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No. 90

Resilience of Transport Systems and Services

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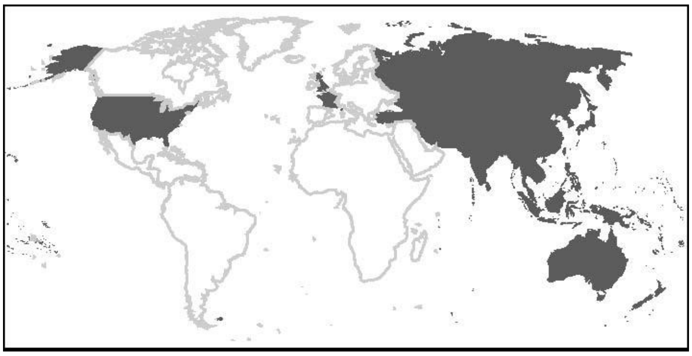

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Editorial Statement

The *Transport and Communication Bulletin for Asia and the Pacific* is a peer-reviewed journal that is published once a year by the Transport Division of the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP). The Bulletin is a medium in which knowledge, experience, ideas, policy options and information on the development of transport infrastructure and services in the Asia-Pacific region is shared. The main objectives to these are to stimulate policy-oriented research and to increase awareness on the policy issues and responses of the transportation industry. The Bulletin attempts to widen and deepen the debate on the issues of interest and concern in the transport sector. For the 90th issue, the Bulletin focuses on the theme of “Resilience”.

Frequency of natural disasters and climate events are increasing in the Asia and the Pacific region. We have witnessed transport infrastructure and services damaged by floods, rising sea levels, cyclones, and earthquakes. Transport infrastructure in mountainous terrain, coastal areas, and near riverbanks are more vulnerable to climate events and natural disasters. Resilience of transport systems and services is vital for socio-economic development as well as in relief operations. The Sustainable Development Goal (SDG) target 9.1 calls to develop quality, reliable, sustainable infrastructure and target 13.1 calls to strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries. Therefore, transport planners, policymakers and designers need to acknowledge the threat posed by the climate events and enhanced intensity and frequency of natural disasters in the region.

Of all the changes brought upon by COVID-19, no other landscape has undergone such a pronounced and sweeping transformation as the city. The increasing urgency of climate change has meant that most cities have already recognised a need for a radical recalibration of people’s urban lifestyles. The speed with which cities have been forced to adapt to COVID-19 proves that such change is possible. Indeed, the experience of cities suggests that successful future mobility will involve a far greater emphasis on active mobility, integrated transport modes, and a more socially inclusive, community-focused system. When COVID-19 first began to spread, people witnessed a dramatic reduction in CO2 levels in many of the world’s most heavily polluted cities. The key now lies in retaining this unquestionably positive side-effect of the pandemic, for our own health and for generations to follow.

Each of the five papers selected for this issue contribute to different aspects and novel perspectives on the theme of resilience, and include various approaches in improving resilience of transport systems in a particular context.

The first article by Nughoro, Zusman et. al focuses on a more niche aspect of transport resilience. The paper assesses school travel behaviour and the impact of awareness-raising to promote a resilient public bus system and uses Semarang, a fast-growing coastal city in Indonesia, as a case study. The paper endorses a modal shift from private to public transport for schoolchildren in order to improve transport resilience. The paper finds that the parents of schoolchildren play a crucial role in this objective, and that campaigns to raise awareness of the importance of public transport have the potential to be highly influential.

The second article by Lee, Carvalho and So draws together tangible evidence on the use of smart transport systems for urban resilience. Although primarily based off of data derived from simulation-based methodology, smart transport systems look to be a promising feature of transport flows going forwards. Access to Realtime information about traffic and public transportation conditions could be hugely useful in building more resilient systems, especially in light of COVID-19, allowing for the even distribution of users, and increased social distancing, across bus and train networks.

The third article by Saksena and Dalal explores resilient transport systems and services from an Indian Railways perspective. Citing increasingly extreme natural phenomena and climate change as the biggest threats to transport systems, the paper contends that the current rail system in India is highly vulnerable and slow to respond to such disasters. To mitigate the risks of climate change on Indian railways, the authors have devised a framework to build long-term resilience under the Rail-Adapt initiative. The initiative brings together rail and other experts to develop common guidance on how to optimise resilience and source funding for the necessary steps to do so.

The fourth article by Schwartz and Regmi assesses the climate-related disaster resilience of urban transport systems in Asian cities. Using a “focused comparison” methodology, the paper 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, the authors have developed a novel tool called the Climate-related Disaster Resilience Framework for Transport (CDRFT). Heralding the benefits of both capital-intensive solutions and lower-cost efforts, the paper contends that the insights gained from the tool can be used to enhance the resilience of transport systems globally.

The fifth article by Raunak, Sawant and Sinha explores the impact of COVID-19 on urban mobility in Indian cities. India has been one of the worst hit countries by the pandemic. This timely study provides an early scope of the impact of India’s lockdown measures on various parameters such as mode choice, vehicular ownership and frequency of travel. The paper also forecasts useful trends that are applicable to wider transport systems. It is clear that urban mobility faces two key challenges in light of COVID-19: consumer behaviour has changed (public trust in government policy has shifted downwards) and private consumption/disposable income has shrunk as a result of job losses and economic uncertainty. Looking ahead, social distancing and heightened hygiene maintenance on public transport will be paramount.

The Bulletin encourages analytical discussion on topics that are at the forefront of sustainable transport development in the region, as well as policy analysis and best practices. Articles should be based on original research and have an in-depth analytical process. Articles should be empirically based and emphasize policy implication emerging from such analysis. Book reviews are also welcomed.

Further inquiries should be addressed to:

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CONTENTS

Understanding School Travel Behavior and the Impact of Awareness Raising to Promote Resilient Public Bus System in the Coastal City in Indonesia: A Case of Semarang city

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ABSTRACT

In fast-growing coastal cities, dependable public transport, diversity of modes, and social inclusion are among several factors that contribute to resilient transport. However, these factors depend critically on whether key ridership segments are aware of the benefits of public transport. This article describes the effects of an awareness-raising campaign intended to encourage junior high school students to use public transport in Semarang, Indonesia. The article analyses the campaign's impact by comparing student responses to a survey on the use of the bus system for school trips before and after the campaign in three junior high schools in Semarang. The survey demonstrated that, though a diversity of modes exists for school trips, parents often influence student mode choices. For some respondents, parents preferred family drop-offs and online taxi pick-up services to public transport. However, the public bus or quasi-bus rapid transit (BRT) (known as Trans Semarang) may hold the potential to increase student mode share because it offers comfort, security, opportunities to socialize as well as discounted student prices. Encouraging a modal shift from private to public transport for school may improve urban transport resilience. However, a lack of public bus infrastructure remains a sizable hurdle to this worthy objective.

Keywords: School Travel, Behavioural change, Junior High School, Trans Semarang, Coastal City

1. INTRODUCTION

The concept of resilience was introduced into environment studies in the early 1970s in relation to the capacity of ecosystems to return to their initial states when subjected to disruption (Holling, 1973). Urban resilience has emerged to frame how actors and infrastructure in urban areas contribute to the capacity to survive, respond, recover, adapt and evolve in reaction to chronic and acute stresses and events that disrupt systems and practices (Ward, 2019). Embedding resilience into complex urban systems and their environments is a priority (e.g. Semarang City Government, 2016; Buteler et al.2016; Ahern, 2011; Staddon, 2010). Resilience is also being incorporated in multiple frameworks related to urban studies and analysis focusing on the practicalities of embedding resilience across the socio-ecological-technical (SET) system (Ribeiro and Goncalves, 2019).

Studies focusing on transport system resilience began in the 1990s (Comfort, 1994). Recently, the United Nations Sustainable Development Goals (SDGs) aims to create more inclusive, safe, resilient, and sustainable cities (United Nations, 2015). Providing safe access, affordable, accessible and sustainable transport systems for all citizen groups by expanding public transport services is one target listed under the sustainable development goals on building sustainable cities. This SDG target generally includes more efficient public transport systems and reduced private vehicle dependency for urban mobility (Zhao, 2010). Transport policies analysis targeting the development of better urban infrastructures and its operational performance can increase urban resilience in the long term (Leung et al, 2017). The multimodal transport system, and developing alternatives to private vehicle use by enhancing public transportation and non-motorized transport, are proposed as two elements for resilient urban transport principles (Khodabaksh et al, 2015)

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The intervention aiming to encourage a modal shift from private to public transport among students and ensure safe travel can help improve urban transport resilience in coastal cities. First, young students are often the largest group of public transport users in a city (IUCCE, 2018). Second, mobility attitudes are deeply influenced by experiences at an early age (Canters et al, 2015) and behavioural interventions for young adolescents between the ages of 12 and 14 represent a "transition phase" between childhood and adulthood. It is therefore more effective compared to older target groups (Stark et al, 2018). A pro-private vehicle orientation seems to be acquired from the age of 12 and increases as people get older (Flade & Limbourg, 1997). Some positive impacts on travel behaviour may become evident after teenagers reach adulthood and can make their own independent decisions on their preferred transport mode.

Although young people often dominate public facilities in developing countries, there has been little engagement on strategies promoted in the name of resilience involving the younger generations as key stakeholders (D. McKoy, 20145). Young people, especially those who come from low-income groups, are rarely invited to sit at the urban planning and policymaking table (Simpson, 1997). Engagement of young people who are usually insecure and highly vulnerable to shocks and stresses (both climate- and non-climate-related) has a strong link to resilience on urban mobility systems. Travel behaviour when going to school and interventions on this behaviour have been widely discussed in Europe and North America, but there is limited empirical information about similar engagement in developing countries. This knowledge gap is particularly problematic in developing countries where the most climate vulnerable towns and cities are concentrated (Revi et al. 2014; Sanderson 2000).

This article aims to close that gap by drawing attention to the importance of understanding school travel behaviour among the youth. It then looks at awareness-raising programs that encourage the modal shift from private to public bus systems as part of an effort to boost transport resilience in Semarang, Indonesia. To support these aims, this research applies widely-used intervention analysis wherein a before-after control group experiment and surveys are used to understand changes in student mode choice preferences at three junior high schools in Semarang, Indonesia (Stark, et al, 2018).

As a first step, a baseline survey was carried out for a large proportion of students before the awareness-raising program. Following this, a post-training survey was carried out for selected participants and non-participants of the awareness-raising program among respondents to the baseline survey. The study found a variation in the total number of passengers on the public Trans Semarang quasi-bus rapid transit (BRT) system due to school holiday seasons and weather conditions. However, Trans Semarang is a promising mode because it offers comfort, security, social connectivity as well as discounted student prices. Trans Semarang is arguably even more important for schools located in a flood zone. The study confirmed an increased willingness to use Trans Semarang after the awareness-raising program. However, insufficient public bus services and infrastructure were identified as the main barrier to shift from private vehicles. Prepaid cards to facilitate non-cash transactions, and sharing information through social media, helped to increase the understanding, evaluation and consequently the use of Trans Semarang for school travel. This research is an important input for the city's government to improve its adaptation strategy in response to climate-related changes such as extreme weather.

The remainder of the article is divided into four sections. The next section reviews literature on raising awareness. The section thereafter describes the study location and provides baseline information. A fourth section presents key results. A final section concludes with a discussion of areas for future research.

2. LITERATURE REVIEW AND METHODOLOGY

Travel behaviour and Urban Transport Resilience

Understanding how travel behaviour change can help policymakers to improve urban transport resilience (Kellen et al, 2011; Liu et al, 2018; Abad and Fillone, 2019, Liu et al, 2017). Disruptive events are usually a central theme of studies on urban transport resilience addressing network disruptions, economic and energy impacts, natural disasters, and more recently, human-induced disasters and terrorist attacks (D'Lima and Medda, 2015; Hong et al, 2019; Fernandes et al, 2019; Santos, et al, 2020; Cox et al, 2011;

Chan and Schofer, 2016; Donovan and Work, 2017). In the last few decades, there have been increased studies to investigate individual travel behaviour in response to disruptive events (Abad et al, 2019; Abad and Fillone, 2017; Sunga et al, 2017). Risk perception is a key determinant of individual adaptation behaviour (Arnell and Delaney, 2006; Moser and Leuers, 2008; Hoffman et al., 2009; Li et al, 2017). The transportation risk perception in urban populations may change over time, but people consistently assessed the risks related to private motorized transportation as higher than corresponding risks in public transportation (Lund et al, 2016). The risk-related factor is believed to be associated with the likelihood of using public or private transportation (Nordfjaern et al, 2014). Some local authorities in European cities sought to increase public transport use by providing a higher frequency of better quality and less expensive public transport options (Mocca, 2015)

Encouraging a modal shift through an awareness-raising program for young people in Semarang city

The share of public transport mode in Semarang city is small compared to private vehicles. However, the number of students who use public transport gradually increases every year (IUCCE, 2018). There are five steps to encourage modal shift from private vehicle to public transport modes for school travel (Jones and Sloman, 2003). Those five steps are as follows: (a) awareness of the problem; (b) acceptance of the need for change; (c) changing attitudes toward alternative modes; (d) initiating action to reduce private vehicle use and (e) assimilation of new behaviour into everyday life. Another European-funded project on education for sustainable transport, called TAPESTRY, developed the “seven stages of change” travel behaviour model by combining the Theory of Planned Behaviour and the Trans-theoretical model. The seven stages consist of the following steps: (a) awareness of key issues; (b) accepting responsibility/ acknowledging relevance; (c) perception of options; (d) evaluation of options; (e) making a choice; (f) experimental behaviour and (g) habitual behaviour (Jones and Sloman, 2003). Steps five and seven emphasize the importance of a phased approach, with awareness as the basic or initial step. The education and awareness attainment of the young generation had various results. There was substantial variation in the ability of individuals to undertake adaptive capacity (Smit and Wandel, 2006; Brooks et al, 2005; Gallopin, 2006). However, the accumulation of knowledge and information received by a person makes them more aware of hazards and improves their risk perception (Qasim et al, 2015).

The awareness-raising program has several goals to improve knowledge on safety-related aspects for daily travel going to and from school; and to encourage a modal shift for travel to and from school by using Quasi-BRT Trans Semarang bus system. The hope is that children can be self-motivated to continue using public transport. The intention to use, and frequency to use, Trans Semarang would be used as indicators to observe behavioural change among students. The frequent use of buses could be categorized into several levels, from “never use” to “use very often”. The ordered logit model that is used to observe the changes in people’s decision to upgrade vehicle ownership level (Dargay and Hanly, 2007) is suitable to capture the frequency to use bus for school travel. The ordered logit model uses the formula as follows:

$$y^{*} = \beta' \mathrm{x} + \varepsilon, \qquad (1)$$

$$Y = \begin{cases} 0 & \text{if } y^* \leq \mu_1, \\ 1 & \text{if } \mu_1 < y^* \leq \mu_2, \\ \cdot & \\ \mathrm{N} & \text{if } \mu_\mathrm{N} < y^* \end{cases} \qquad (2)$$

where y^* represents the observed responses of the possibility to use public bus Trans. The **β** is vectors of parameters, **x** is vectors of independent variables associated with the students. The *μ* is threshold value that divides a continuous joint distribution of error terms *ε* into intervals associated with different levels of frequency use of Trans Semarang (y=0 (never use); y=1 (very rarely); y=2 (rarely); y=3 (often); y=4 (very often)). The ordered logit model was developed by considering: (a) individual attributes: grade level and gender; (b) distance from home to the nearest bus shelter; (c) distance from school to the nearest bus stop; (d) how they have come to know about Trans Semarang; (e) existing mode for going to school trip; (f) perceived opinion on the barrier and merits of Trans Semarang.

3. STUDY LOCATION AND DATA

Semarang city and its public transport system

Semarang is the capital city of Central Java Province, located around 450 km east of the capital city, Jakarta, and between the two main cities on Java Island, Jakarta and Surabaya. It is the fifth largest city in Indonesia with a total population of 1,674,358 (as of December 2019) and a total area of more than 370 square kilometres. The gross regional domestic product (GRDP) per capita is USD 6,461.5 (USD1= IDR 13,000) and the largest contributor to GRDP is the secondary sector, including manufacturing, food, beverages and tobacco, chemical and pharmaceuticals, and other industries such as textiles and transport equipment (IGES, 2017). Urban mobility in Semarang relies heavily on road transport and the majority of people use private vehicles (80%) with only 20% using public transport. The main roads are dominated by motorcycles (58%), private cars (22%) and public transport (20%) (GCF, 2018). The share of public transport consists of angkots (minibuses) (50%), the quasi-BRT (Trans Semarang) (40%) and regular buses (10%). The angkots and regular buses cover 88 routes served by 1766 angkots and 83 regular buses. Trans Semarang has adopted an all-BRT standard without a dedicated lane and still uses mixed traffic lanes, sharing the road with other modes. It covers eight main routes served by 144 buses and two feeder routes served by 44 buses (as of December 2019). Although the share of public transport modes in Semarang is small compared to other private vehicles, the largest group of public transport users usually are young people and students (IUCCE, 2018). The number of student passengers on Trans Semarang has increased steadily year on year (See Figure 1a).

The Semarang government developed Trans Semarang in an effort to provide better public transportation that is safe, resilient, comfortable, and affordable for citizens. The bus system is expanding and expected to ply all 12 corridors by 2021. Even though Trans Semarang is a good initiative and has a good performance track record, there is still ample scope for improvement. Such improvement will arguably encourage people to shift from private vehicles to public transport. Based on the 2016 survey, the majority of BRT users (51%) were formerly regular angkot and bus users (IGES, 2017). Without a rearrangement of the route, many angkot and regular buses overlap with Trans Semarang and lose their passengers. There are around 15 public transport routes that overlap more than 20% with corridor 1 of Trans Semarang. This means that more vehicles are on the road with a low occupancy. Therefore a comprehensive public transport system is needed, not only to enable effective and efficient mobility, but to reduce vehicle use. Such changes would potentially lead to a resilient and environmentally-sustainable mobility system.

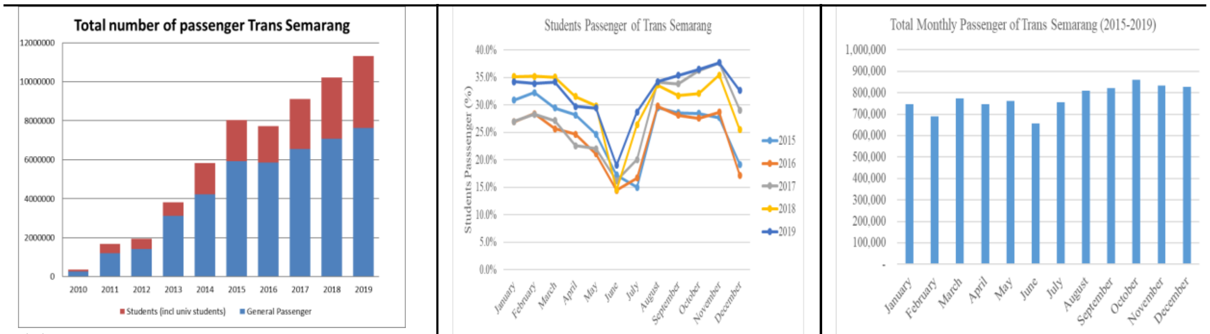
Passenger of Trans Semarang and Its Variations

There has been a gradual expansion of the coverage area of Trans Semarang through the additional routes and corridors, from one corridor at the beginning of operations in May 2009 to 10 corridors (8 corridors & 2 feeder corridors) in 2020, resulting in an increased number of total annual passengers. The total number of passengers using Trans Semarang grew from 371,336 passengers in 2010 to about 11,308,912 passengers in 2019 or more than 30 times within 10 years of operations (Figure 1a). The special pricing policy from the city government for students and elderly passengers made Trans Semarang more popular for school travel (include university students) (Figure 1b). As a result, over the last five years students have grown to make up around 35% of the total passengers (2015-2019). The highest passenger volume of Trans Semarang is around 2677 passengers per hour per direction in corridor 1 — a passenger volume that rivals Beijing or Islamabad (ITDP, 2018).

