteeing lifeline routes (NDPMC, 2015). The NDRMP demonstrate a sizeable understanding of the hazards that face the city and have attempted to account for the effect of climate change. The city is developing a comprehensive flood-risk assessment, which considers climate change and socio-economic aspects (100 Resilient Cities, p. 69). Though this initiative does not focus on transport, the impact on the sector is acknowledged.

Bangkok's natural resilience, currently poor, is being improved though largescale initiatives to install green infrastructure throughout the city. A notable example being the Pilot Study on Urban Water Retention, which seeks to highlight locations for future water-retaining green infrastructure, such as roadside bioswales. The BMA is also in the process of rehabilitating its canals, which will improve water quality and overall drainage, and leaves opportunity for further water-based transport (100 Resilient Cities, 2017).

4.2 Manila

Metropolitan Manila (Metro Manila) is incredibly disaster-prone, being at risk to severe earthquakes and floods from tropical cyclones, rainfall, and tidal surges. The city is inundated annually during the rainy season, and overall flooding is predicted to increase with climate change (GFDRR, 2013). Metro Manila has a well-developed roadway system but insufficient railway infrastructure, with three light rail lines and one commuter rail line. Accounting for 50% of all commuting trips is the plethora of road-based public transit options, which include buses, tricycles, community taxis, and the infamous “jeepneys.” These transport modes are privately owned and scarcely regulated – there are an estimated 1200 private bus operators alone (Almec Corporation, 2014, p. 2-5). Public transport is woefully inadequate to serve the population. As a result, personal car ownership has increased and traffic congestion remains a paralyzing issue (Ibid, p. 2-4). Annual flooding and other hydro-meteorological events greatly exacerbate the congestion issue, which stunts overall development.

Manila							
Dimension	**Physical**		**Social**	**Economic**	**Institutional**		**Natural**
Score	**Question 1:** Is current and future transport infrastructure well designed to reduce the impacts of current and future climate risks?	**Question 2:** Would a significant loss of service and transport infrastructure be expected during a natural disaster?	**Question 3:** Is CDR inclusive to all communities?	**Question 4:** Does the city have a sufficient financial plan for transport CDR?	**Question 5:** Does the city have adequate pre- and post-disaster planning and governance?	**Question 6:** Does the city have knowledge of key hazards that the city face and the likelihood of their occurrence, with regards to transport?	**Question 7:** Is GBI being promoted on major urban transport projects?
3							
2			**2**	**2**		**2**	
1	**1**	**1**			**1**		**1**
0							
Total	**1**		**2**	**2**	**1.5**		**1**
Aggregate (out of 15)	**7.0**						
Main Data Source	JICA Report - Roadmap for Transport Infrastructure Development for Metro Manila (2014) AIIB Report - Metro Manila Flood Management Project (2017)	World Bank Study - Climate Risks and Adaptation in Asian Coastal Megacities (2010)	Centre for Disaster Management Report - Preparing Metro Manila Toward Urban Resiliency (2015)	Strategic National Action Plan (2009) Department of Budget Management (2020)	National Disaster Response Plan (2018)	World Bank Study - Climate Risks and Adaptation in Asian Coastal Megacities (2010)	Pasig River Rehabilitation Program (2004)
Data Range	**2009 - 2020**						

Table 6: Manila CDRFT results

The National Adaptation Plan of the Philippines does not specify actions for the transport sector, and Metro Manila lacks a cohesive adaptation framework (Balgos et al, 2015). Yet, physical resilience building projects exist. The Metro Manila Flood Management Project is a major public works initiative to strengthen the resiliency of existing infrastructure and neighborhoods (AIIB, 2017). Nevertheless, much of the city's transport infrastructure currently remains vulnerable to hydro-meteorological hazards (The World Bank, 2010, p. 37). Manila's roadway system is consistently inundated from hydro-meteorological hazards regardless of whether it is a "most probable" or "most severe scenario". Abad and Fillone (2020) found that 75% percent of commuters surveyed encountered flooding on their commute, with 60% changing their travel plans to work. Per a study by the World Bank (2010), these disruptions will increase without a significant investment in flood resilient infrastructure as climate change exacerbates storms.