An overview of the variation in numbers of total monthly passengers reveals a typical decrease in numbers during the school holiday seasons (June – July & December) every year. The total number of passengers in June is the lowest compared to other months (Figure 1c).

Baseline Survey

The awareness-raising campaign featured in this article was carried out at three junior high schools in Semarang: school no. 1 (SMP 1); school no. 7 (SMP 7) and school no. 31 (SMP 31) considering the accessibility to Trans Semarang corridors and its locations. Two schools are located near bus corridors (SMP 1 and SMP 7) while the other school (SMP 31) represented a control location without access to a bus corridor. There is a bus shelter in front of SMP 7 served by six out of seven corridors (bus corridors no. 1,2,3,4,5 and 7) making it the most accessible from all directions. The SMP7 is also located in the city center around 600 meters from the city hall in the central business district. The SMP1 is served by three out of seven corridors of Trans Semarang (corridors no. 1, 4 and 5) but the nearest shelter was around 300 meter from school. The SMP1 is located slightly outside the city center but is still within a radius of less than 5 km from the city center. The SMP31 is located in a residential sub-urban area around 8 km from the city center and a long way from any bus route—about around 1.5 km from the school. Due to limited resources, only three schools were selected for this research.



(a) Total number of passenger since 2010

(b) Proportion of student as passenger

(c) Monthly variation of passenger Trans Semarang

Figure 1 Profile and Seasonal Variation of Passenger of Trans Semarang

Two surveys were conducted within a three-month interval to evaluate the effect of awareness-raising among participants and non-participants. The baseline survey was performed through an online survey targeting all three school in October 2017. The baseline survey gathered basic information on several issues such as: (a) understanding traffic safety; (b) recognition levels of Trans Semarang; (c) comprehension for Trans Semarang; (d) travel modes for school travel; and (e) the perceived evaluation on barriers and benefits of using Trans Semarang for daily activities. Participation in the survey was on a voluntary basis for all three grades at the surveyed junior high schools. The sample size was 857 students or approximately 38% of the total population. The questionnaires were distributed to all three grades at each school and the largest sample of around 39.8% was obtained from grade 2, while the other remaining two grades (grade 1 and grade 3) were around 30%. Larger sample sizes were obtained from two schools (SMP 1 and SMP 7) while SMP 31 representing a control school comprised 21.3% of the sample. About 55.4% of the students participating in the baseline survey were female.

Table 1 Sample Distribution (Baseline Survey and Post Training Survey)

Sample Size by School	**Total all Grade**		**Grade 1**		**Grade 2**		**Grade 3**	
	N	**%**	**N**	**%**	**N**	**%**	**N**	**%**
A. Baseline Survey								
SMP1 (School 1)	350	40.8%	132	15.4%	132	15.4%	86	10.0%
SMP 7 (School 2)	335	39.1%	114	13.3%	116	13.5%	105	12.3%
SMP 31 (School 3) (Control/far from bus shelter)	172	20.1%	17	2.0%	84	9.8%	71	8.3%
Total Sample Size	857	100%	263	30.7%	332	38.7%	262	30.6%
B. Post Training Survey	P	Non- P	P	Non- P	P	Non- P	P	Non-P
SMP1 (School 1)	26	14	3	4	23	10	0	0
SMP 7 (School 2)	30	11	9	1	12	1	9	9
SMP 31 (School 3) (Control/far from bus shelter)	21	23	7	3	10	5	4	15
Total Sample Size	77	48	19	8	45	16	13	24

Note: P: Participants & Non-P: Non-participant

The baseline survey measured the level of student’s recognition of Trans Semarang (Table 2). Less than 10%of students knew about the Trans Semarang, while more than half of students knew about Trans Semarang in general. However, around 35% of students knew more detailed features of Trans Semarang such as (a) total corridors; (b) the role of bus shelters; (c) student discounts on weekdays etc. Around 70.3% of the surveyed students acquired this information about Trans Semarang from direct observation; this was especially the case for schools located nearby or served by the buses. Social media was the second most common channel through which students learned about the system; this channel played a key role in the suburban school. More than 28% of students recognized the shelter near their house.

Table 2 Knowledge about Trans Semarang & daily travel patterns

No	Variables	All Schools		SMP 1 & SMP 7		SMP 31	
		Freq	%	Freq	%	Freq	%
1	Knowledge about Trans Semarang BRT						
	a. Don't know	86	10.0%	77	11.2%	9	5.2%
	b. Know in general	465	54.3%	371	54.2%	94	54.7%
	c. Understood in more specific (example: routes, shelter, pricing for students, etc)	295	34.4%	228	33.3%	67	39.0%
	d. Understood very well (almost all aspects of BRT)	11	1.3%	9	1.3%	2	1.2%
2	Source of Information (Multiple answer)						
	a. Direct observation (see it every day)	641	71.1%	533	74.9%	108	57.1%
	b. Social Media	134	14.9%	76	10.7%	58	30.7%
	c. Newspaper, bulletin, leaflet	41	4.6%	32	4.5%	9	4.8%
	d. Family, Friend or Network	39	4.3%	35	4.9%	4	2.1%
	e. Others	13	1.4%	7	1.0%	6	3.2%
	f. No response	33	3.7%	29	4.1%	4	2.1%
3	Shelter near house						
	a. Yes	524	58.8%	408	58.2%	116	61.1%
	b. No	333	37.4%	277	39.5%	56	29.5%
4	Distance from home to nearest shelter (m)						
	a. < 500 m	253	28.4%	198	28.2%	55	28.9%
	b. 500.01 - 1000 m	181	20.3%	151	21.5%	30	15.8%
	c. 1000.01 - 1500 m	78	8.8%	59	8.4%	19	10.0%
	d. > 1500 m	92	10.3%	77	11.0%	15	7.9%
	e. Don't know	253	28.4%	200	28.5%	1	0.5%

Source: Author's survey

Daily school travel patterns in Semarang city

Most students use different modes for going to and from school, and only a quarter of students use similar modes for both trips (Table 3). Most students who used a drop-off service used a different mode for returning home, such as an online ride-hailing motorcycle taxi system, Trans Semarang, or walking home from school. In contrast, many motorcycle users use the same mode of transport to return home from school. A similar pattern was also observed for users of Trans Semarang. While Trans Semarang plays a significant role for returning home from all schools, the role of non-motorized modes was important for travelling to school. Further, walking was the preferred non-motorized mode in the suburban school. Bicycles are preferred for students at schools located in the city center and surrounding areas. The proportion of students walking home from school increased to 33.8% in suburban areas and was even higher in the city center. This suggests the important role and flexibility of non-motorized transport (bicycle and walking) as a mobility option. The use of motorcycles was higher in the suburban school.

Yet another finding from the survey involved the strong dependence of student mode choices on parents and relative travel patterns. Drop-off services from parents, family members or relatives often delivered students to school. However, the pick-up/drop off services were not often feasible for return trips due to mismatched schedules between school and work. Instead, online taxis that provide a point-to-point service similar to the family drop-off service were often preferred to return home (Nugroho, 2019). The use of the online taxi system tends to be more popular and increase slightly in the city center.

Table 3 Modal Shift of school trips, from going to & return from school

To School/ From School	Walking	Motorcycle	BRT	Shared Taxi	Pick-up & Drop off	Bicycle	Other public transports (Minibus, etc)	No answer / missing data	Total
Walking	**2.6%**	0.4%	0.3%	0.2%	1.0%	0.3%	0.4%	0.0%	5.2%
Motorcycle	0.4%	**10.1%**	1.5%	1.0%	2.0%	0.4%	1.1%	0.0%	16.6%
BRT	0.3%	1.5%	**7.5%**	0.9%	3.3%	0.1%	2.7%	0.0%	16.4%
Shared Taxi	0.2%	1.0%	0.9%	**3.8%**	3.0%	0.2%	1.1%	1.0%	11.2%
Pick-up & Drop off	2.0%	3.3%	3.0%	18.0%	**0.9%**	3.0%	0.0%	0.3%	**30.6%**
Bicycle	0.4%	0.1%	0.2%	0.9%	2.8%	**0.1%**	0.0%	0.4%	4.9%
Other public transports (Minibus, etc)	1.1%	2.7%	1.1%	3.0%	0.1%	6.5%	**0.0%**	0.0%	14.5%
No answer/ missing data	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	**0.0%**	0.5%
Total	7.1%	19.1%	14.6%	**28.0%**	13.1%	10.7%	5.7%	1.7%	1

Source: Author's survey & calculation.

Perceived Perception on the merits and barriers of using Trans Semarang

The survey found around 44% of students do not face any barriers to using Trans Semarang. Moreover, the suburban school had the fewest barriers compared to the other schools. In fact, the largest barrier is insufficient coverage service of Trans Semarang. The existing eight corridors and two feeder corridors are not enough to cover all areas within the city. Hence, students continue to use private vehicles (Table 4). The mismatch in schedules between school and work is another important barrier for students in the suburban area. Affordable fares are the main merit of Trans Semarang because the government offers a special pricing scheme (discount) for students on weekdays of about 1000 rupiah (7 US cents, 1 USD=14000 rupiah), which is equal to 28% of the normal fare for regular passengers. The bus service is comfortable and convenient because buses have air conditioning for hot weather in the dry season and humid conditions in the wet season.

While Trans Semarang has many desirable features, there were also some drawbacks and downsides, including overcrowding. A sharp rise in demand occurs when school finishes; bus operators have tried to address this issue with rescheduling to reduce headway during peak demand periods. However, crowding persists and may require additional attention moving forward. Some of the challenges involved only one of the schools. For example, distance to the bus shelter is a problem associated with the suburban school (9.1%). In all of the schools, the majority of students believe that social media (Instagram, Facebook and Twitter) is the most appropriate approach for raising awareness of the bus program.

Table 4 Perceived evaluation on BRT Trans Semarang

No	Variables	All Schools		SMP 1 & SMP 7		SMP 31	
		Freq	%	Freq	%	Freq	%
1	Barrier to use BRT						
	a. Odd Route (not covered by bus route)	190	20.1%	152	21.7%	38	20.0%
	b. Odd Schedule (mismatch schedule)	23	2.4%	12	1.7%	11	5.8%
	c. Expensive Ticket	2	0.2%	2	0.3%	0	0.0%
	d. Not comfortable and not convenient	35	3.7%	32	4.6%	3	1.6%
	e. Not safe (security aspect)	4	0.4%	4	0.6%	0	0.0%
	f. More comfortable with private vehicles	112	11.9%	99	14.1%	13	6.8%
	g. Others	76	8.0%	72	10.3%	4	2.1%
	h. No barrier (already use it)	415	43.9%	312	44.5%	103	54.2%
2	Merits/Benefits to use BRT (multiple answer)						
	a. Price is cheap	604	34.7%	483	35.4%	121	32.2%
	b. Comfortable (with air conditioning, etc)	376	21.6%	289	21.2%	87	23.1%
	c. Punctuality (schedule)	42	2.4%	29	2.1%	13	3.5%
	d. Secure (security aspect)	185	10.6%	139	10.2%	46	12.2%
	e. Social Fabric (ride together with friends)	180	10.3%	132	9.7%	48	12.8%
	f. Closed to the shelters	169	9.7%	153	11.2%	16	4.3%
	g. Other reason	20	1.1%	20	1.5%	0	0.0%
	h. Don't answer	107	6.1%	89	6.5%	18	4.8%
3	Problem related on Boarding and Alignment (multiple answer)						
	a. Distance in between shelters is too far	64	6.8%	45	6.1%	19	9.1%
	b. Crowded in the bus (load factor is high)	290	30.7%	243	33.0%	47	22.5%
	c. Short interval of stop	58	6.1%	49	6.7%	9	4.3%
	d. Don't know how to ride	14	1.5%	14	1.9%	0	0.0%
	e. Others	26	2.8%	23	3.1%	3	1.4%
	f. No Barrier	370	39.2%	283	38.5%	87	41.6%
	g. Don't answer	87	9.2%	62	8.4%	25	12.0%
4	Method for awareness raising campaign (multiple answer)						
	a. Social Media (Instagram, Facebook, etc)	627	50.0%	495	49.9%	132	60.3%
	b. Wall magazine at school	158	12.6%	134	13.5%	24	11.0%
	c. Hard copy: Newspaper, Magazine or Leaflet/Pamphlet	140	11.2%	114	11.5%	26	11.9%
	d. Formal education (course inside class)	185	14.8%	146	14.7%	39	17.8%

	e. Others	53	4.2%	47	4.7%	6	2.7%
	f. Don't Answer	43	3.4%	32	3.2%	11	5.0%
5	Frequency to use BRT						
	a. Never	159	18.6%	126	18.4%	33	19.2%
	b. Very rarely	128	14.9%	116	16.9%	12	7.0%
	c. Rarely	233	27.2%	184	26.9%	49	28.5%
	d. Often	224	26.1%	172	25.1%	52	30.2%
	e. Very often	113	13.2%	87	12.7%	26	15.1%

Source: Author’s survey.

Understanding student’s travel behaviour on the public bus Trans Semarang

An ordered logit model was used to determine which factors influence the frequency of bus use among the surveyed students. As shown in Table 5, the model was calculated using the software LIMDEP (NLOGIT) (Greene, 2002). In developing the model, the first step was examining whether there were any differences in the use of Trans Semarang across different schools. The frequency of use of Trans Semarang was differed significantly between the reference school (SMP31) and the others (SMP1 and SMP7). Although SMP1 and SMP7 are located in the city center, the frequency of bus use is significantly lower than students in the suburban school (SMP31). The estimation result also confirmed that Trans Semarang played a more important role for school travel among students in the flood hazard area (SMP31)—an important finding with implications for resilience.

The model could also help evaluate the impacts of other factors on the use of Trans Semarang. For instance, the model showed that usage pattern remained consistent across grades. However, female students and students who depended on the drop-off service tended to avoid the bus. Another set of potentially important factors involved the built environment. In the survey, one way this possibility was examined involved looking at the distance to the nearest bus shelter to the house. The frequency of using the bus increased significantly if the bus shelter was located less than 1000 meters from the home. However, the built environment surrounding schools was not significant variable.
How information on bus services is obtained is another influential variable associated with the perception and opinion about the bus services. When students observe bus services directly, this improves their motivation to use the service. The perception on the merits of Trans Semarang, such as affordable ticket prices and comfort to deal with hot and humid weather, had a positive and significant influence on the estimation results. In contrast, the evaluation on the service coverage and bus frequency had a negative and significant influence on frequency use of Trans Semarang. Looking at model performance, the threshold value (μ) that divides a continuous joint distribution of error terms ε into intervals associated with different levels of possibility is substantively and statistically significant in the estimation results. The constant term μ represent the threshold parameter between all levels is clear and significant. This suggests that the model fits the survey data well.

Table 5 Estimation results of ordered logit model

Variables	Beta (t-score)
Constant	1.434 (4.599)***
Student's Attributes	
Female	-0.400 (-3.041)***
Grade – 2	0.060 (0.363)
Grade - 3	-0.175 (-0.992)
School Location (SMP 31 as reference)	
School 1 (SMP No 1 – City Center)	-0.580 (-2.270)**
School 2 (SMP No 7 – Within city boundary)	-0.615(-2.395)**
Built Environment	
Distance from home to nearest bus shelter less than 500 m	0.606 (3.737)***
Distance from home to nearest bus shelter 501 – 1000m	0.758(4.3710***
Distance from school to nearest bus shelter less than 500 m	0.341(1.431)
Distance from school to nearest bus shelter 501 – 1000m	0.385(1.418)
The way to get information about Trans Semarang	
Direct observation	0.549(2.759)***
Through social media (Facebook, Instagram, twitter, etc)	0.017 (0.075)
Going to school by drop-off service by family	-0.465(-3.530)***
Barrier to use public Transport	
Barrier relate coverage area of bus service	-1.460(-8.836)***
Barrier relate to odd schedule between bus and school	-0.866(-2.140)**
Opinion about benefit of Trans Semarang	
Cheap fare ticket	0.932 (6.106)***
Comfortable because of air conditioning system inside the bus & shelter	0.396(2.904)***
Problem on boarding and alignment due to distance between station	0.196 (0.770)
Threshold parameter for index (μ)	
μ (1) (between Y=0 and Y=1):	1.060 (15.125)***
μ (2) (between Y=2 and Y=3)	2.502 (31.903)***
μ (3) (between Y=3 and Y=4)	4.302 (38.173)***
Model's Attributes	
Degree of Freedom	17
AIC	2.879
BIC	3.001
Mc Fadden Pseudo R-squared	0.099

Source: Author's calculation

4. AWARENESS-TRAINING PROGRAM AND RESULTS

Awareness-raising program

The awareness-raising program consisted of four main phases:

1) Planning activities in collaboration with multiple stakeholders. First, a cross-sectoral discussion was held together with relevant institutes and organizations in October 2017. Second, materials were designed and developed for raising awareness of Trans Semarang. There were several relevant stakeholders involved in the program, including: the City Planning Department, Education Department, Chairman of Junior High Schools, Parents Association, Local Police Department, Transport Authority; and the operator of Trans Semarang. Following the discussions between these different groups and

organizations, the team developed materials for the program, including: (a) modules and (b) leaflets on how to ride the bus. The modules were developed for three main groups within the schools: (a) teachers; (b) parents; and (c) students (Figure 2). The leaflets were developed to provide detailed guidelines on how to ride the Trans Semarang (Figure 2). The leaflet provided: (a) general information on how to ride the bus safely; (b) specific information about safety aspects inside the bus; (c) payment methods to buy tickets; (d) standard rules and regulations; and (e) regular schedules and maps of routes.

Figure 2. Modules on road safety and leaflet on how to use the bus

2) Capacity building and training for trainers (school teachers, parents and peer educators)

The second step was capacity building for trainers to increase their knowledge and awareness of Trans Semarang, and to carry out traffic safety assessments regarding the vulnerability of schools. The activities included a workshop on developing plans for activities under the program together with teachers and parents as participants; selecting trainers for each school; and identifying school activities to be used to implement the awareness-raising campaign. Participants gathered information such as knowledge about road safety, information on traffic policy and how to use public buses safely for junior high school students, traffic problems and vulnerability in the school vicinity, and the basic needs for implementation of awareness training for students. Training for trainers was performed over two days in November 2017. The activities covered practical training on road safety, recognizing trafficked areas surrounding the schools and riding the buses. Three main points related to the assessment of traffic vulnerability such as pedestrian access, traffic jams and traffic situation in the morning (start) and afternoon (finish), and additional street occupation by street vendors (especially during the afternoon) were also covered. Finally, participants were able to develop maps indicating traffic vulnerability and transport infrastructure in a .5-1 km radius of each school.

3) Implementation of the awareness-raising program;

The third step was the actual implementation of training programs by the facilitators. The training encouraged active participation from the students, self-assessment, hands-on activities and role-playing. The program consisted of three steps: (a) assessing the traffic vulnerability for commuting; (b) providing knowledge, information and skills on traffic safety and (c) encouraging students to pass on the knowledge to classmates. The awareness-raising program was held from mid-November to early-December 2017 or around 2 –3 weeks depending on time availability at each school. There was a student-led activity to assess traffic vulnerability for commuting, knowledge information and skills on traffic safety, and a practical program on how to ride the bus (Figure 3).

Figure 3 Awareness-raising program

4) Monitoring and evaluation of the program:

The final step was the monitoring and evaluation of the impact of training on the intentions and behaviour when using the Trans Semarang. A comparative analysis was conducted by using the data from the baseline and post-training survey. The post-training survey was distributed to two groups of respondents: participants and non-participants of the awareness-training program. By comparing the responses of these two groups, it was possible to analyze the initial impact of the training program on the intention to use Trans Semarang for school travel. The post-training survey was conducted at the end of December 2017 to gather about 125 students from all grades and schools. The sample size was around 14.5% of the participants of the baseline survey (Table 1) and 61.6% of the sample were those who had participated in the awareness-raising program while the remaining set of respondents did not participate (Table 1).

Table 6. Impact on knowledge, intentions and behavior

No	Variables	Participant		Non-participant	
		Freq	%	Freq	%
A	**Impact on the sharing of knowledge and information**				
1	Transfer of knowledge and information to other classmates or friends				
	a. Distribute the information to other colleagues	64	83.1%	n/a	n/a
	b. Don't pass on information to others	12	15.6%	n/a	n/a
	c. Missing Data	1	1.3%	n/a	n/a
2	How to distribute information to others (multiple answer)				
	a. Direct communication	45	29.8%	n/a	n/a
	b. Wall Magazine	45	29.8%	n/a	n/a
	c. As an agent of change (show to other students)	23	15.2%	n/a	n/a
	d. Through extracurricular or class room	38	25.2%	n/a	n/a
B	**Impact on the intentions and behavioral changes**				
3	Intention to use Trans Semarang				
	a. Yes, willing to use Trans Semarang	56	72.7%	n/a	n/a
	b. No, not willing to use BRT	8	10.4%	n/a	n/a
	c. No response	13	16.9%	n/a	n/a
4	Behavioral Change				
	a. Increase the frequency to use Trans Semarang	38	49.35%	n/a	n/a
	b. Don't change the frequency to use Trans Semarang	15	19.48%	n/a	n/a
	c. No response	24	31.17%	n/a	n/a

Source: Author's survey & recapitulation.

The monitoring data demonstrated the impact on the awareness-raising campaign to use Trans Semarang in the short-term. The number of students willing to use Trans Semarang increased to 72.7% while the remaining 10.9% did not want to use the bus for various reasons. The survey confirmed almost 50% of students increased their willingness to use Trans Semarang, while nearly 20% of students did not. An assessment of the reasons indicated that the main reason students were reluctant to use Trans Semarang was because of its coverage areas (odd routes and no shelter near their house). We also found student's ability to make mode choice decisions was another reason. In many cases, parents did not allow students to use Trans Semarang for school travel. This is consistent with claims elsewhere that students may not be able to make decisions about their mobility options (E. Mocca, 2015) and parents may be an important audience for future awareness-raising programmes (Ahsan, 2015). By comparing the response given by participants and non-participants, the results suggest that the awareness-raising program also encouraged students to act as a messenger by transferring the information to their other colleagues (Table 6). Finally, the survey showed about 83.1% of participants passed their knowledge on to classmates through direct communication and wall magazines.

5. DISCUSSION AND CONCLUSIONS

Although the share of public transport is relatively small compared to other modes in Semarang, there has been an increasing trend in student use of Trans Semarang over the last five years. Increasing our understanding of travel behaviour among students, one of the largest groups of Trans Semarang users, is the first step in an inclusive process that can boost transport resilience. With these important aspects in mind, it is important to take the next steps--that is, discouraging the use of private vehicles for daily school travel, and preventing the modal shift to private vehicles as young adults. To encourage a modal shift from private to public transport, especially for the young generation, raising awareness of students will be critical. A series of awareness-raising training activities were carried out for these purposes in three junior high schools in Semarang. The activities were facilitated by a multi-stakeholder process wherein the education department facilitated communication with teachers, parents, students and other critical stakeholders such as the police department, transportation agency, and bus operators. It was particularly important to engage parents because, as survey results would later show, parents play an important role in the program, as some students lack the autonomy to make decisions about how they get to school.

The research found variation in the number of passengers due to school holiday seasons. The study also confirmed the modal shift of going to and returning from school in Semarang. The drop-off service with private vehicles is popular for going to school; Trans Semarang is used more frequently to return home from school. The affordability, comfort, security and opportunity to socialize are some of the benefits of Trans Semarang. However, the online ride-hailing service is also popular and may overtake buses in the future (Nugroho, 2019).

This article shows that an awareness-raising program can be an effective way to alter attitudes and travel behaviour among young people. It also demonstrates that a social experiment can help shift these attitudes and behaviours. The article further clarified that this can be achieved through a cascade and a peer-to-peer system. The cascade system involved disseminating information through trainers to about 77 students who voluntarily participated in the program. The peer-to-peer system helped the transfer of knowledge from participants to classmates—for instance, about 83% of training participants passed on the knowledge to their classmates through direct discussion/communication and wall posters. A further set of activities involved the provision of trainers for the subsequent training of teachers, school committees and parents. Delivering messages or campaigning to other students by trained students (a peer-based system) is also effective and efficient, especially in light of time and budget restrictions. To make awareness raising sustainable, however, it is imperative to integrate these activities into the curriculum and relevant school activities, such as orientation programs for new students.

The fact that awareness-raising increases the willingness to use Trans Semarang is also important to boosting transport resilience in Semarang. Doing so will encourage a key segment of the ridership to use a mode that is inherently more resistant to climate and related impacts. Awareness-raising has the potential to encourage those from a young age to shape transport patterns in the future. Semarang's government seems to have recognized this potential. For instance, it has introduced programs such as special pricing for students to encourage students to use Trans Semarang. It may also adopt other similarly motivated efforts such as a smart card for non-cash payments. However, as this article makes clear, a critical piece of the resilience puzzle is raising awareness of the benefits of public transport for key ridership segments. Above all, awareness-raising should not only feature cost, comfort, and socialization opportunities, but also public safety.

Another dimension of building resilience is appreciating the shortcomings of the current system. On this point, the survey research revealed that a lack of infrastructure is a key barrier in preventing a modal shift to the public transport system. The lack of access for some students is a considerable constraint. One way of addressing these kinds of barriers is not simply to raise awareness, but to create an interactive consultative process that informs decisions on public transport. Such a process could be used to generate inputs which could then be put towards bottom-up sustainable and resilience urban mobility strategies.

There is still the need for future research to derive effective interventions and improve programs for adolescences. What is the best campaign, over what duration, and for which grade and age group? Which are the most influential encouraging modal shifts? These remain key questions. Such questions require more systematic and evidence-based research on the impacts of awareness programs. This study can only draw conclusions on the short-term effects of behavioural change. Future research should also investigate whether the effect persists. An additional challenge, but also a potentially fruitful avenue of inquiry, involves expanding the program to other schools in Semarang to create a bigger impact on travel behaviour among junior high school students.

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An Analytical Approach on Transport Resilience with Smart Transport Systems

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ABSTRACT

As urban areas across the world continue to witness explosive growth, transport operations have become vital to meet the economic needs and social well-being of the populace. Transport operations facilitate the movement of people to their places of employment, to leisure activities, and enable social and cultural interactions. Climate change, natural disasters and temperature rises pose an increasing risk to transport systems and economic growth. Transport resilience is therefore a key agenda item for policy makers. Advances in smart transport systems have meant that such threats can be monitored and managed effectively to increase the resilience. So far there has not been substantial analysis of the benefits of smart transport systems in enhancing transport resilience. This research seeks to make a tangible contribution by a way of a two-step analysis approach. Namely, the research 1) uses a microscopic multimodal traffic flow simulation tool to analyze the impact of incidents and natural disasters on traffic conditions in a target area, and 2) estimates the benefits (e.g., reduced congestion, improved safety and reduced vehicle emissions) by smart transport systems in response to incidents and natural disasters. Given the lack of analysis in this area, it is expected that the research's findings will provide the right directions for policy makers which can make a positive contribution to achieve the 2030 Agenda of Sustainable Development Goals.

Key words: smart transport systems, transport resilience, microscopic multimodal traffic flow simulation, vehicle emissions, natural disaster

1. INTRODUCTION

Transport systems are an engine for trade and the backbone of the global economy. At the national level, the transport sector is an enabler of economic and social development as transport moves people and goods resulting in social and cultural interactions. Rural communities are also dependent on transport systems to connect them to markets and urban centers, thus enabling the development of rural areas. In such an environment, the indispensable role of transport systems is clear, and when transport comes to a halt, all economic and social activities comes to a halt. At the same time, the world today is witnessing rapid urbanization, with over 50% of the global population living in urban areas which is expected to rise in the coming years particularly in Asia (United Nations Department of Economic and Social Affairs, 2019). The rural to urban migration taking place in the developing world, as people move in search of employment and a better quality of life, has resulted in cities that are increasing in size and complexity. Naturally, city infrastructure and resources are increasingly under pressure to meet the demands of residents. Transport systems in particular are getting more complex which is resulting in various traffic issues in cities. To mitigate such negative implications, smart transport systems, including Intelligent Transport Systems (ITS), have been engaged in many cities to manage complex traffic conditions and to keep systems functioning at optimal levels. Among various definitions, smart transport systems, particularly ITS, are defined as an agglomeration of diverse technologies that enhance the sustainability of transport systems in a safer, smarter and greener way (United Nations Economic and Social Commission for Asia and the Pacific, 2019).

While smart transport systems have greatly enhanced the ability to manage intricate transport systems, transport infrastructure is increasingly vulnerable to disruptions from traffic incidents, natural disasters, terrorist attacks and extreme weather conditions. Transport resilience can be defined as "the capability to

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recover from a disruption to an operational level similar to prior to the disruption in a timely manner" (Linkov and Palma-Oliviera, 2017). Ensuring resilient transport systems is therefore a top priority for policy makers around the world as transport networks can be quickly overwhelmed by unexpected events that can bring transport systems to a halt. Examples can be found easily. The 2010 and 2011 earthquakes in Christchurch, New Zealand, resulted in damage to road infrastructure which affected traffic flows in parts of the city (Koorey, 2018). Pacific Island states given their geographic locations are particularly vulnerable to natural disasters such as hurricanes, floods and landslides, which can quickly overwhelm their transport infrastructure resulting in huge economic losses. In Fiji, for instance, the road authority is allotted a third of the government budget (World Bank, 2017), highlighting the importance of road transport networks to the economy. In 2015, an earthquake in Nepal resulted in damage to several key roads which required the deployment of helicopters in some areas to deploy emergency relief (Xie et al., 2017).

Although transport resilience is not the primary goal of smart transport systems, they can play an important role in improving the resilience of transport systems to unexpected events like traffic incidents and natural disasters by enabling restoration of transport operations and services. Smart transport systems can monitor the occurrence of such events on a continuous basis, and alert drivers and passengers in the vicinity of an affected site. By using a variety of data from sensors embedded in emergency vehicles (e.g., ambulances and firefighting vehicles) and infrastructure, smart transport systems can react and assist in post event efforts, thus improving the resilience of transport systems. However, while smart transport systems can contribute to improve transport resilience, there is a gap in research on identifying tangible benefits of such systems for transport resilience.

Further, following the COVID-19 pandemic, transport resilience has been receiving renewed interest as a result of a sharp drop in demand for transport services due to lockdowns. Although social and economic activities have significantly decreased, governments are still required to provide transport services to ensure fundamental social and economic interactions in a limited but safer way. Smart transport systems have increasingly gained attention because the full utilization of these systems could enhance the continuity of transport services during the COVID-19 pandemic resulting in a more resilient transport systems.

In response to growing interests in utilizing smart transport systems for traffic incidents and natural disasters, and the impact of COVID-19 pandemic, it would be worthwhile to explore the advantages of such systems from the viewpoint of transport resilience.

2. PURPOSE AND SCOPE

According to the facts mentioned above, the main purpose of this research was to find tangible evidence on the use of smart transport systems for transport resilience. Particularly, this research focused on traffic incidents and natural disasters, which would significantly affect traffic conditions. Given that it is difficult to reflect unexpected incidents and natural disasters accurately into the research, the simulation approach based on scenarios was used to achieve four objectives:

1. Set up the experiment environment to replicate the reality of traffic conditions with a microscopic multimodal traffic flow simulation tool.
2. Analyze the impact of incidents and natural disasters on traffic condition in a target area;
3. Estimate the benefits (e.g., congestion, safety and vehicle emissions) of smart transport systems in response to incidents and natural disasters.
4. Interpret the findings from the viewpoint of transport resilience.

Note that this research adopted a high-quality of techniques to achieve the above objectives.

3. RELATED STUDIES

Although previous studies regarding the use of smart transport systems for transport resilience have been rarely found, a review of the literature on transport resilience reveals that much of the focus has been on the vulnerability of transport infrastructure to natural disasters, weather-related events or traffic incidents. Dawson et al. (2016) assessed the extent to which projected sea-level rise was likely to impact the functioning of coastal railway lines in England, in particular segments of the London to Penzance railway line. Vajjarapu et al. (2020) evaluated climate change adaptation policies for urban transport in India with a focus on flooding, and proposed policies to improve the resilience of the city transport infrastructure through flood adaptation strategies.

Other studies have looked at the economic impact of natural disasters, such as earthquakes and sea level rise on transport infrastructure. Market Economics Limited (2017) looked at the impact of the Kaikoura earthquake of 2016 on freight transport and tourism in the Canterbury region of New Zealand. McCarron et al. (2018) assessed the impact of rising sea levels on sea ports in Asia and the Pacific and estimated that it would cost between US$ 31billion and US$ 49 billion to protect and elevate fifty-three of the region's largest port areas to adapt to climate related risks.

On research for the use of smart transport systems to improve transport resilience, although there are few, the research focus has been on how these technologies could be deployed prior to and following a natural disaster. For instance, the use of probe car data, following the 2011 earthquake and tsunami in Tohoku Japan, assisted in post disaster efforts by identifying roads that were operational after the earthquake, and roads that needed to be repaired or inspected (Tanaka et al., 2014). In the United States, Louisiana Department of Transportation and Development collaborated with United States Geological Survey to deploy Information Stations that can gather and transmit data on traffic and water level conditions along frequently used hurricane evacuation routes, enabling monitoring of road and traffic conditions in near real time (Federal Highway Administration, 2003). Federal Highway Administration successfully piloted in 2016 a "Mobile Solution for Assessment and Reporting" which uses mobile applications to collect and upload data needed for the restoration of transport infrastructure following natural disasters (Hendrickson, 2018). This application can respond to the need for speedy damage assessments of transport infrastructure in the aftermath of a hurricane, flood, or storm, and enables transport infrastructure damage to be repaired quickly and restored for normal traffic conditions. It was revealed that the process time by using this application was shortened from 18 hours to 20 minutes on average, resulting in savings of US$ 1.2 million per disaster. Aside from the response to natural disasters, weather incidents have been of great interest to researchers. In Finland, a road weather information system was expected to save an average of 23 minutes per de-icing activity for road maintenance (Pilli-Sihvola et al., 1993). The deployment of weather information controlled variable speed limitations showed relatively good benefit-to-cost ratios ranging from 1.1 to 1.9 (Schirokoff et al., 2006). However, in this analysis, ancillary impacts on pollution were assumed marginal and were not included.

Although it is at an early stage, emerging technologies have been highlighted as a measure for managing traffic operations, particularly including the evacuation. Bahaaldin et al. (2017) revealed that more than 50% of traffic delays could be decreased when the market penetration rate of connected vehicles reaches 30%. Other studies predicted that 20% of delay could be reduced by deploying connected vehicles for the evacuation on short-notice (Intelligent Transportation Systems Joint Program Office, 2015), and 88% of delay and crossing conflicts could be decreased with an autonomous reservation-based intersection control for the evacuation traffic control (Chang and Edara, 2017).

As can be seen from the literature review, smart transport systems can be utilized for reducing the vulnerability of transport infrastructure. However, there remains a gap in the literature quantifying the benefits of smart transport systems for transport resilience. To be specific, studies relating to transport resilience have mostly not explored the options of smart transport systems. Although there are some studies about the use of smart transport systems for traffic incidents or natural disasters, it is not directly linked to transport resilience or is limited and does not take into account detailed benefits including vehicle emissions.

4. METHODOLOGY

Overall approach

In response to the objectives of this research, the multi-level procedure was used which included i) setting up a microscopic multimodal traffic flow simulation tool, ii) establishing scenarios that can evaluate the impact of smart transport systems in traffic condition in a target area, ii) applying scenarios to the experiment environment, iv) calculating benefits by each scenario from the experiment, and v) analyzing the results to see the impact of smart transport systems in a target area. Figure 1 elaborates the details of overall approach.

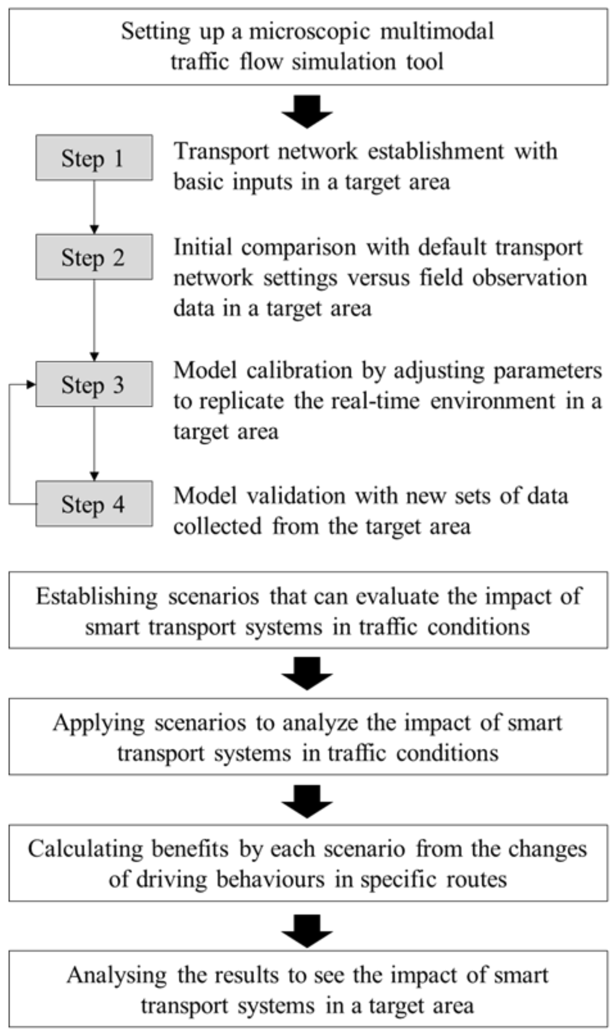


Figure 1: Overall process for the analysis

Approach taken in this research is quite straightforward, except for setting up a microscopic multimodal traffic flow simulation which requires a systematic approach. This has multiple loop processes to replicate the real-world traffic conditions.

Particularly, for step 3, the calibration procedure continues in a loop until signal timings, traffic volume for each intersection, travel speed at all link sections and travel time for all network sections meets specific thresholds. For step 4, travel times from the model are compared point by point with the ones from predesignated matching sections in a target area. Although above steps are described separately, in real setting procedure, calibration and validation steps are interconnected (step 3 is iterated until step 4 is satisfied).

Data sources

Considering that a microscopic multimodal traffic flow simulation tool requires a wide range of data sets, this research chose Broward County in Florida, U.S.A. as a target area where most of data are publicly available.

Figure 2 describes a specific research boundary in a target area which consists of six corridors. Six corridors are the East-West direction of Oakland Blvd, Sunrise Blvd, Broward Blvd and Davie Blvd, the North-South direction of State Road 7 and US 1.

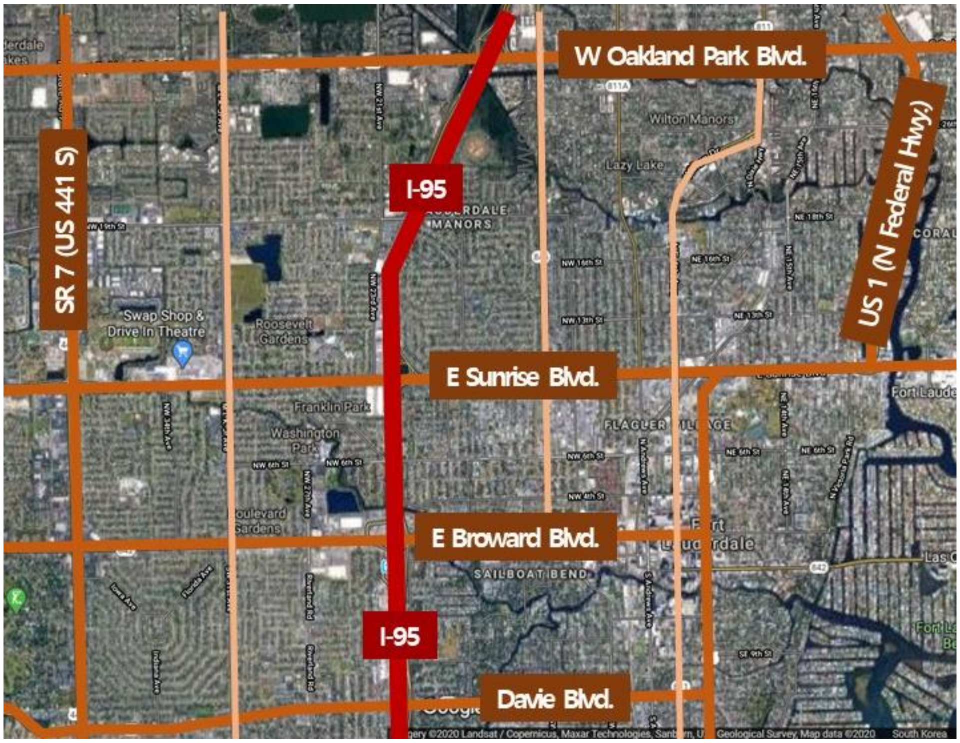


Figure 2: Specific research boundary in a target area

Data sources used for this research are summarized in Table 1. It should be noted that traffic counts including turning movements, which were extracted from different sources, were collected in the same year (i.e., 2013), and the geometry settings were also identical with the year of 2013.