Manila scores slow on the social dimension due to the lack of top-down initiatives. Although the government has expressed plans to build CDR capacity in 115 communities in the Metro Manila Area, the level of implementation varies significantly per barangay, the lowest census division (JICA, 2004, p. 17, Balgos et al., 2015). Though the majority of commuters have innate resilience and respond accordingly during hydro meteorological events, many respondents of the survey conducted by Abad and Fillone (2020, p. 20) indicated that they were forced to travel despite flooding as they are penalized financially for late arrival to work.

Manila's economic resilience is the result of a comprehensive funding system for disasters at the national level. The National Calamity Fund (NCF) is an annual lump sum which can be employed for capital expenditures regarding pre-disaster operations, rehabilitation, and reconstruction (NDCC, 2009). The Quick Response Fund (QRF) is an in-budget standby allocation of funds for specific use in times of disaster. A portion of the fund is dedicated specifically to the Department of Transport, and the Department of Public Works and Highways has its own QRF for the rehabilitation of roads and other major infrastructure (DBM, 2020, DOTr, 2015,).

Institutionally, Manila's central authority, the Metro Manila Development Authority (MMDA), lacks competence with regards to its ability to coordinate activities that transcend municipal borders, such as disaster response and transport, and fails to dictate the actions of its constituent cities (Romero et al. 2014). There is no comprehensive disaster plan for the transport sector nor for Metro Manila proper (AIIB, 2017). With regards to post-disaster activities, the MMDA is tasked with securing lifeline road routes, while the DOTr is responsible for ensuring continuity at the airport (JICA, 2014). In terms of hazard assessment, the most unique initiative is the concept of Open Data Law for Climate Resilience and Disaster Risk Reduction *(Lagmay, 2018). The country has attempted to create disaster resilience laws based on open data to approach CDR with an integrated, society-wide approach. Open sourced data and its applicability to congestion alleviation and hazard information in a decentralized city like Manila has immense potential.*

Though Manila's natural resilience has been eroded by urban sprawl, the Metro Manila Development Authority has invested heavily in the rehabilitation of the Pasig River, arterial to the city. Included in the efforts were flood protections as well as investments to ensure the reinstatement of a ferry service, with the intention of alleviating congestion (HIC, 2004).

4.3 Dhaka

Dhaka, the capital of Bangladesh, is one of the most flood-prone cities in the world (Bird et al., 2018). As a low-lying city with a tropical monsoon climate, it faces annual flooding which has increased in severity with climate change. Rapid industrialization and urban growth have worsened the issue, as unplanned development has destroyed many of the natural flood barriers existing in the city. Dhaka, with a population density of nearly 20,000 people /km^2 , is one of the world's most densely populated urban areas. Expansion to less-developed areas of the city will be key to future sustainable growth, highlighting the importance of flood prevention measures (Rabbani, 2018). Dhaka is also one of the most congested cities globally (Bird et al, 2018). The majority of public transport in Dhaka is via modes such as motorcycle, rickshaw, and buses (e-Alam, 2018). There is no mass rapid transport in the city, although there are plans for extensive BRT and MRT lines. Walking and cycling, increasing in popularity among the lower- and middle-income classes, are being supported by government through accessibility initiatives (Ibid). In Dhaka, investment in sustainable, efficient transport is seen as foundational to the pathway towards achieving broader development.