Table 1: Specific data sources for the research

Group	Specific Types	Sources
Geometry	Links, nodes, intersection characteristics, road classifications, stop sign locations, speed limits, conflict areas, right-turn-on-red status	Google Maps (2020)
Traffic signal	Signal timing/heads/displays, detectors and signal controllers in 160 signalized intersections	Broward County (2020)
Public transportation schedule	Railroad/bus stations/stops, lines, service schedules and boarding information in east of I-95 and west of I-95.	
Traffic information	Turning movement field counts for 99 intersections	
	Turning movement counts for 50 intersections	Florida Traffic Online (2013)
	Traffic counts for the other 11 intersections	So et al. (2016)
	Link traffic volumes (annual average daily traffic, vehicle classifications, etc.)	Florida Traffic Online (2013)
	Link travel time in 2010 and 2013	So et al. (2016)

5. APPLICATIONS

Among many microscopic traffic simulation models such as VISSIM, Aimsun (Siemens, 2018), and SUMO (Lopez et al., 2018), VISSIM was ultimately selected for this research as a microscopic multimodal traffic flow simulation tool with two main reasons—i) the capability of modeling detailed driving behavior for various incidents and natural disasters (e.g., Liang et al., 2015), and ii) the flexibility of scenario design for incidents and natural disasters (e.g., Lin et al., 2020).

Transport network establishment

Fundamental transport networks were extracted from the U.S. Geological Survey. Detailed geometries (e.g., 1,300 stop signs, over 4,000 conflict areas) were fine-tuned by aerial images from Google Maps (2020) and by manual investigations of a target area (So et al., 2016). Furthermore, 160 signalized intersections and related traffic links were established; signal timing plans and turning movements were provided by the Broward County Traffic Engineering Division; link traffic volumes were extracted from Florida Traffic Online (2013); and travel time data were collected by manual surveys on the study site (So et al., 2016). Figure 3 shows constructed transport networks in a VISSIM environment.

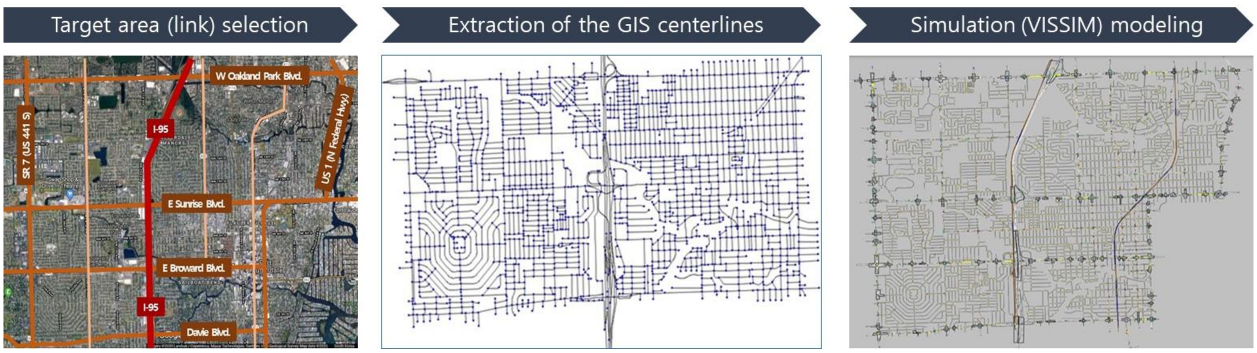


Figure 3: Constructed transport networks

Model calibration and validation

Parameter adjustments

After initial comparison between the default settings of transport networks and field observation data, parameters were adjusted as a first step of the model calibration to replicate the actual traffic conditions. To reflect change in driver's behavior following incidents and natural disasters, two parameter sets were calibrated for normal urban traffic conditions, and for forced merges and lane changes by incidents in terms of car-following and lane change behaviors. Major adjustments are as follows:

Table 2: Parameter adjustments by different situations

Parameters	Default		Urban		Incident	
Safety distance (ft) (additive/multiplicative)	2/3		3.5/4		3.5/4	
	Own	Trailing	Own	Trailing	Own	Trailing
Maximum deceleration (ft/sec^2)	-13.12	-9.84	-13.12	-9.84	-29.13	-29.13
Accepted deceleration (ft/sec^2)	-3.28	-3.28	-3.28	-3.28	-29.13	-29.13
Waiting time before diffusion (s)	60		60		120	
Minimum headway (ft)	1.64		1.5		1.35	
Safety distance reduction factor	0.6		0.5		0.3	
Max deceleration for coop braking (ft/sec^2)	-9.84		-12.84		-29.79	

Calibration checks

The remaining procedure for calibration comprises of checking traffic volume, speed and travel time to assure the accuracy of outputs from the experiment.

- Traffic volume: Traffic counts from the simulation on six corridors were compared with field data in a target area (4:00 PM to 6:00 PM in 15 minutes intervals). The established experiment produced very close match with field data which at least showed 0.92 R-squared.

  - Oakland Blvd (0.94), Sunrise Blvd (0.92), Broward Blvd (0.92), Davie Blvd (0.96), State Road 7 (0.92) and US 1 (0.94).

- Speed: Simulated vehicle speeds at all segments in a target area were checked with desired speeds observed from the field. That is, the distribution of vehicle speeds in the simulation were adjusted to follow the desired speeds from the field.

- Travel time: Simulated travel times in designated segments (2 per each corridor) in six corridors were compared with actual travel times. R-squared showed at least 0.8 between simulated and observed data.

Model validation

After the calibration procedure, travel time, traffic volume, travel speed and occupancy rate were used to validate the experiment settings in the simulation. Note that new data sets acquired from ITS devices like Bluetooth devices and detectors in five corridors in both directions as one corridor did not have such available data.

- Traffic time: The sections for examination were matched with the locations of Bluetooth devices in the corridors. Although some sections showed the lower R-squared (0.75), most of the sections showed a high correlation (more than 0.8 R-squared) between simulated and observed travel times. This means that the settings of simulation tool are generally able to replicate actual travel time along the major corridors in a target area.

- Traffic volume, travel speed and occupancy rate: Daily traffic data during PM peak hours were used to validate hourly traffic volumes, travel speeds and occupancy rates. Given that these performance measures can vary widely by many factors, validation results are generally not as satisfactory as traffic time. However, the R-squared showed relatively good correlation between simulated and observed performance measures on average (traffic volume: 0.57, travel speed: 0.52, occupancy rate: 0.51).

6. SCENARIO SET-UP FOR THE IMPACT ANALYSIS

In assessing the advantages of smart transport systems for transport resilience, detailed scenarios need to be set up with a VISSIM environment. Selected smart transport systems and necessary assumptions in the scenarios are as follows:

- Four relevant applications were presumed to be operated in a target area considering their roles to maintain smooth traffic conditions in response to any incidents and natural disasters on the roads.
  - Traffic incident management
  - Road weather management

- Pre-trip traveler information
- En-route traveler information

- With above applications, two further assumptions were made for traveler information based on default values from the Tool for Operations Benefit/Cost (Federal Highway Administration, 2013).
  - En-route traveler information: Devices provide useful information during 25% of travel time and 10% of drivers act on the information.
  - Pre-trip traveler information: 10% of drivers would access the traveler information and 22% of drivers act on the information.

The target area is prone to being affected by natural disasters, i.e., hurricanes, where various attempts have been made to minimize the impact on traffic conditions through the use of smart transport systems (e.g., Liao, 2017). Besides, the COVID-19 pandemic has been sweeping the world which affects traffic conditions as a result of measures, such as lockdowns and social-distancing, and dealing with patients. As of July 5, 2020, there have been 11,125,245 confirmed cases including 528,204 deaths (World Health Organization, 2020). In this regard, two scenarios were set up to analyze the impact of smart transport systems on transport resilience in a target area.

- Two major roads were closed because of traffic incidents on routes to two hospitals (Broward Health Medical Centers at State Road 7 and Davie Blvd.) which affected the movement of emergency vehicles and/or vehicles transporting the patients.

- A major road to the international airport was closed (Fort Lauderdale-Hollywood International Airport) because of the natural disaster (i.e., hurricane).

The first scenario was to test the response to sudden traffic incidents on the roads under the medical emergency, including COVID-19 pandemic. It was presumed that there was severe traffic congestion due to unexpected incidents (e.g., crashes, breakdowns, road damage, etc.) which would affect traffic conditions significantly. Emergency vehicles and/or any vehicle that transport patients to the hospitals would be particularly affected and transport resilience was tested under this scenario.

The second scenario was based on the fact that the Florida government had decided to close the roads and provide traffic alerts via smart transport systems in response to the Hurricane Irma in 2017 (Liao, 2017). Irma was a category 5 hurricane and the strongest one ever recorded in the Atlantic Ocean outside of the Caribbean Sea and the Gulf of Mexico (Potenza, 2017). In this scenario, it was presumed that the hurricane could affect one of the major transport facilities which could critically break down traffic conditions in a target area.

Two paths were selected—i) the shortest route and ii) the alternative route—to reach each destination. SB-2a/3a, NB-2a/3a and SB-a are the shortest routes, and SB-2b/3b, NB-2b/3b and SB-b are the alternative routes in Figures 4 and 5. Detailed analysis was undertaken with four different cases under each scenario (a total of eight cases) —i) normal situation (Case 1), ii) scenario situation without smart transport systems (Case 2), iii) scenario situation with smart transport systems (10% diversion, Case 3), and iv) scenario situation with smart transport systems (22% diversion, Case 4).

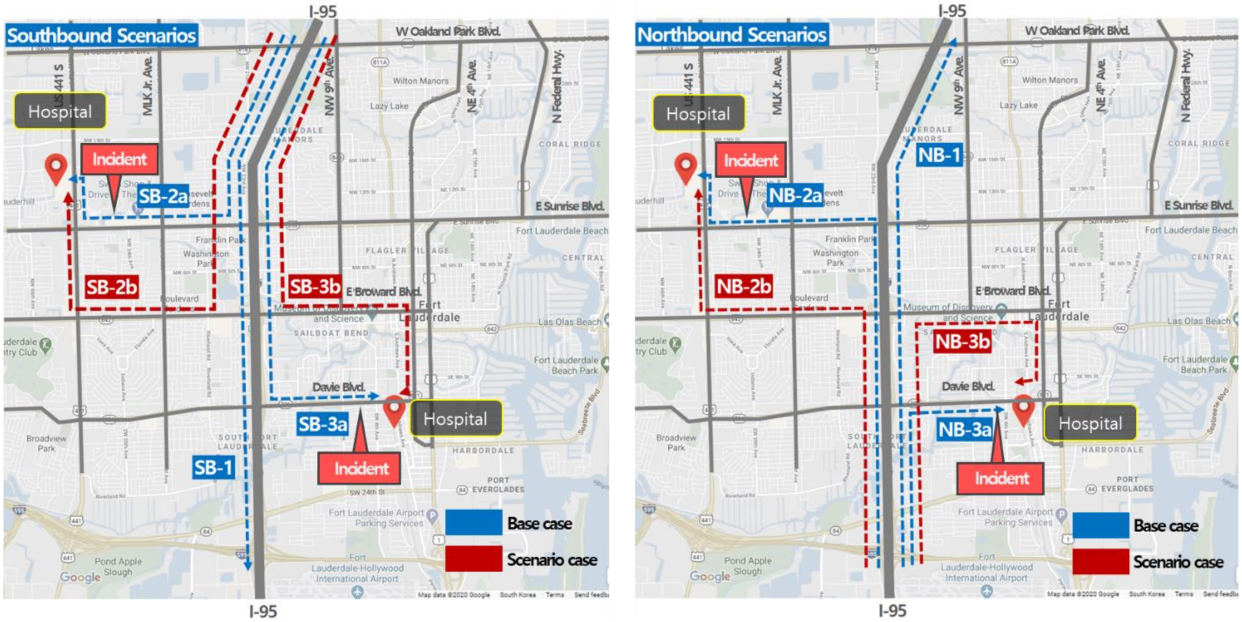


Figure 4: Pictorial description of the first scenario

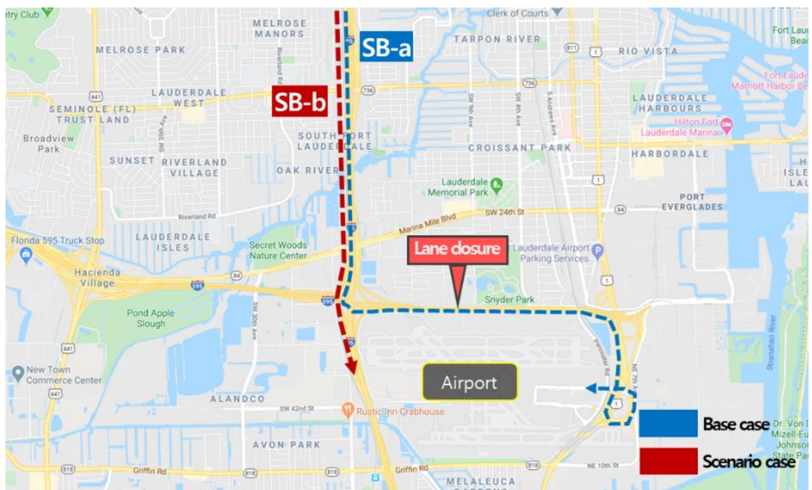
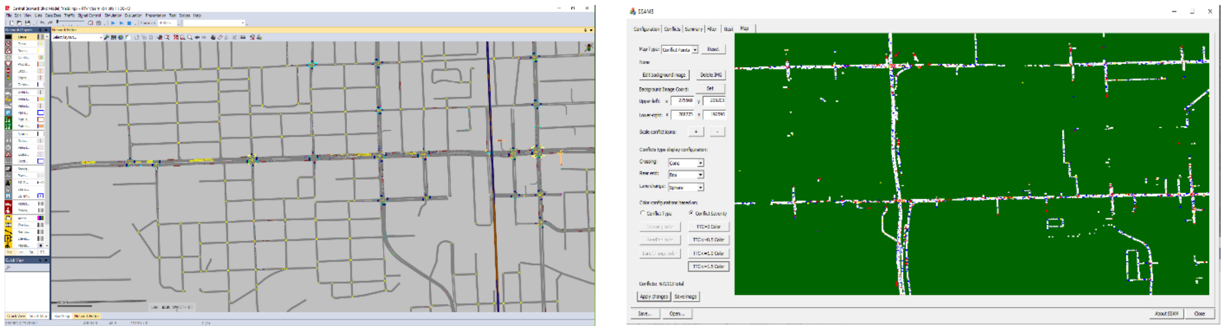


Figure 5: Pictorial description of the second scenario

Note that in the scenarios, the changes in traffic demands during the natural disaster times and COVID-19 pandemic were not considered because of the difficulty to estimate accurate numbers without solid revealed information. It was presumed that traffic demands were unchanged.

Performance measures

The impacts of smart transport systems in incidents and natural disasters were assessed in terms of mobility, safety and sustainability. The mobility impact was assessed by delays, which is one of the representative performance measures for signalized arterials; the safety impact was assessed by traffic conflicts, which is a probability of traffic crashes; and the sustainability impact was assessed by vehicle emissions including CO (g/Km), HC (g/Km), NOx (g/Km) and PM (g/Km). Note that delays and vehicle emissions were extracted directly from the VISSIM while traffic conflicts were estimated by the Surrogate Safety Assessment Model (SSAM) software based on the vehicle trajectories extracted from VISSIM (Federal Highway Administration, 2008) (Figure 6). VISSIM and SSAM are linked in part; VISSIM generates a specific SSAM input file, which is a binary coded output file (.trj) including vehicle trajectories, and SSAM loads the .trj file and estimates the number of conflicts based on various surrogate safety measures including time-to-collision (TTC), post-encroachment time (PET), deceleration rates, and many others. (Federal Highway Administration, 2008)



a) VISSIM run b) Traffic conflict estimation by SSAM

Figure 6: Snapshots of VISSIM Run and SSAM analysis

7. RESULTS AND DISCUSSIONS

Based on the scenarios defined, the impact of smart transport systems in a target area were estimated with suggested performance measures—delays, traffic conflicts and vehicle emissions (CO, HC, NOx and PM). Table 3 presents the experiment results in the first scenario.

Table 3: Summary of findings from the first scenario

Scenario 1		**Case 1**	**Case 2**	**Gap (Case 1 – Case 2)**	**Case 3**	**Gap (Case 2 – Case 3)**	**Case 4**	**Gap (Case 2 – Case 4)**
Average delay per vehicle (Seconds)	**All roads in a target area**	286.4	310.3	**23.9 (8.4%)**	309.9	**-0.4 (-0.13%)**	306.1	**-4.3 (-1.4%)**
	SB-1	247.3	258.3	**11.1 (4.5%)**	255.3	**-3.0 (-1.2%)**	251.3	**-7.0 (-2.7%)**
	SB-2a+SB-3a	553.3	1,376.5	**823.2 (148.8%)**	1,177.5	**-199.0 (-14.5%)**	700.4	**-676.1 (-49.1%)**
	SB-2b+SB-3b	397.2	396.0	**-1.2 (-0.3%)**	398.5	**2.4 (0.6%)**	413.9	**17.9 (4.5%)**
	NB-a	60.7	62.3	**1.6 (2.6%)**	62.0	**-0.3 (-0.4%)**	62.3	**0.1 (0.1%)**
	NB-2a+NB-3a	731.4	1,344.7	**613.3 (83.9%)**	1,253.2	**-91.5 (-6.8%)**	1,072.5	**-272.2 (-20.2%)**
	NB-2b+NB-3b	430.2	456.6	**26.4 (6.1%)**	530.5	**73.9 (16.2%)**	610.8	**154.2 (33.8%)**
Total number of conflicts	**All roads in a target area**	602,484	672,113	**69,629 (11.6%)**	667,583	**-4,530.0 (-0.7%)**	636,539	**-35,574.0 (-5.3%)**
	SB-1	111,833	119,875	**8,042 (7.2%)**	119,844	**-31.0 (-0.03%)**	118,302	**-1,573.0 (-1.3%)**
	SB-2a+SB-3a	5,320	24,930	**19,610 (368.6%)**	23,932	**-998.0 (-4.0%)**	18,022	**-6,908.0 (-27.7%)**
	SB-2b+SB-3b	3,023	2,993	**-30 (-1.0%)**	3,533	**540.0 (18.0%)**	4,203	**1,210.0 (40.4%)**

	Sum of SB	120,176	147,798	**27,622 (23.0%)**	147,309	**-489.0 (-0.3%)**	140,527	**-7,271.0 (-4.9%)**
	NB-1	58,352	73,923	**15,571 (26.7%)**	70,293	**-3,630.0 (-4.9%)**	65,332	**-8,591.0 (-11.6%)**
	NB-2a+NB-3a	4,882	9,884	**5,002 (102.5%)**	9,401	**-483.0 (-4.9%)**	6,332	**-3,552.0 (-35.9%)**
	NB-2b+NB-3b	3,492	3,383	**-109 (-3.1%)**	3,493	**110.0 (3.3%)**	3,622	**239.0 (7.1%)**
	Sum of NB	66,726	87,190	**20,464 (30.7%)**	83,187	**-4,003.0 (-4.6%)**	75,286.0	**-11,904.0 (-13.7%)**
Average emission per vehicle (g/km/vehicle)	CO (g/Km)	898.234	1,080.737	**182.504 (20.3%)**	999.811	**-80.9 (-7.5%)**	986.931	**-93.8 (-8.7%)**
	HC (g/Km)	24.098	28.985	**4.887 (20.3%)**	26.885	**-2.1 (-7.2%)**	26.768	**-2.2 (-7.6%)**
	NOx (g/Km)	75.897	91.213	**15.315 (20.2%)**	85.184	**-6.0 (-6.6%)**	86.685	**-4.5 (-5.0%)**
	PM (g/Km)	0.688	0.826	**0.138 (20.0%)**	0.780	**-0.05 (-5.5%)**	0.824	**-0.002 (-0.3%)**

In all aspects of delays and conflicts, after incidents happened (Case 2), they were noticeably increased in the shortest route by increased traffic congestion: 148.8% (SB-2a+SB-3a) and 83.9% (NB-2a+NB-3a) in average delay per vehicle, and 368.6% (SB-2a+SB-3a) and 102.5% (NB-2a+NB-3a) in total number of conflicts. After applying smart transport systems (Case 3 and Case 4), average delay per vehicle was reduced by 49.1% (SB-2a+SB-3a) and by 20.2% (NB-2a+NB-3a) at maximum with traffic/weather information and optimized strategies. For the total number of conflicts, similar findings were observed—maximum reduction of 27.7% (SB-2a+SB-3a) and 35.9% (NB-2a+NB-3a). It was noted that Case 4 showed superior outcomes in both measurements. Congestion and safety might not be direct proxies for transport resilience. However, they can be indirect means to understand how fast traffic conditions can be restored in status quo as less delays and potential conflicts between vehicles would lead to less required time for returning to the original state which would result in secondary impact to the society and environment.

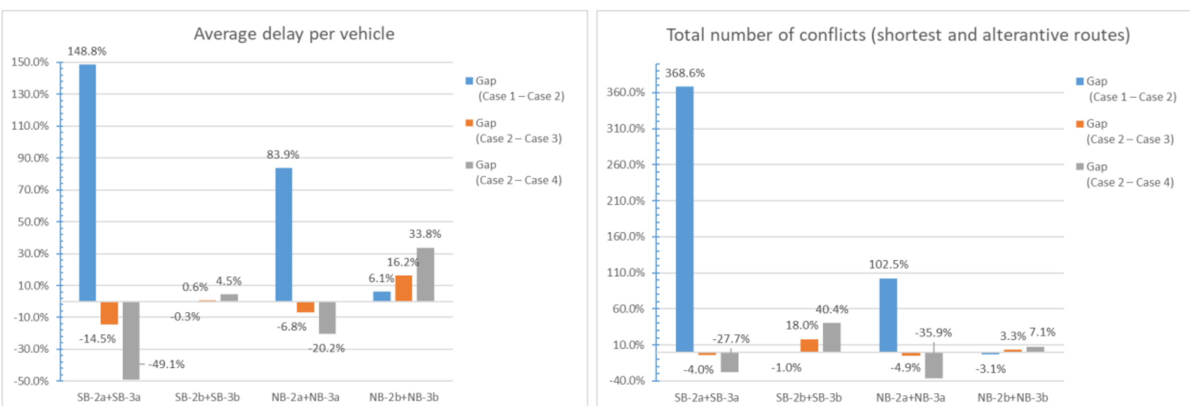


Figure 7: Average delay per vehicle and total number of conflicts in the first scenario#1

Aside from that, one interesting result was found from the alternative routes (SB-2b/3b and NB-2b/3b) (Figure 7). After introducing smart transport systems, there were increases in both measurements which were suspected to be affected by vehicles that were originally planning to use the shortest routes. Because of smart transport systems, they had the information about incidents and options to avoid that. The alternative routes would be one of the options they could choose. Given that the shortest routes showed the positive impact on two measurements, while the alternative routes had the negative impact, it was necessary to check the overall impact in transport networks in a target area.

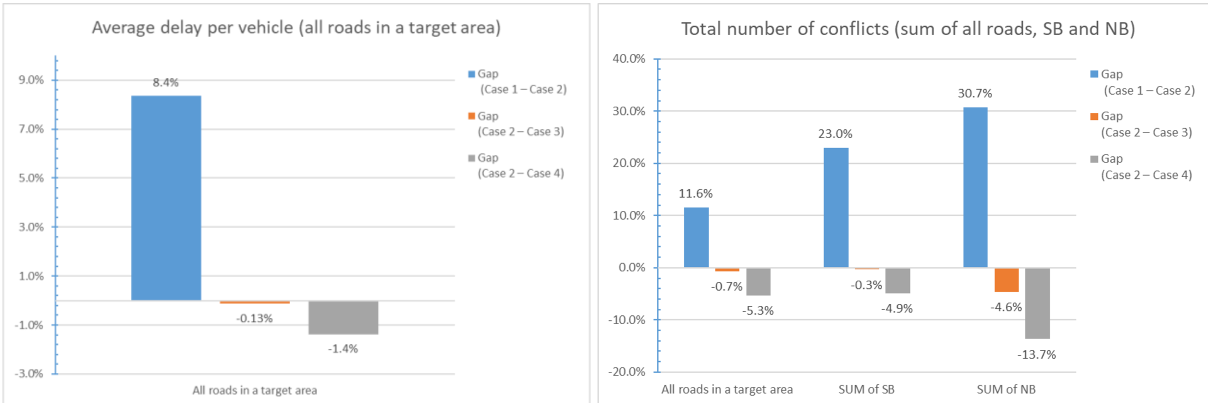


Figure 8: Average delay per vehicle and total number of conflicts in the first scenario #2

As shown in Figure 8, average delay per vehicle and total number of conflicts in all roads in a target area were decreased up to 1.4% and 5.3%, respectively. Particularly, total number of conflicts in three northbound routes showed 13.7% reduction. Even though the decrease rate in delay looked relatively small (1.4%), smart transport systems brought crucial resilience impact considering the delay in the original state (286.4 seconds) and the one after applying the systems during incident period (306.1 seconds). Namely, in all roads in a target area, only 19.7 seconds delay gap per vehicle was produced between the original and incident states by smart transport systems, which eventually would contribute to increase the transport resilience.

More importantly, in terms of the average emission per vehicle, after incidents occurred (Case 2), all elements (CO, HC, NOx and PM) were increased by around 20% but it was considerably reduced by 7.5% (Case 3) and by 8.7% (Case 4) at maximum by the reduction of delays with smart transport systems (Figure 9).

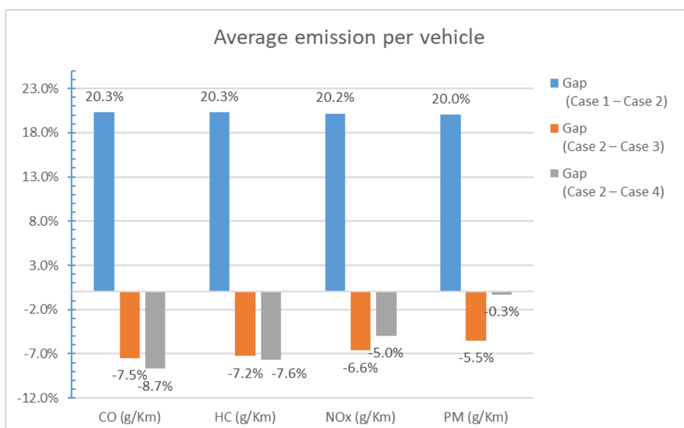


Figure 9: Average emission per vehicle in the first scenario

Given that transport resilience is directly related to environmental externalities, these exceptional improvements through smart transport systems can show to what extent such systems could contribute to the society and environment. The results from the second scenario are summarized in Table 4.

Table 4: Summary of findings from the second scenario

Scenario 2		**Case 1**	**Case 2**	**Gap (Case 1 – Case 2)**	**Case 3**	**Gap (Case 2 – Case 3)**	**Case 4**	**Gap (Case 2 – Case 4)**
Average delay per vehicle (Seconds)	SB-a	717.6	1,651.6	**934.0 (130.2%)**	1,472.1	**-179.5 (-10.9%)**	1,373.5	**-278.1 (-16.8%)**
	SB-b	479.4	549.4	**70.0 (14.6%)**	509.4	**-40.0 (-7.3%)**	497.1	**-52.3 (-9.5%)**
Total number of conflicts	SB-a	2,403	6,012	**3,609 (150.2%)**	4,933	**-1,079.0 (-17.9%)**	4,122.0	**-1,890.0 (-31.4%)**
	SB-b	130,293	140,221	**9,928 (7.6%)**	138,042	**-2179.0 (-1.6%)**	13,3009.0	**-7,212.0 (-5.1%)**
	Sum of SB	132,696	146,233	**13,537 (10%)**	142,975	**-3,258.0 (-2%)**	137,131	**-9,102.0 (-6.2%)**
Average emission per vehicle (g/km/vehicle)	CO (g/Km)	1,119.199	1,549.703	**430.503 (38.5%)**	1,257.128	**-292.6 (-18.9%)**	121.9	**-1,427.8 (-92.1%)**
	HC (g/Km)	30.077	41.611	**11.534 (38.3%)**	33.818	**-7.8 (-18.7%)**	32.7	**-8.9 (-21.5%)**
	NOx (g/Km)	95.137	131.336	**36.198 (38.0%)**	107.256	**-24.1 (-18.3%)**	103.8	**-27.5 (-20.9%)**
	PM (g/Km)	0.869	1.195	**0.326 (37.5%)**	0.984	**-0.2 (-17.7%)**	1.0	**-0.2 (-20.4%)**

Likewise, average delay per vehicle and total number of conflicts were notably increased up to 130.2% (SB-a) and 150.2% (SB-a), respectively, in Case 2. However, the reduction rates by smart transport systems in Case 3 and Case 4 struck the eyes in both the shortest and alternative routes: up to -16.8% (SB-a) and -9.5% (SB-b) in average delay per vehicle, and -31.4% (SB-a) and -5.1% (SB-b) in total number of conflicts. Note that the Case 4 results showed a higher decrease (almost doubled) in terms of both average delay per vehicle and total number of conflicts, compared to the Case 3 results.

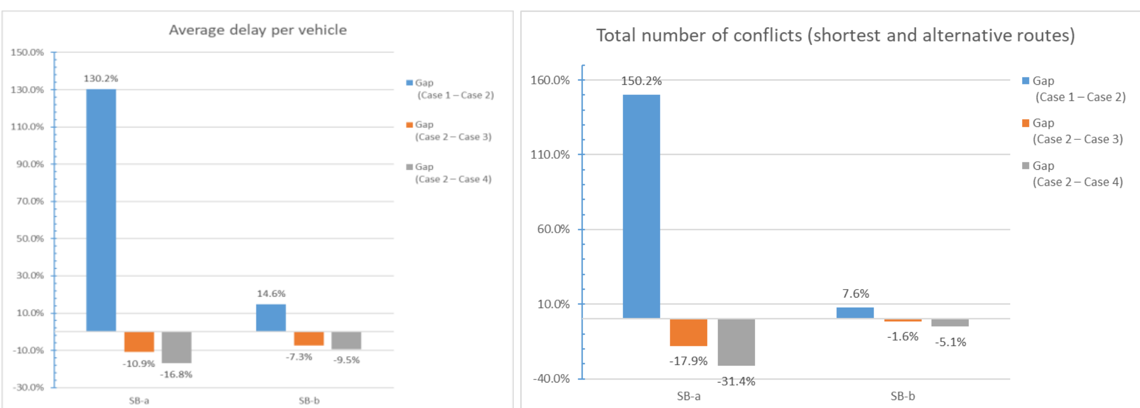


Figure 10: Average delay per vehicle and total number of conflicts in the second scenario

Looking into the average emission per vehicle, the road closure by the hurricane would noticeably result in increased emissions in a target area which was much higher than the one by the incident in the first scenario. Around 38% increase was observed in all aspects of emission-related elements, such as CO, HC, NOx and PM. Interestingly, the positive effects of smart transport systems to mitigate vehicle emissions were outstanding, which were 18.9% (Case 3) and 92.1% reductions (Case 4) for CO (g/km) at maximum. From the viewpoint of transport resilience, it is quite meaningful because limiting vehicle emissions from the transport sector is an essential element of building more resilient transport systems to climatic events. As shown in Figure 10, smart transport systems could cut down vehicle emissions at least by 17.7% when a particular negative event happens.

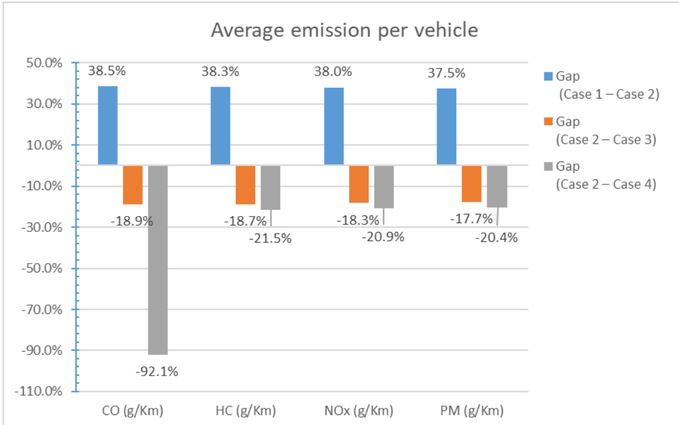


Figure 11: Average emission per vehicle in the second scenario

It was noted that comparing to the results from the first scenario, smart transport systems could contribute more to mitigate vehicle emissions which were caused by increased delays from the natural disaster (i.e., hurricane) (Figure 11). Given that damage to transport networks by natural disasters can comprise an important share of destruction in transport resilience, findings from the second scenario can encourage the use of smart transport systems to reinforce resilient transport systems.

8. CONCLUSION

Efficient transport systems are instrumental in enhancing resilience by meeting the demand for mobility and connectivity in a society. Existing transport systems are however vulnerable to climate change and extreme weather conditions. The vulnerability of transport systems can already be seen in the rise in traffic incidents and natural disasters around the world. At the same time, smart transport systems have increasingly gained attention as one of the feasible solutions to address such challenges. Yet, the supporting evidence is scarce with details lacking on the extent such systems can contribute to enhancing transport resilience.

In this regard, this research attempted to quantify the benefits of smart transport systems to transport resilience across the three dimensions of mobility, safety and sustainability. To replicate actual conditions in a real world, a simulation-based methodology was applied which assessed the impact of smart transport systems on traffic issues and natural disasters in given scenarios. Four smart transport systems, including traffic incident management, road weather management, pre-trip and en-route traveler information, were presumed to be used with two scenarios (four cases) to test their capability for transport resilience in a target area (Broward County, Florida, U.S.A). To sum up, the results revealed that the traffic incident and natural disaster seriously affected traffic conditions by increasing delays, traffic conflicts and vehicle emissions which could deteriorate the transport network resilience. After deploying smart transport systems, all cases showed a positive impact on the shortest paths to the destinations. Emphasizing on the effects for vehicle emissions which are directly linked to the environmental issues, the first scenario for traffic incidents showed a reduction of 7.5% (Case 3) and of 8.7% (Case 4) at maximum with smart transport systems. The impact from the second scenario was greater, which was 18.9% (Case 3) and 92.1% reductions (Case 4) at maximum. This is because there were fewer alternative routes in the second scenario where the impact of the natural disaster (i.e., hurricane) was greater while the positive effect due to smart transport systems was higher than the ones in the first scenario.

Although transport resilience may not be assessed only on the performance measures selected in this research, significant changes on these measures indicate that smart transport systems could help restore traffic conditions or at the least prevent situations from deteriorating. More importantly, given that reduced vehicle emissions could contribute to more resilient transport systems, such significant impacts on vehicle emissions are very meaningful. As found from one case, providing smart transport systems on the primary route might worsen the traffic situation on the alternative route because of increased traffic influx by detours. However, in spite of such case, an improvement to vehicle emissions in the overall transport network was found in both scenarios which strongly supports the critical role of smart transport systems for environmental issues. Such findings can be a good reference to apply smart transport systems for increasing transport resilience in cities or countries of the Asia-Pacific region which are vulnerable to traffic incidents with high crash rates and/or natural disasters like earthquakes or tsunami. This will be a cost-effective solution without significant infrastructure investment.

This research could be further enhanced with additional considerations. There was an assumption regarding the compliance rate of drivers by smart transport systems which was based on the previous research. However, given that traffic incidents and natural disasters have different influential areas and magnitudes of impacts, that assumption needs to be more customized as the compliance rate can vary by traffic conditions and the types of smart transport systems. Even though most effective applications of smart transport systems were employed in this research, other applications including emerging technologies (e.g., connected vehicles) can be considered to evaluate transport resilience to traffic incidents and natural disasters. In terms of the geographical size of a target area, it could be extended to the state or national level as transport networks are organically connected which will eventually affect overall transport resilience. In addition to quantifying delays, traffic conflicts and vehicle emissions, it would be valid if actual values to return to the normal state (i.e., recovery time) following traffic incidents or natural disasters are estimated. Technically, the approach would not be easy, but it would be of great interest to researchers and policy makers in this field. Lastly, although smart transport systems showed good results in increasing transport resilience in this research, the operation and maintenance costs for these systems need to be considered when adopted in cities or countries.

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Resilient Transport Systems and Services: The Case of India's Railway System

Arun Saksena[4] *and Debabrata Dalal*[5]

ABSTRACT

Natural hazards and man-made disasters have an adverse impact on the transport system. Existing vulnerabilities within the transport system exacerbate the impact of such disasters. Infrastructure managers follow a two-step approach. The first step is planning, designing and executing a system that helps to prevent and minimise the impact of disruptions caused by disasters. This includes real-time condition-monitoring systems to prevent the occurrence of disasters wherever possible. The second step involves building a sufficient coping strategy to assist in post-disaster recovery and restoration. Reducing existing vulnerabilities helps to lessen the severity of a disaster's impact on the transport system and facilitates faster recovery. Indian Railway entities bring rail and other experts together to share good practices and issue guidelines on how to optimise cost-effective resilience, prioritise resilience activities, and source funding for investment to build future resilience.

Most rail transport engineering systems are designed with a passive and fixed design capacity. This design often makes their response to disasters unreliable. These transport systems are designed with system redundancies to ensure the required level of availability to operate. However, a high level of system redundancies increases a system's life-cycle cost. A more proactive maintenance approach would help to detect, diagnose, and predict the effects of adverse events. Incorporating these proactive methods at an early design stage has the potential to transform passively reliable (or vulnerable) systems into adaptively reliable (or resilient) systems, all while reducing costs. This paper proposes a resilience-focused system for designing transport systems, with a specific focus on building resilience in the railway network.

Key words: resilience, vulnerability, susceptibility, capacity, reliability, prediction, railway

1. INTRODUCTION

Increasingly extreme natural phenomena and disruptive climate events have been witnessed across many regions of the world. The increasing frequency and extremity of these events have had an adverse impact on the built environment. Transport infrastructure and services are subject to heavy damage caused by floods, land-slides, storms, cyclones, wild-fires and earthquakes. Infrastructure in mountainous terrain, coastal areas and near riverbanks are particularly at risk. Between 1970 and 2018, the average number of people affected annually by natural disasters in Asia and the Pacific was 142 million and the average number of fatalities per year was 42,000 (UNESCAP, 2019). Overall economic losses from the 2004 Indian Ocean earthquake and tsunami disaster are estimated to be around US$ 10 billion, with major damage caused in Indonesia, Thailand, Sri Lanka, and India. These losses include severe damage to infrastructure, including roads and railways, systems for water supply and electric power, as well as schools and hospitals. The Asia-Pacific region suffered damages and losses equating to US$ 266.8 billion out of US$ 366 billion globally in 2011 (NDMA, 2012). In the last decade, the number and severity of disasters, including floods, earthquakes, storms, landslides, have led to the immense loss of life and property, thereby hampering development and disrupting trade. India is more prone to disasters due to geo-climatic conditions and a high degree of socio-economic vulnerability. Between 2001 and 2010, World Bank data revealed losses of US$ 1.2 trillion due to climate change and natural disasters (UIC, nd) (Figure 1). In light of this, the International Union of Railways (UIC) has embarked upon a strategy framework to build long-term resilience

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in rail transport under the Rail-Adapt Initiative. The initiative brings together rail and other experts to share good practices and develop common guidance on how to optimise cost-effective resilience, prioritise resilience activity, source funding for the necessary investment, and forge connections with International Finance Institutions (IFIs) and other development banks.