Dhaka							
Dimension	**Physical**		**Social**	**Economic**	**Institutional**		**Natural**
Score	**Question 1:** Is current and future transport infrastructure well designed to reduce the impacts of current and future climate risks?	**Question 2:** Would a significant loss of service and transport infrastructure be expected during a natural disaster?	**Question 3:** Is CDR inclusive to all communities?	**Question 4:** Does the city have a sufficient financial plan for transport CDR?	**Question 5:** Does the city have adequate pre- and post-disaster planning and governance?	**Question 6:** Does the city have knowledge of key hazards that the city face and the likelihood of their occurrence, with regards to transport?	**Question 7:** Is GBI being promoted on major urban transport projects?
3							
2	**2**						**2**
1		**1**	**1**	**1**	**1**	**1**	
0		.					
Total	**1.5**		**1**	**1**	**1**		**2**
Aggregate (out of 15)	**6.5**						
Main Data Source	JICA Report - The Project on the Revision and Updating of the Strategic Transport Plan for Dhaka (2015)	Research Paper - Performance of Flood Control Works around Dhaka during Major floods in Bangladesh. (2010)	World Bank Report - Climate Disaster Resilience of Greater Dhaka Area: A Micro Level Analysis (2015)	ADB Paper - Disaster Risk Financing in Bangladesh (2016)	National Plan for Disaster Management (2017)	World Bank Report - Urban Flooding of Greater Dhaka in a Changing Climate (2018)	JICA Report - The Project on the Revision and Updating of the Strategic Transport Plan for Dhaka (2015)
Data Range	**2010 - 2018**						

Table 7: Dhaka CDRFT results

Dhaka's physical resilience is bolstered by ambitious planning. Specific actions are outlined in the Revised Strategic Transport Plan (RSTP), which places an emphasis on resilient transport, focusing on MRT, BRT, elevated roads, and water transport (Almec Corporation, 2015). With the aim of reducing congestion and increasing accessibility, it will inevitably increase the city's resilience in the transport sector. However, none of the major works of this plan have currently been completed. As many of the estimated completion dates are towards 2035, the sector remains vulnerable (Bird et al., 2018). As Dhaka transport consists of various road-based modes, its ability to operate during disaster scenarios depends directly on the conditions of its road system. In Dhaka, even smaller rain events may cause road flooding in some areas (Mark et al., 2001). Though flood protections in the western part of the city exist, many areas are unprotected from flooding entirely, which impedes transport (Bala et al. 2010).

According to the World Bank (2015) Dhaka demonstrates a moderate level of social resilience, which is parameterized into preparedness, interlinking of social class, acceptance of community leaders, and population evacuating voluntarily, among others. However, the level of community resilience varies significantly across Dhaka, as Eastern Dhaka has an extremely low level of resilience (Ibid). As in Manila, the city lacks a central transport authority, therefore the onus belongs to individual drivers to take risk avoiding precautious in the event of a flood.

There is a consistent funding gap for disaster mitigation and response efforts, despite the fact that the government of Bangladesh has a comprehensive resource mobilization strategy (DDM, 2014, p. 31). Domestically, Bangladesh has several budgetary resources. The Disaster Risk Reduction Fund is dedicated specifically for disaster risk reduction; however, the funds are reported to be modest (Ozaki, 2016, p. 17). Other funds, such as The Emergency Fund Disaster Management, are smaller and more localized, and the role of transport is vague in all funds in comparison to the specific allotments for food and shelter.

Dhaka lacks institutional resilience as there is no city-wide master plan, development plan, nor disaster management plan (Shaw et al. 2016, p. 28). In the NPDM, the effect of climate change on natural disasters in Bangladesh is clearly acknowledged, as is the SFDRR, the SDGs, and their linkages. Transport and its management in a disaster scenario is scarcely covered. Though the NPDM alludes to the role of transport in disaster response, there is a lack of specificity with regards to lifeline routes and emergency logistics, which is detrimental to the resiliency of the transport system as a whole (GOB, 2017, p.39). With regards to hazard assessment, the WBI (2009) employed GIS technologies to provide information on the populations, land areas, and infrastructure that would be impacted by varying flooding scenarios. Further studies have modeled the effect of climate change on flooding based on different emissions scenarios (Dasgupta et al., 2015). Although these are not transport specific studies, they specifically assess road vulnerability to flooding, which is intrinsically related to transport.

Though Dhaka once contained a system of urban wetlands and canals which aided in flood protection, they have since been mostly destroyed (Bird et al., 2018). There is an ongoing initiative to boost natural resilience by incorporating both green and blue infrastructure into Dhaka's transport planning, notably including the rehabilitation of a circular waterway system (Almec Corporation, 2015).

4.4 Discussion

4.4.1 Comparing City Results

The above results reveal the variety that exists with regards to transport CDR in Asian megacities. Figure 1 shows CDRFT spider diagram for three cities. Bangkok, Manila, and Dhaka received aggregate scores of 9, 7, and 6.5, respectively. Bangkok's higher aggregate score was mainly due to its superior performance on the physical dimension. Bangkok possesses numerous resiliency-building initiatives and has invested heavily in public transport, which is better adapted for disasters. Thailand, as an upper-middle income country, has more financial resources, both domestic and foreign, than the Philippines and Bangladesh, both lower-middle income countries. The lack of financing makes physical adaptation, the costliest dimension, less attainable. Nonetheless, Bangkok's progressive strategy can be emulated by other large cities in upper-middle income countries such Kuala Lumpur or Tehran.

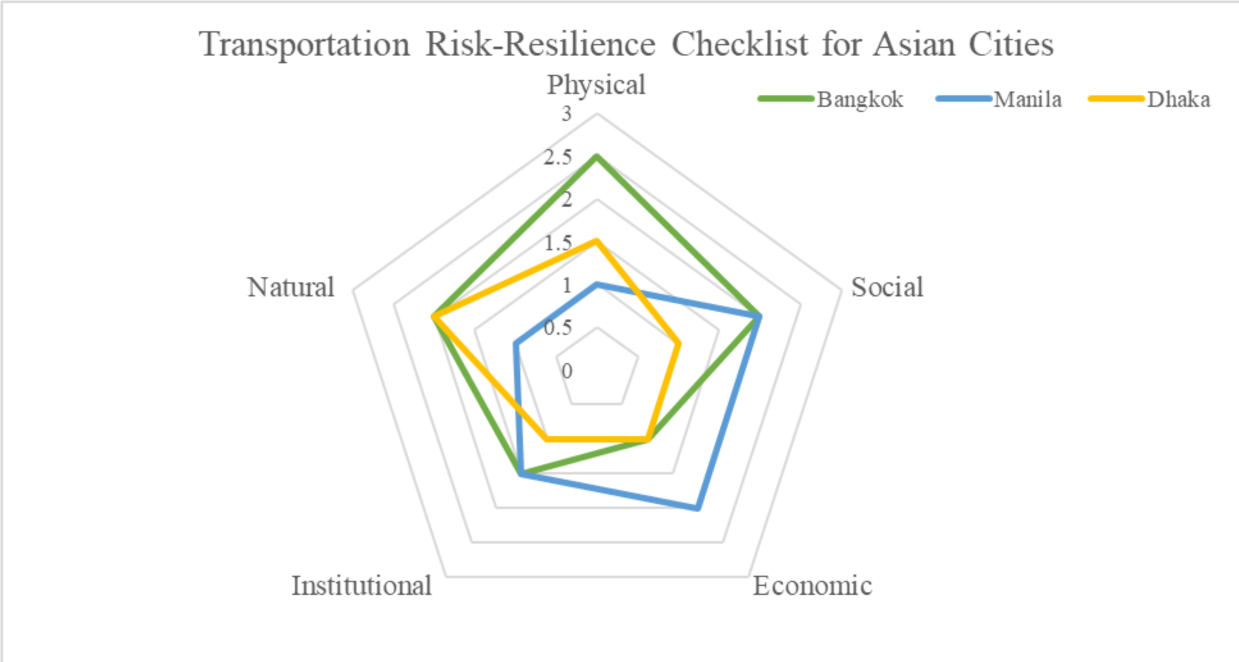

Figure 1: CDRFT spider graph

Yet, the CDRFT highlighted measures in Bangkok that were not cost-intensive as well, notably Bangkok's numerous community engagement efforts. These initiatives, while strongest in Bangkok, were also present in Manila and Dhaka. The analysis of Manila demonstrated the holistic nature of resilience, as commuters felt obliged to travel despite risky conditions due to the lack of flexibility at the workplace. To create an enabling environment for a resilient transport system, governments of disaster-prone cities should mandate flexible working policies during hazard periods. Overall community resilience is key for all three cities, due mainly to the decentralized nature. Lacking a city-wide strategic action plans leaves communities and individuals in charge of CDR. An exploration of community resiliency in a Northern city would likely illustrate lower levels, due to dependency on central governments.