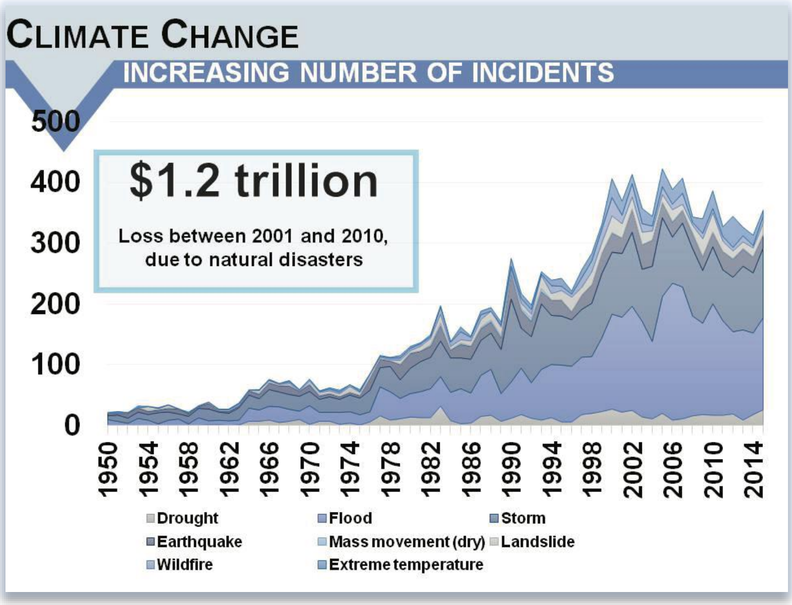

Figure 1**:** Climate change – increasing number of incidents (source: UIC)

Natural and man-made disasters cause widespread disruption. They lead to the loss of human lives and adversely affect the economy, often exceeding the ability and capacity of a society to cope up with its existing resources. Disasters are classified as either “natural” or “man-made.” Disasters which result from human action and/or inaction, including chemical or industrial hazards, environmental pollution, transport crashes and societal unrest, are classified as “man-made” or “man-induced”. However, the current social understanding of disasters views this distinction as artificial, as most disasters result from the action or inaction of people and their socio-economic behaviour. Living in a manner that degrades the environment, such as developing and over-populating urban centres, or creating socio-economic systems without attention to ecological balance, can lead to man-made disasters. Communities in areas susceptible to river flooding, earth tremors and nuclear power units are highly vulnerable. Disasters are further compounded by seasonal and sudden fluctuations that can make the timing, frequency and magnitude of their occurrence more difficult to predict. Transport systems and communication services are vital for socio-economic growth and provide a lifeline for many regions to fulfil their development goals. To mitigate the adverse effects of disasters, transport systems must have more resilient operations in place. Building resilience will provide necessary relief on transport services when a disaster does indeed occur, and will allow time for infrastructure assets to be restored.

2. SUSTAINABLE DEVELOPMENT GOALS

The United Nations have outlined 17 Sustainable Development Goals (SDGs) to be achieved by the year 2030 (United Nations, 2015a). SDG-9, related to industry, innovation and infrastructure, is oriented to "build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation" and SDG-11 is focussed towards building sustainable cities and communities - "to make cities and human settlements inclusive, safe, resilient and sustainable." In addition, SDG-11 stipulates the aim of creating safe, affordable, accessible and sustainable transport systems for all. This is to be achieved by improving safety and expanding public transport in order to reduce the number of deaths and the number of people affected, as well as to decrease the economic losses caused by disasters.

Resilient transport infrastructure forms the backbone of a prosperous economy, providing access to markets, jobs and social services. For this reason, SDG-9 calls for increased access to sustainable transport infrastructure in less developed countries. As per estimates, collectively these less developed countries will need to spend between 1 to 3 percent of Gross Domestic Production (GDP) annually on new transport infrastructure by 2030, with an additional 1 to 2 percent for maintenance (World Bank, 2019). Securing resources for maintenance is crucial to ensure the continued safety and reliability of transport systems, but many countries have struggled to sustain their spending on maintenance.

SDG-13 stipulates countries to strengthen the resilience and adaptive capacity of all public infrastructure. It stresses the urgent need to combat climate change and mitigate its adverse effects, particularly on transport systems. Moreover, the Sendai Framework for Disaster Risk Reduction (United Nations, 2015b) stipulates improved risk management while building and managing infrastructure networks. Proactive policies, directives and regular reviews of infrastructure planning and design standards are particularly important for developing countries. Their investment needs are high, but risk assessments are often scarce and the potential impact of disasters are either underestimated or go undetected.

3. INDIA'S TRANSPORTATION SECTOR

India's transport sector is large and diverse and caters to the needs of more than 1.3 billion people. In 2007, the sector contributed about 5.5 percent to the nation's GDP, with road and rail transportation largely providing physical connectivity to remote urban and rural regions. This paper defines "Resilient Transport Systems and Services" to mean providing transport between any two points, using any mode on demand. Given the current transportation infrastructure in India, it would be unwise to depend on only one mode of transport from a resilience perspective.

The Indian Railway (IR) is one of the largest railways under single management. On a total route network of 67,415 kilometres in March 2019, IR carried more than 23 million passengers and 3.36 million tonnes of freight daily in the financial year 2018-19 (MOR, 2019). Annual passenger traffic stood at 8.4 billion, as compared to 1.3 billion in 1950-51. Around 1.2 billion tonnes of freight were transported, as compared to 73.2 million tonnes in 1950-51. This mainly included bulk commodities such as minerals, ores, steel, fertilizers, petrochemicals and agricultural produce to remote corners of the country.

The IR has undergone significant changes and advancements. These include: the movement of block rakes; the construction of new lines and doubling tracks; the provision of rail flyovers, underpasses, road overbridges and rail bypasses with electrification; the application of decongestion techniques; embedding advanced signalling, train control and automation; the segregation of freight corridors, and the increasing of rail speeds to 130/160 kmph. These strategic changes have been introduced following an evaluation of available technologies in rail transport. They have been incorporated into the IR system based on their affordability and ability to be customised according to local needs. Although the IR system provides an important lifeline to remote areas and creates cross-border linkages, many of the system's major corridors suffer from a capacity constraint and require capacity-building plans. Rail transportation has a number of favourable characteristics when compared against road transport. For example, it is six times more energy-efficient and four times more economical (Kumar, 2019). Rail construction costs are approximately six times lower than road for comparable levels of traffic. It is also the only major transport mode capable of using any form of primary energy.

4. DEFINING RESILIENCE AND THE MODEL FOR ASSESSMENT

This paper defines transport resilience as the ability to avoid and recover from sources of adversity, disturbance, damage or catastrophe that affect system performance (NIAC, 2009). Resilience is also defined by a system's ability to adjust and adapt in the face of disturbances and unpredicted changes (Hollnagel et al., 2006). Resilient systems can sustain the impacts of external and internal disruptions without interruption or change to performance, and are able to recover rapidly and completely in case of disruption (ASME. 2009). In the context of engineering systems, resilience is defined as the sum of the passive survival rate (reliability) and the proactive survival rate (restoration) (Youn et al, 2011). The transport sector and its infrastructure have been recognized as important contributors to the national economies and societies, with some studies carried out on their resilience (Percoco, 2004). Resilience should not be mistaken for stability (Meadow and Earthscan, 2009). Resilient systems can be very unstable. For example, short-term oscillations, periodic outbreaks, long cycles of succession, climax, and the collapse of natural phenomenon may represent a normal unstable condition. Resilient transport systems are those that can respond successfully to such vulnerable situations.

4.1 Resilience in Transport Systems

Recent research on resilience in transport systems has largely focused on climate change and extreme weather. Initial investment in their durability helps to ensure that a transport system requires fewer resources to keep it maintained in the future. A comprehensive asset management program and predictive maintenance strategy also help to improve a system's resilience. Moderate upgrades, enhanced and proactive maintenance and more effective information sharing can reduce lifecycle costs**.** Investing in resilience strategies ensures transport systems will be safer and more efficient in the future.

One of the most cost-effective means to enhance resilience is information management. Real time data of system components and external interferences can be used to predict the likelihood of disruption, thereby allowing transport management to take immediate preventive steps to avoid a catastrophe, minimize the potential impact and take steps to ensure an alternative outcome Further, once one mode of transportation fails (e.g., train), the information on the nature of the failure, its duration and alternative services available for passengers, can become attributes of resilience. Passenger information has been conventionally associated with service level and comfort, but it can also be utilised in the context of fostering resilience.

Transport systems are comprised of several subsystems. These subsystems are more manageable for infrastructure owners and decision makers because they segment components of resilience and provide scalable indicators of the system's operations. This resilience model can be applied to transport infrastructure and used as a starting point for the initial engineering stage and in the assessment of risks. Designing resilience or appraising the existing reliance of a transport system is a holistic and extensive task. The model proposed in this paper may be regarded as a practical tool. The model is proposed to be applied, developed and operationalised by the Finnish Transport Safety Agency for ensuring safety and reliability aspects of transport system (FTA, 2015).

4.2 Components of Resilience

Resilience is the inverse of vulnerability in a system (Leviäkangas Pekka, 2015). Vulnerability is a function of exposure, susceptibility and coping capacity (Molarius et al, 2014). The Disaster Reduction Terminology in UNISDR Report (United Nations, 2009) highlights the following:

- *Coping capacity: the ability of people, organizations and systems, to use available skills and resources in order to face and manage adverse conditions, emergencies or disasters.*
- *Exposure: people, property, systems, or other elements present in hazard zones that are thereby subject to potential losses.*
- *Vulnerability: the characteristics and circumstances of community, system or asset that make it susceptible to the damaging effects of a hazard.*

Molarius et al. (2014) presented the following conceptual model for vulnerability and resilience:

$$Vulnerability = \frac{Exposure\ \times Suseptibility}{Coping\ Capacity} = \frac{1}{Resilience}$$

$$Resilience = \frac{Coping\ Capacity}{Exposure \times Suceptibility}$$

Leviäkangas (2015) has also discuss the application of the above resilience model. Resilience indices may be calculated by using statistical data available in publications and applying the model above.

4.3 **Subcomponents Description**

The components of resilience can be separated into subcomponents and attributes. Levels of exposure can also be separated. Coastal and river railways are more exposed to sea storms and flooding, and networks in mountainous areas to landslides and avalanches. Resilience is the Ratio of the System Strengths and Weaknesses as given below:

$$Resilience = \frac{Resources, Skills, Features_{(Strength)}}{Risk, Sensitivity,\ Features_{(Weakness)})}$$

To explain the potential use of the resilience model, the following attributes in Table 1 can be incorporated as shown in Figure 2.

Table 1: Attributes of resilience

SNo	Attribute	Explanation - Example
1	Risk	Probability of an adverse event – heavy rains, flooding, land slide etc.
2	Feature Weakness	Worn-out components of infrastructure – end of useful life or poor quality leading to higher failure rate.
3	Sensitivity	Components without backup – critical standalone system like Overhead Electrical Equipment (OHE).
4	Co-variance	Dependence on environment, other components/sub-systems – power supply.
5	Resources	Skills, warning systems, availability of quality spares, tools, budget
6	Feature - Strength	Reliable design, engineering and construction practices like factor of safety, redundancy.
7	Hedging	Protective framework, standby systems, insurance.

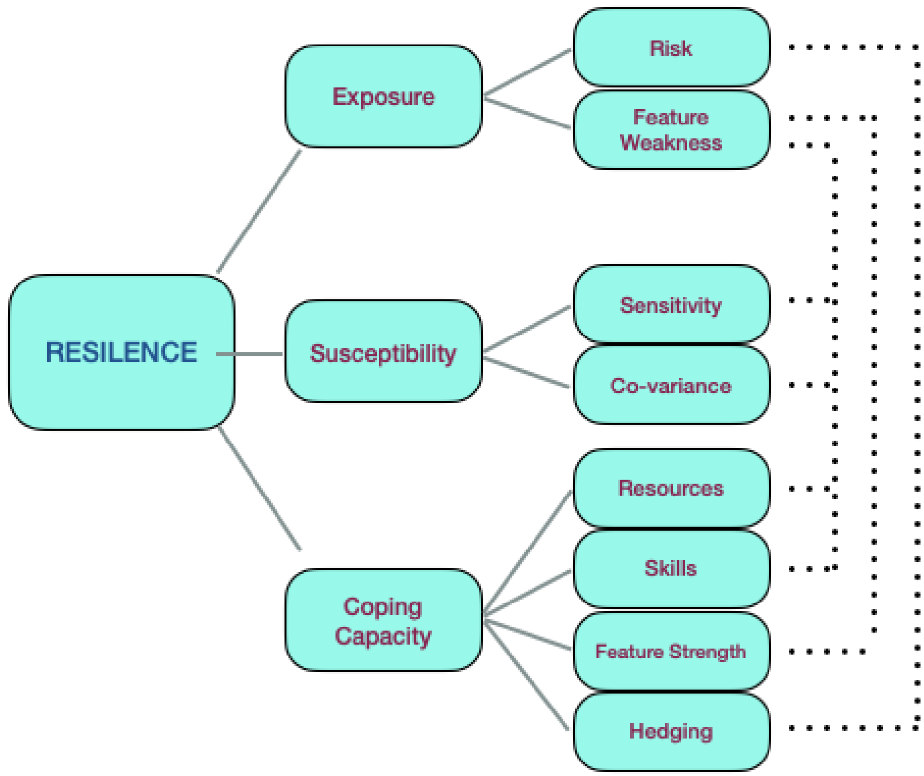

Figure 2: Resilience conceptual hierarchy **(**The dotted lines between attributes represent individual perception of their inter-dependencies)

4.4 Components of Railway Transport System

Applying this concept of resilience to transport infrastructure is demanding for several reasons. Firstly, it comprises several interconnected subsystems, which are inherently complex. Further, the transportation modes (rail, road etc.) differ widely in relation to technology and systems, network capacity, monitoring and governance, customer profile and marketing.

There is no universally accepted definition of what comprises a transport system because the components and subsystems of each mode are different. In the rail network, several specific subsystems like rails, bridges-culverts and their substructures, rolling stock and traction power, electricity, signalling and communications, operations, safety and control mechanisms exist in addition to stations, terminals, shunting yards, depots and workshops. Table 2 shows indicatively some subsystems of the rail transport system.

Table 2 – Components of railway transport system

Transport Mode	Supplementing Structures	Sub Systems	Nodes
Railways	Stations, Rail Tracks, Tunnels, Bridges	Rails, Bridges/Culverts, Track bed, Crossovers, Stock and Switch Rails, Sleepers, Ballast, Tunnels, Over Head Traction Catenary, Interlocking & Blocks, Colour Light Signals, Point Machines, Track Circuits, Digital Axle Counters, Level Crossings, Locomotives and Rolling Stock etc.	Terminals, Stations, Shunting Yards, Connection to other Modes

4.5 **Resilience – Transport System Matrix**

As the attributes and qualities of subsystems vary widely, a uniform approach to the management or enhancement of their resilience must be adopted. In Table 3, the generic resilience component and attribute structure is combined with transport infrastructure system model, where multiple needs can be accommodated within the Resilience Matrix. The matrix can be modified, expanded, simplified and improved as required.

Table 3 - Resilience matrix

Transport Subsystems		Resilience								
		Exposure			Suceptibility		Coping Capacity			
		Risk	Features / w	Sensitivity	Sensitivity	Covariance	Resource	Skills	Features / s	Hedging
Pathways	Roads									
	Rails									
	Waterways									
Nodal Points										
Supplementary Structures										
Supplementing Systems										

The ownership and governance structure for resilience enhancing strategies and associated issues are not clearly laid down. Queries and issues will be raised at the time of investment decision and long-term resource allocation - Who needs resilience? Who will pay for it? Who will bear the recurring costs?

The Finnish Transport Safety Agency intends to use the matrix to capture the potential parameters and to assess each attribute's quantitative valuation to make resilience measurable, manageable and understandable (FTA, 2013). Therefore, the proposed framework enables breaking-up the challenges into subsystems and investigating each resilience component and attribute at a time, instead of trying to solve all challenges together. This approach provides tools to overcome the problem of general views and paves the way for a more detailed, structured analysis. Entities, who are responsible for not only transport systems, but also of other critical infrastructures like water supply, sanitation, energy and electricity, face a more serious challenge to prioritise their efforts and to assess the interdependencies of different infrastructures. Capacity development covers the strengthening of institutions and mechanisms at all stakeholder levels. UNISDR (United Nations, 2009) defines 'Capacity Development' as "*the process by which people, organisations and society systematically stimulate and develop their capability over time to achieve social and economic goals, including through improvement of knowledge, skills, systems, and institutions – within a wider social and cultural enabling environment*."

5. STATUS AND INITIATIVE FOR RESILIENCE ON INDIAN RAILWAY

The above model for resilience evaluation and assessment may be applied on segments of IR. The current status is discussed in the forthcoming chapter.

The planning and development of capacity and connectivity on the IR network is based on inputs received from various stakeholders, state governments, ministries, public representatives, industries and associations. However, a more holistic view of railway infrastructural needs is required in terms of standards, technologies and network design to ensure minimal disruption. Table 4 below highlights the outcomes due to consistent development efforts of IR and resilience attributes of important components and sub-systems of fixed infrastructure of railway are explained.

Table 4: Growth of Indian Railways

Indices of Growth of Traffic Output and Inputs (1950-51=100) *Revised							
Financial Year	**Traffic Output Indices**		**Investment Input Indices**				
	Freight Traffic (Net Tonne Kms) (Revenue+ Non-Revenue)	**Passenger Traffic (Non-suburban Passenger Kms)**	**Wagon capacity**	**Passenger coaches**	**Route Kms.**	**Running track Kms**	**Tractive effort of locos**
1950-51	100	100	100	100	100	100	100
1960-61	199	110	152	154	105	107	144
1970-71	289	159	226	188	112	121	178
1980-81	359	279	269	210	114	128	201
1990-91	550	394	278	219	116	133	192
2000-01	715	614	246	254	118	138	233
2012-13	1,475	1,512	325	367	122	150	390
2016-17	1,407	1,675	385	409	125	155	475
2017-18	1,571	1,715	393	413	125*	159*	494
2018-19	**1,675**	**1,685**	**409**	**422**	**126**	**162**	**528**

The Railway Track is the main component of the rail transport system. The safe running of trains at maximum permissible speed depends on the availability of a stable track maintained within safe parameters. Rails are sensitive to climatic variations. This thermal stress leads to corrosion, buckling or fractures. The risk of damage by natural hazards is currently mitigated by intensive activities with multiple layers of patrolling, maintenance, inspection and repairs through manual and mechanized means, which are systematically monitored. Track geometry is observed in periodical runs of Track Recording Cars (TRC) and vulnerable spots are advised for correction. Real time monitoring of rails is increasingly required to detect adverse conditions due to low winter temperatures, when cracks lead to broken rails and minimize risk. Track Circuits using both the rails, Ultrasonic Detectors and Optical Fibre Cables (OFC), have been tried on a small scale for detecting rail cracks early. Wheel flats and rail fractures can be detected by optical reflectometers connected to OFC laid parallel to the track by sensing of track vibrations leading to back-scatter of light. Land slide detection systems have been used by one of the Railways. IR has been working to reduce these weaknesses within the components to improve coping capacity and overall resilience.

The design layout of the tracks, along with corresponding signalling and overhead electrical equipment (OHE), is built to be flexible and reliable. Resilience has been improved by the provision of alternative signalled routes for yard layouts, isolation with simultaneous reception and dispatch facility, twin single line working, subsidiary backup signals (Calling On, Shunt), redundancy in train detection, higher factor of safety in power supply design and centralized hot standby interlocking and remote control. Fall back manual train operation procedures and temporary working orders are part of Standard Operating Procedures (SOPs). All these measures have contributed significantly to reduce system failures.

The Track Circuit gets short circuited by the presence of train axles and provides a means for detection of a train vehicle. It is the most basic device for reliable train detection but is susceptible to failure when the track gets wet or water logged. IR has made considerable strides to implement track circuiting for safe train detection at stations and 96.6% of all BG station have been covered. This has also provided partial rail breakage detection in order to strengthen the safety of the system.

Signals: Interlocking and Block signalling are vital for safe and efficient operations in yards and pushing them at close headway in the section. Route Relay/Panel/Electronic Interlocking (RRI/PI/EI) along with Multiple Aspect Colour Light Signals (MACLS) have been provided at about 5886 stations (94% stations March 2019). These systems have the capacity to recover quickly. The replacement of old outdated, multi-cabin mechanical signalling equipment by electronic interlocking with hot standby has reduced system weaknesses. The provision of MACLS fed through underground cables has made the system more robust and less susceptible to interference and adverse weather conditions. Shifting block equipment from disturbance prone overhead lines to underground cables, provision of electronic non-cooperative blocks, Block Proving by Axle Counters (BPAC) and Intermediate Block (IBS) and Automatic Block Signalling (ABS) has improved safety and reliability.

Operations Control Centre (OCC): The management of train movements is largely performed manually. A centrally located train controller is typically responsible for a specific sector or station. Trains are signalled by the station master posted at each station, who records details based on feedback received by telephone. The main weaknesses in manual control centres are inefficient utilisation of the track, sluggish control of movements, errors in operations and reporting, congestion, inadequate maintenance time and absence of real time planning. IR attempted to strengthen the system by automating the information needs of the controller and customer via a video display of the entire rail network in the form of the Train Management System (TMS). TMS was installed on congested sections of Central, Eastern and Western Railways. Maintenance and operations were improved, providing real time train charts and real time accurate information to customers. OCC was provided at Tundla (Figure 3) on Prayagraj division of North Central Railway (NCR) for remote operations and control of trains on a section of about 440 kms having 40 stations. All relevant information relating to signals, track occupancy, point/switch status, route setting, level crossing gate status, train number and attributes of crew and rolling stock, local control panel status, parameters of functions and their status is aggregated and displayed on a video wall in the OCC on a real time basis. Train operations have also been improved by making use of stored/long route settings, automated control charts, train conflict resolution, maintenance planning, punctuality control and accurate passenger information forecast.

Figure 3: Operations control centre Tundla, North Central Railway

25 kV Electrification: 25 kV Electrical Traction Power network supplies power for electrical locomotives. 51% of the routes on IR spread across 34319 kms are electrified as of March 2019 (MOR, 2019). Electric traction consumes substantial energy, which is increasing steadily, and requires real-time monitoring of sub-systems for optimum usage, power factor control and functioning. Resilience has been improved by the Realtime monitoring of transformers, circuit breakers, lightning arrestors, and interrupters, using a Supervisory Control and Data Acquisition (SCADA) System and Remote Control (RC). SCADA systems monitor, store and analyse various parameters including catenary current, voltages, power factor, indications and device status using telemetry from switching and sub-stations, which help to identify faults and facilitate rapid recovery. Remote Controls operate without the need for human intervention, which

enables faster restoration and recovery after a disruption. The engineering data in combination with AI to identify patterns of failure and highlight weaknesses.

Mobile Train Radio Communication (MTRC): The communication of information is key to an efficient, safe and resilient transport system. The Global System for Mobile Railways (GSM-R) has an emergency built-in communication feature. This has been rolled out on some sections of IR using fibre-optic cables. GSM-R exists on the more vulnerable rail network between New Delhi and Guwahati on the eastern route and New Delhi and Jhansi towards the south. An save our soul (SoS) button on the user terminal can be used for emergency situations like heavy rains, fog, flooding, storms or accidents on the rail route. Communication between train crew and station staff is vital for preventing holdups, resolving conflicts and avoiding accidents.

IR has also implemented predictive maintenance measures to integrate rolling stock parameters such as wheel impact load detection (WILD) (Figure 4). This will help to check for developing defects automatically, thereby reducing risk of disruption.

Figure 4: Integrated rolling stock parameters detection systems on IR.

Rolling Stock Initiatives: Passenger coaches on IR are provided with a crash buffer and anti-climbing mechanism. These absorb excess collision energy and reduce the risk of injury and loss of life. To make the rail coaches fire resistant, fire detection and alarm systems have been provided.

IR Rail Network Initiative: To ensure a more resilient rail network on the congested eastern and western routes of IR, a separate rail corridor dedicated for freight traffic is under implementation (Figure 5). From a co-variance point of view, it may be assumed that the two sets of networks are independent from each other. Disruption in one may not impact the other. The freight trains would be separate from the passenger trains to reduce over-burdening one of the systems. In the event that one system is disrupted, rapid restoration and recovery can be done by a switch over to the other network.

Figure 5: Dedicated freight corridors – East and West

6. INITIATIVES ON IR FOR DISASTER RECOVERY

Disaster Risk Management: IR has an organized system of relief, rescue, restoration and rehabilitation operations for managing train disasters and natural calamities. Accident Relief Medical vans (ARMVs) and Accident Relief Trains (Figure 6 - ARTs) are on hand to provide medical assistance. Communication facilities are made available to passengers and railway officials to empower them to take decisive action to mitigate the effects of a disaster. Steps are taken to provide prompt and effective relief to the affected passengers in the event of any train accident. The senior-most officer at each site takes full responsibility for the situation, and supervises the overall relief operations. Special inquiry booths are opened at originating, terminating and important stations enroute.

Figure 6: Accident relief train

Disaster preparedness: The National Disaster Management Plan promulgation of the Disaster Management (DM) Act in 2005 showed a commitment to adopt a more collaborative strategy to disaster preparedness. Based on recommendations made in the Railways Disaster Management Plan (Indian Railways, 2019), the plan broadened its scope to include a wide range of incidents, including terrorism related activity and natural calamities. The aim is to share resources with other governmental departments to make the IR system more resilient.

7. CONCLUSIONS AND RECOMMENDATIONS

This paper introduces a framework that can be used to assess a rail network's resilience and ability to recover from disaster. Natural hazards and man-made disasters have an adverse impact on the transport system. Existing vulnerabilities within the transport system exacerbate the impact of such disasters. Reducing existing vulnerabilities helps to lessen the severity of a disaster's impact on the transport system and facilitates faster recovery. In putting forward the recommendations the paper hopes to stimulate discussion and bring railway operators and other experts together to share good practices and consider approaches and guidelines on how to optimise cost-effective resilience, prioritise resilience activities, and source funding for investment to build future resilience.

When the global pandemic struck, there was total disruption of normal operations of all modes of transportation due to restrictions imposed to stop the spread of COVID-19. IR provided assistance by transporting essential goods across the nation during the continued lockdown ensuring that there was no shortage of essential goods. Trains hauled a number of truckloads of freight containers (Figure 7) to reduce congestion on roads and the susceptibility of the truck drivers to the impacts of COVID-19 pandemic.

Figure 7: Long container wagons freight train

Based on the ideas explored in this paper, the following recommendations may be considered for adoption:

- Coordination across all stakeholders should be strengthened and the focus should be on building transport capacity and resilience at local, national and international levels, integrating transport in programs and activities through coherence between sectors/entities.
- Risk and vulnerability assessments of existing transport systems, as well as new project proposals, should focus on building resilience. The Framework model suggested in this paper may be used.
- Transport infrastructures should upgrade and adopt technical standards that are climate resilient. They should have the appropriate capacities to integrate a new system design and means of operation. This includes emergency preparedness and regular maintenance.
- Emphasis should be placed on telemetry, monitoring, evaluating and reporting passenger user data to improve predictions and prevent future disruptions.

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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,*

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

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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 CO_2 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.

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	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 4: Suggested actions for CDRFT dimension scores

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.

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).

Table 5: Bangkok CDRFT results

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**						

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.

Table 6: Manila CDRFT results

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**						

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.

Table 7: Dhaka CDRFT results

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**						

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.

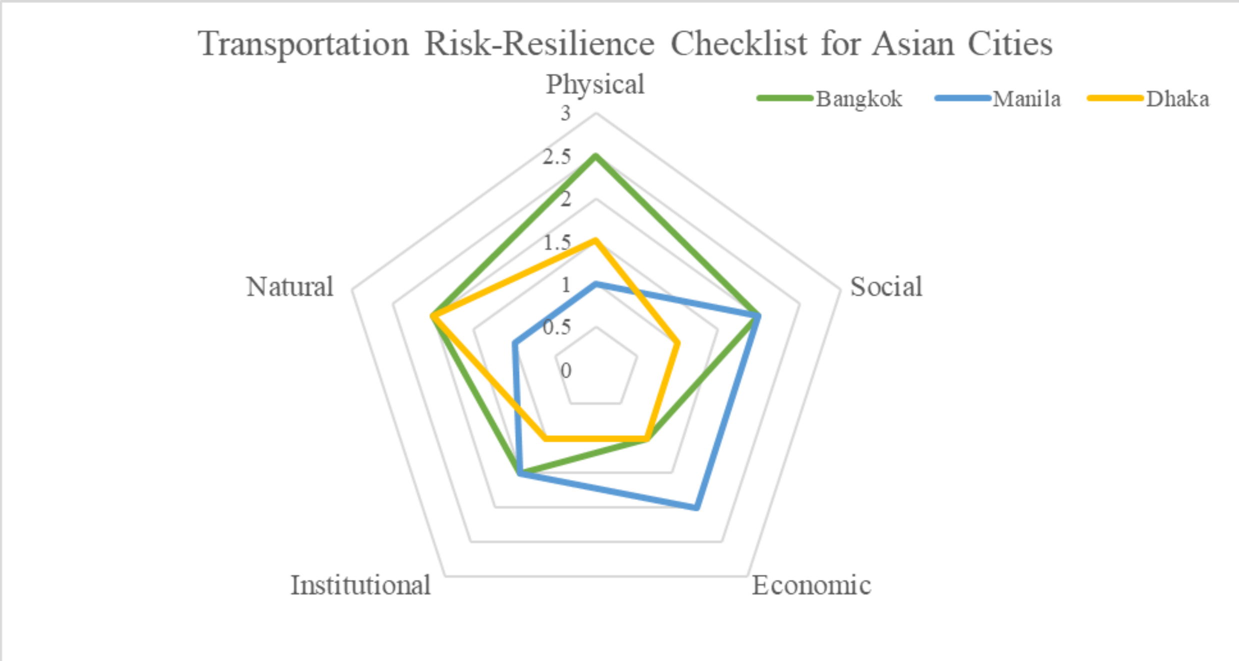

Figure 1: CDRFT spider graph

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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Impact of COVID-19 on Urban Mobility in Indian Cities

Ramit Raunak, Nishant Sawant and Shalini Sinha

ABSTRACT

COVID-19 is the biggest disruption of the century. It has had an unprecedented impact on the mobility sector across the world. This research presents the perceptions of people living in Indian cities with regards to the impact of COVID-19 on the urban transport sector following India's nationwide lockdown. The paper investigates the impact of lockdown on various parameters like mode choice, vehicular ownership, public transport patronage, frequency of travel and expectations from public transport operators. It also compares how globally public transport operations were altered during the pandemic. The study suggests that public transport will experience an ongoing reduction in demand as existing public transport users prioritise their health and safety while commuting. Moreover, many do not trust the current public transport system found across most of the Indian cities as a result of inadequate supply and poor operation. Middle-income group families, many of whom were previously dependent on public transport to commute, will contribute the highest in new vehicular purchases. As public transport will remain the pillar of urban transport to cut GHG emissions and reduce congestion, the paper discusses vision and actions that will help in creating a resilient, decarbonized and sustainable mobility system both in the short- and long-term.

Key words: Public transport, physical distancing, COVID-19, GHG emissions

1. INTRODUCTION

The COVID-19 pandemic has been one of the most abrupt shocks to the global economy in modern times (Hausler et al. 2020). The situation has been so unprecedented that almost everyone has been effected, some to a lesser degree than others, but the impact of COVID-19 on the mobility sector has been universal. Travel needs, travel options and commuter behaviour around the world have been forced to change drastically to mitigate the effects of COVID-19, as well as to meet the prescribed physical distancing protocols (Budd and Ison 2020).

The map below illustrates the status of operations of public transport globally on 30th May 2020. 80% of the world had either suspended or significantly reduced the PT operations to limit the spread of the pandemic. Countries like India, China, Pakistan, Egypt, Brazil, Argentina, and Ukraine completely prohibited the operation of public transport. Meanwhile, countries like Japan, Norway, Sweden, Finland, Australia, New Zealand and Germany kept their public transport services operating without any reduction in supply.

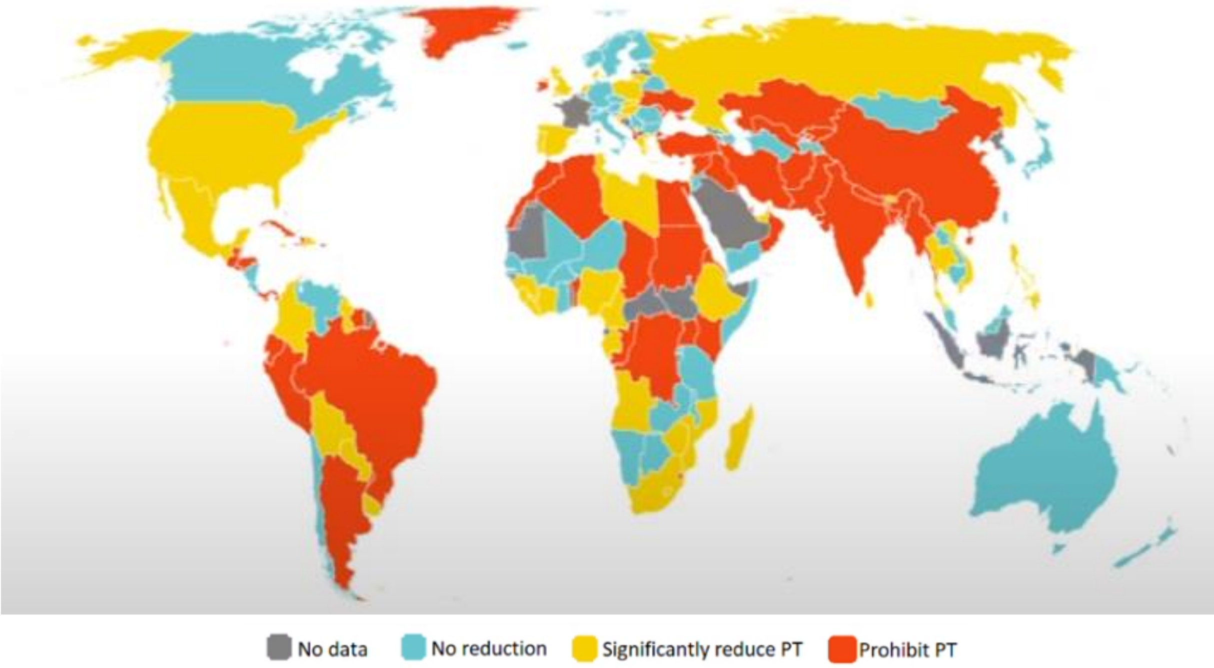


Figure 1: Status of operation of public transport globally on 30 May 2020
(source: Blavatnik School of Government, University of Oxford, Radcliffe Observatory Quarter 2020)

Internationally, public transport operators took concrete measures to make public transit safe for passengers and staff. Measures such as the regular disinfection of public transport, strict adherence to physical distancing protocol, and extensive contact tracing and communication helped various cities to keep public transport systems operating with no reduction in supply (Canon and Darido 2020). The results led to growing evidence to show that public transport riders are not at higher risk of infection (Arturo 2020). A robust public transport system, such as those seen in Japan and France, is able to adapt with appropriate sustained actions and therefore be more resilient, highlighting the need for scalable and resilient public transport infrastructure in cities (Sullivan 2020).

The paper presents the outputs from a study on the impacts of COVID-19 on travel behaviour carried out across various cities in India through an online survey in the months of May and June 2020. This paper is divided into six sections. The first section provides an overview of global fluctuations in travel demand during the initial COVID-19 lockdown. The second section is focused on the scenario of urban mobility during the first unfolding of COVID-19 infections and cases in India. The third section describes the research methodology framework followed by sample descriptions. Section 4 presents the findings from the perception study, with a particular focus on the impact of COVID-19 on mode choice, public transport user expectations and vehicular ownership. To conclude, Sections 5 and 6 discuss various actions to facilitate resilience in urban mobility in the future.

2. THE SCENARIO OF URBAN MOBILITY DURING COVID-19 IN INDIA

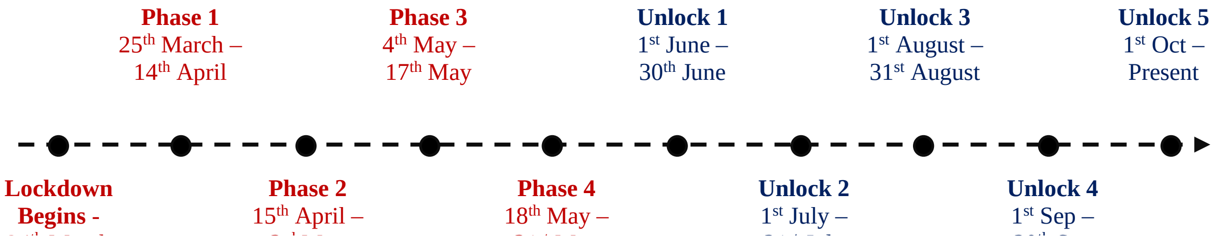


Figure 2: The timeline of Lockdown and Unlocking in India (*Source: De, 2020)*

The figure above shows the Lockdown and Unlock phases in India. The first case of COVID-19 in India was reported on 30^{th} January 2020 (Perppadan 2020). Given the steady rise in cases in February and March, the lockdown was announced from 24^{th} March 2020 (Figure 2) and public transport services were put on hold for more than two months during the 4 phases of lockdown (24^{th} March 2020 – 31^{st} May 2020). Unlock phase one was announced from 1^{st} June, however, access to public transport remained limited to essential workers in the Indian cities (Sharma and Ghosh 2020). In the subsequent Unlock phases, and as economic activity gradually resumed, public transport gradually resumed operations, though numbers were still not at pre-COVID-19 levels. Travel demand through public transport has improved, but is still significantly lower than the pre-COVID-19 levels (Kaushik et al. 2020). Bangalore Metropolitan Transport Corporation (BMTC) reported an average daily ridership of 35 lakhs before lockdown. However, the perceived risk associated with the spread of the virus and physical distancing norms has meant that BMTC's current ridership is at 10 lakhs per day (July 2020), 30% of pre-COVID-19 ridership (The Hindu 2020). BEST Mumbai is also experiencing a similar 65% to 70% reduction in ridership from pre-COVID-19 times (Sen 2020). People have restricted their travel to the most necessary purposes and, for many, typical commuting activities for reasons related to work and education are still being replaced by teleworking or online systems. Positive preferences of people have also been observed as a result of increased personal safety concerns, with a shift towards walking and cycling (Thakur et al. 2020).

Google has been releasing COVID-19 community mobility reports of various countries, including India. According to the reports, which are released periodically, trips to the public transport nodes were reduced significantly as compared to the baseline (Pre-COVID times denoted as 0 at the Y-axis) in the initial lockdown period from March to mid-April. Since mid-April 2020, when the lockdown norms were eased, the trips to PT nodes have witnessed steady growth (Figure 3). However, the trips to the PT nodes are at -37.18 to the baseline and reflect the reduced demand for travel (Google 2020).