Bangkok, Dhaka, and Manila all invested in BGI in the transport sector. The rehabilitation of canals creates an opportunity for further water-based transport along with increasing water retaining capabilities. This Figure

creates redundancy in the overall transport system and relieves congestion. Low-lying flood-prone cities such Jakarta and Ho Chi Minh City can benefit from an increase in BGI investments, as seen in Bangkok, Dhaka, and Manila. Even cities with more strictly planned development, such as Toronto, have seen a massive decrease in GBI with growth, which in turn decreases resiliency. Increasing natural resiliency is a relatively lower-cost form of disaster risk management.

Bangkok and Manila demonstrated innovative approaches to hazard assessment, which were reflective of their respective economic situations. Potentially paradigm shifting with regards to disaster management, the open-data movement and its application to transport and disaster management in the Philippines is a lower-cost method of hazard assessment, as it outsources the data collection and interpretation to entrepreneurs, academics, and business. Open sourced data allows for the creation of effective disaster risk management at all levels, from locals mapping informal bus routes to governments utilizing the most accurate data to create policies. Bangkok's data-bank initiative makes the task of mainstreaming CDR simple and streamlined, providing all parties involved with accurate data. Any government with a data gap can emulate the efforts of these two cities to create an enabling environment for effective CDR.

4.4.2 Policy Directions

The CDRFT illustrates that Bangkok should focus on its economic and institutional dimensions. Despite investing heavily in resilient transport, there is little evidence of contingency funds to support resilience efforts for the sector. Moreover, the city utilizes national rather than municipal CDR plans, which lowers its robustness per the institutional dimension. As Bangkok's needs are unique in comparison to the broader national context, a city-specific plan will bolster its overall disaster preparedness and allow for transport policies unique to Bangkok.

Per the CDRFT, Metro Manila has many vulnerabilities. Future policies should focus on social resilience, due to the decentralized nature of the transport system. As the majority of commuters take privately owned rickshaws, jeepneys, and buses to work, resilience awareness on behalf of commuters, drivers, and business can drastically improve Manila's overall flood coping ability. The CDRFT also indicates a deficiency with regards to the natural dimension; Manila has many other rivers which could benefit from rehabilitations similar to the Pasig River, which could improve this score.

Dhaka scored lowest on the CDRFT; however, it is also located in the country that has the lowest GDP per capita of the three countries analyzed. Consequently, Dhaka lacks the financial resources needed to adequately prepare for climate change and is reliant on international aid for many development and disaster response initiatives. Nevertheless, lower-capital solutions, such as risk sensitive land use planning as well as emergency governance capacity building, can improve overall transport CDR.

5. CONCLUSION

The socioeconomic impact of climate change will grow as global temperatures continue to increase. Cities which currently have been seemingly eluded by climate-related disasters will likely see their fortunes reverse. Importantly, the incidence of glacial, tidal, and riparian floods will increase globally. As resilience to climate-related disasters enters the development spotlight, the importance of the transport sector will become mainstreamed, due to it being foundational for industrialized society. Yet, for a policymaker or a researcher, there are few existing tools for gauging a city's resilience to climate-related disasters.

This paper developed the Climate-related Disaster Resilience Framework for Transport (CDRFT) to provide users with a qualitative framework to measure transport sector resiliency across cities and to assist users in gaining straightforward insights on the efforts similar cities are making to adapt their transport systems for climate change-related natural disasters. Using five dimensions (Physical, Social, Economic, Institutional, and Natural), this paper creates a holistic understanding of the local transport CDR situation, and highlights which dimensions could use improvement.

This paper demonstrated the utility of the CDRFT by analyzing Bangkok, Manila, and Dhaka. The results showed that though Bangkok had the highest levels of resilience, all three cities had unique resilience-building initiatives. For example, Manila is incorporating open data into their disaster response planning, while Dhaka is in the process of rehabilitating an historic waterway network to gain natural resilience as well as a water-based transport system. Ultimately, the CDRFT can serve as a necessary starting point for researchers, practitioners, and professionals policy makers on their mission to mitigate the effects of climate change-related disasters on urban transport systems.

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