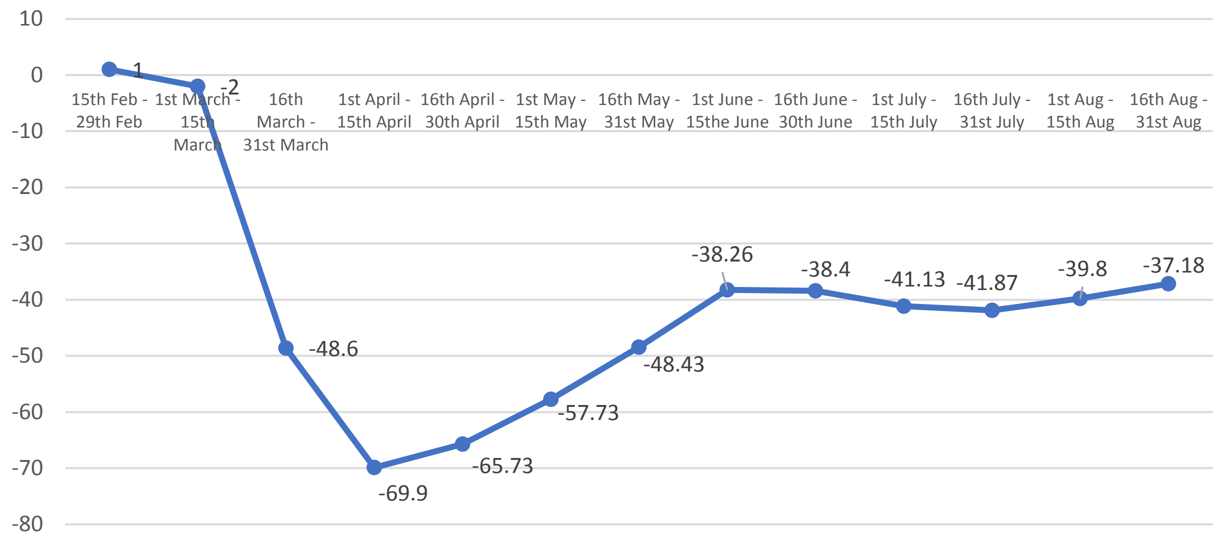


Figure 3: COVID-19 community mobility trips to public transit nodes in India (Source: Mobility Report by Google)

Overall, mobility in India has been significantly impacted by the lockdown imposed as a result of the pandemic. Even during the 'unlocking' stages, public transport has witnessed reduced ridership and travel demand has not reached pre-COVID levels.

3. RESEARCH FRAMEWORK

This study aims to assess the impacts of COVID-19 on mode choice, public transport ridership, and vehicular ownership. Moreover, the study discusses various actions that have the potential to help rebuild public trust in public transport, to enhance understanding during such unprecedented circumstances, and to facilitate sustainable mobility in the future.

To capture the perception of Indian citizens, an online survey was conducted through electronic mail and various social media platforms. The survey was live during phase 4 of lockdown (18th May – 31st May 2020) and 1st phase of unlock (1st June – 30th June 2020) from 19th May to 16th June 2020. The form was divided into two sections – the first section included the socio-economic profile of respondents such as city of residence, age, gender, profession, household income, and household and individual vehicular ownership. Section two was focused on capturing the impact of COVID-19 on travel behaviour, which includes stated mode preference after lockdown, reasons for change in travel behaviour and willingness to buy new vehicles. Respondents were also asked to rate various implementable measures that would help to reduce the spread of COVID-19, particularly when using public transport. A total of 1202 responses were received from people across 72 Indian cities.

It should be noted that the purpose of this survey was to assess the general trend towards the change in travel behaviour during lockdown and in the unlock phase, and the stated perceptions in the later phase, and not to extrapolate this across the entire population. An additional limitation of the survey was that it was not able to reach out to respondents who are without access to internet and social media.

3.1 Sample Profile

A total of 1202 samples were collected from 72 different cities spread across 22 states and Union Territories (Figure 4). The sample size of some major Indian cities is also mentioned along with the state-wise distribution of samples (
Table 1).

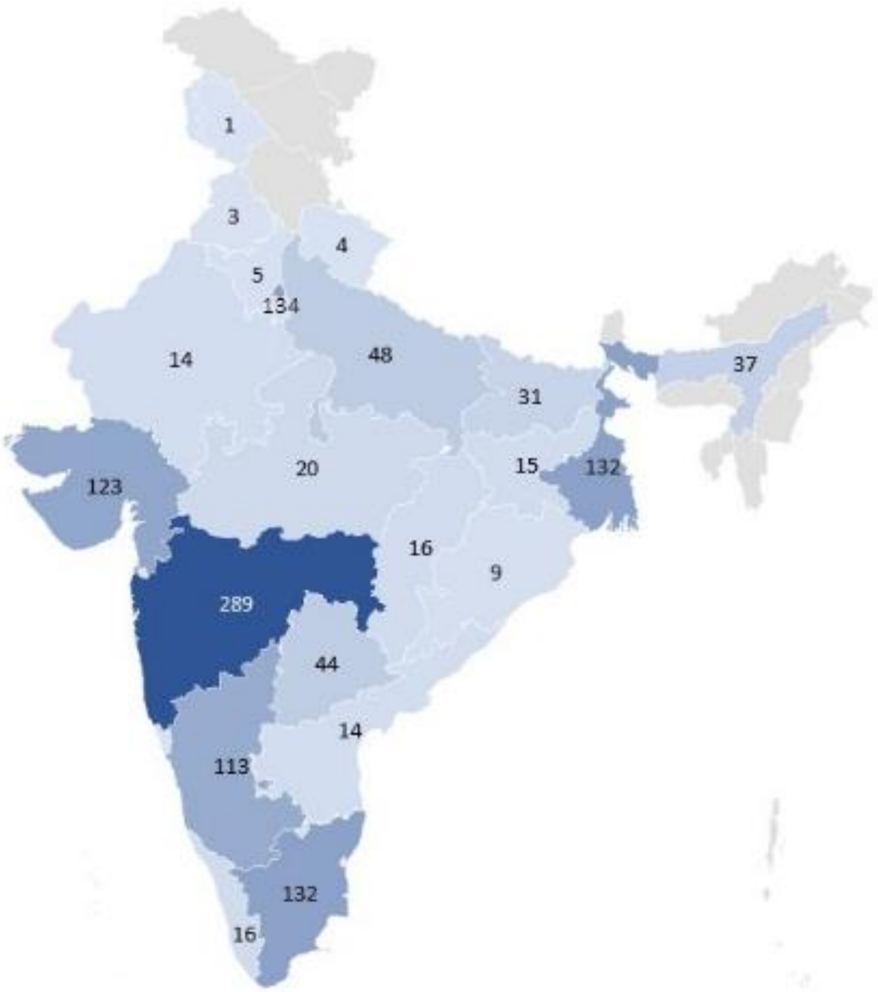


Figure 4: State-wise distribution of samples

Table 1: Number of Samples from major Indian cities

City	Samples
Ahmedabad	90
Bengaluru	91
Chennai	130
Delhi	134
Hyderabad	42
Kolkata	116
Mumbai	169
Pune	34

The sample distribution by gender reveals responses from 43% females and 57% males. In terms of occupation, the private service respondents have the highest share (41%), followed by students (27%). The smallest sample collected was from the retired (5%) and housemaker (8%) category (Table 2).

Table 2: Profile of samples

Category	Sub-category	% of samples
Gender	Male	57%
	Female	43%
Age	<20	21%
	20-40	38%
	40-60	23%
	>60	18%
Occupation	Private service	41%
	Student	27%
	Self-employed	10%
	Govt. service	9%
	Housemaker	8%
	Retired	5%
Monthly Household and Income	< 25000 INR	18%
	25000 – 50000 INR	33%
	50000 – 100000 INR	31%
	> 100000 INR	18%
Household and individual Vehicular Ownership	No vehicle	25%
	Only cycle	3%
	Only 2-wheeler	31%
	Only 4-wheeler	15%
	Multiple vehicles	26%

Lockdown restrictions meant that the survey was conducted online. However, samples collected have the proportional distribution of low, medium and high-income groups. Levels of vehicular ownership appear to be correlated to the income levels of the respondents (Figure 5), as vehicular ownership for the low-income category is low and increases with increment in income levels. Overall, 25% of the respondents do not own any vehicles, 3% only cycle, 31% own only a 2-wheeler, 15% only a 4-wheeler and the remaining 26% own a combination of either a cycle and 2-wheeler, 2-wheeler and 4-wheeler, or all three modes.

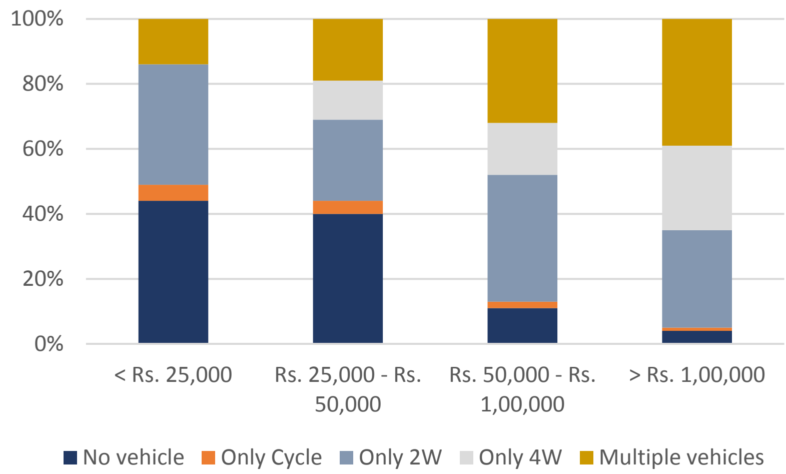


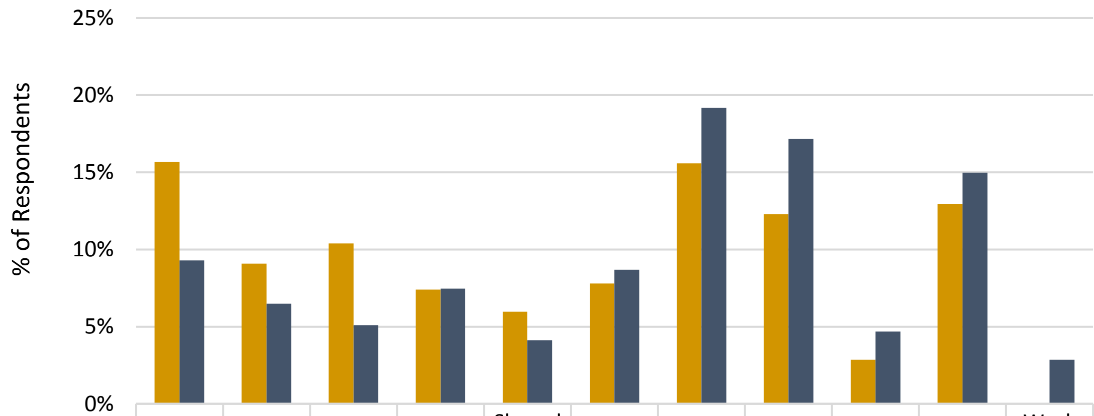
Figure 5: Income group-wise percentage distribution of vehicular ownership

4. DATA ANALYSIS

4.1 Impact on mode choices

The new physical distancing advice of maintaining a 2-metre distance between individuals seems to have reduced levels of public transport users' trust in the operators. 67% of the respondents suggest that safety from COVID-19 is the most significant criteria while travelling. The graph below illustrates the likely modal shift that cities may witness after lockdown from the stated choice of the respondents (Figure 6).

The sample survey suggests that all the public transport modes (bus, rail, metro, and shared auto/cab) will experience a drop-in user demand. Simultaneously, the private modes are likely to become the preferred mode of travel, with results indicating that the 2-wheeler mode share will likely increase from 15.6% to 19.2% and 4-Wheelers from 12.3% to 17.2%. Non-motorized modes are also anticipated to witness an increase. It is interesting to note that 3% of the respondents indicated that they are likely to work from home and will not be making any regular trips (Figure 6). Therefore, it is probable that the pandemic will significantly alter the mode choice and travel patterns in cities. Working from home is expected to be widely accepted and adopted, and improved virtual infrastructure in cities may further reduce the need for travel.



	Bus	Rail	Metro	Private Auto	Shared Auto/Cab	Private cab	2W	4W	Cycle	Walk	Work from Home
Before lockdown	15.67%	9.09%	10.39%	7.40%	5.97%	7.79%	15.58%	12.29%	2.86%	12.94%	0.00%
After lockdown	9.30%	6.48%	5.10%	7.46%	4.12%	8.69%	19.17%	17.17%	4.69%	14.97%	2.85%

Figure 6: Impact of COVID-19 on Mode Share

4.2 Impact on public transport

In the perception survey, 40.1% of regular pre-COVID public transport users suggested that they would still not prefer to use public transport. This is because of the perceived high risk of contamination on public transport, and the belief that maintaining physical distancing when using public transport would be difficult. As these respondents deemed public transport to be unsafe, the following are the modes the respondents would prefer to use post lockdown (**Figure 7**).

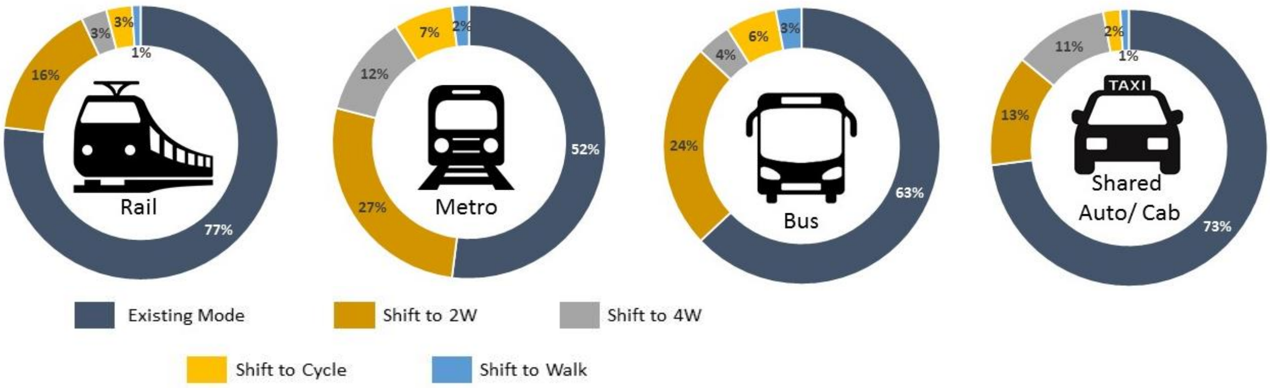


Figure 7: Post lockdown probable mode share of various collective modes

From the survey, it is likely that collective modes will experience decreased demand and riders will shift to personalized modes, e.g. 2-Wheelers, 4-Wheelers, Cycle and Walk. Interestingly, metro users indicate the maximum likelihood of a shift, with 12% indicating preference for 4-Wheelers and 27% for 2-Wheelers. A large proportion of these metro users belong to the income group who earn greater than 50,000 INR per month and have higher vehicular ownerships compared to other income groups. However, the urban rail, which is extensively used in Mumbai and Chennai for intra-city travel, is expected to see a much lower shift of 23%. This is because most of the rail users do not own vehicles and belong to the income group who earn less than INR 25000 per month. Shared cab service is also anticipated to witness a 27% reduction in demand, as people currently using the service belong to medium and high-income groups and own 2-Wheelers or cars.

Based on the perception study, the occupation that is likely to shift from public transport the most is the retired category (age group above 60). 44% of these respondents were public transport users and, out of these, 49% indicated an inclination to shift to personalized modes for commute in the future. Interestingly, occupations such as 'Housemaker' and 'Student' indicated a desire to continue the use of public transport relatively more than other occupations. Additionally, 42% of these respondents do not own personal vehicles. A logical conclusion to deduce from these results is that not owning a vehicle compels these public transport users to continue with the service.

4.3 City-wise impact on public transport

City-wise analysis indicates that Ahmedabad, Hyderabad, and Bangalore are likely to witness the maximum shift of PT users to other modes as compared to Mumbai, Delhi and Kolkata. This is likely due to long trip lengths, increased congestion, and high travel time in private vehicles in big cities like Mumbai, Delhi and Kolkata (**Error! Reference source not found.**).

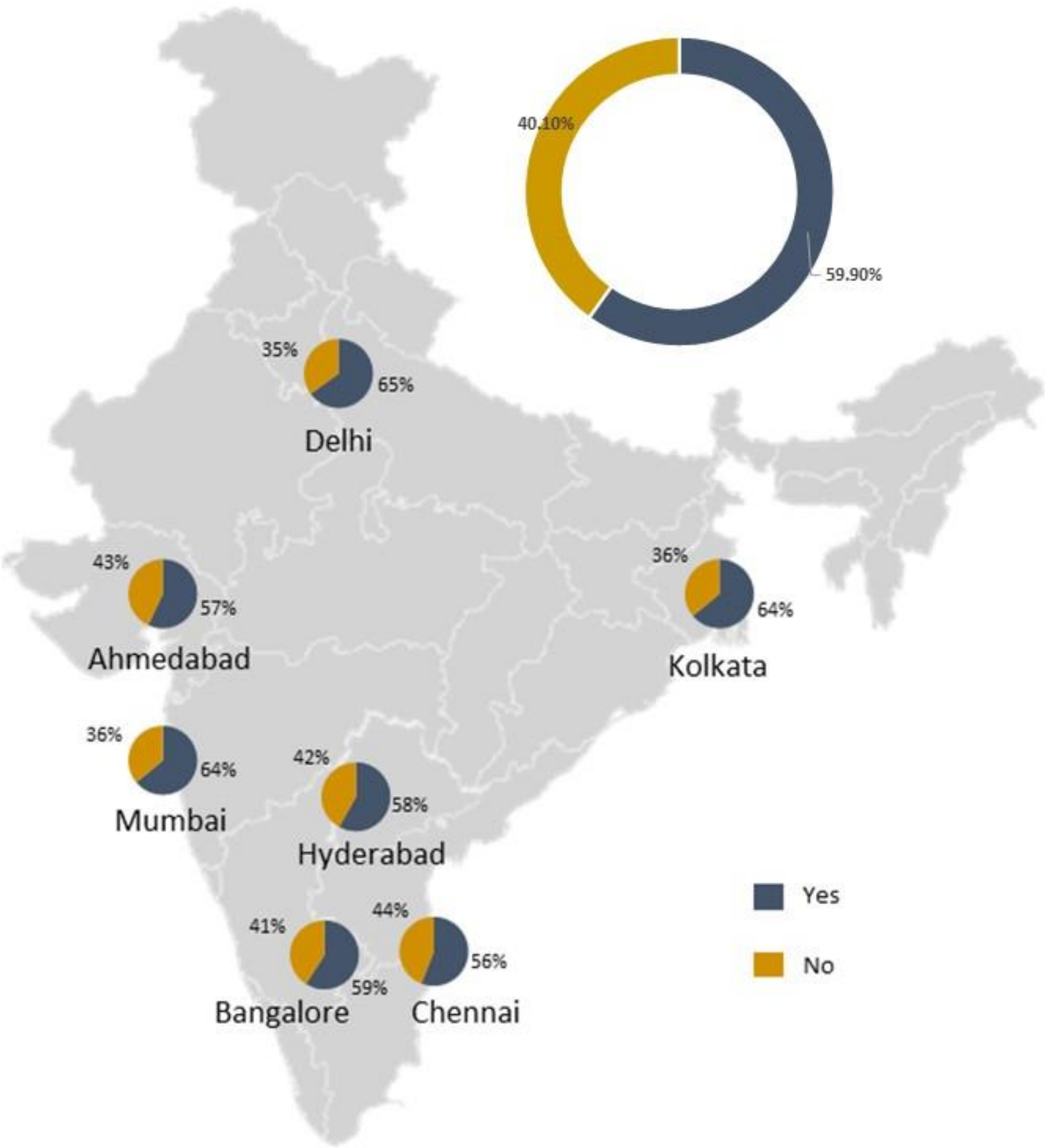


Figure 8: City-wise response on the use of public transport post lockdown

59.9% of existing public transport users will continue to use the service post-lockdown. There are different factors behind this figure. Out of the continuing public transport users, 72% do not own vehicles and are hence forced to use PT or endure long trip distances. Approximately 28% of the same group of respondents believe that the PT operations will improve, and safety will be ensured (**Error! Reference source not found.**).

City-wise analysis indicates that commuters have maximum trust in the PT operators of Bangalore (43%) and Delhi (35%), as they believe the government and operators will take appropriate measures to ensure public user safety, as compared to other cities (**Error! Reference source not found.**).

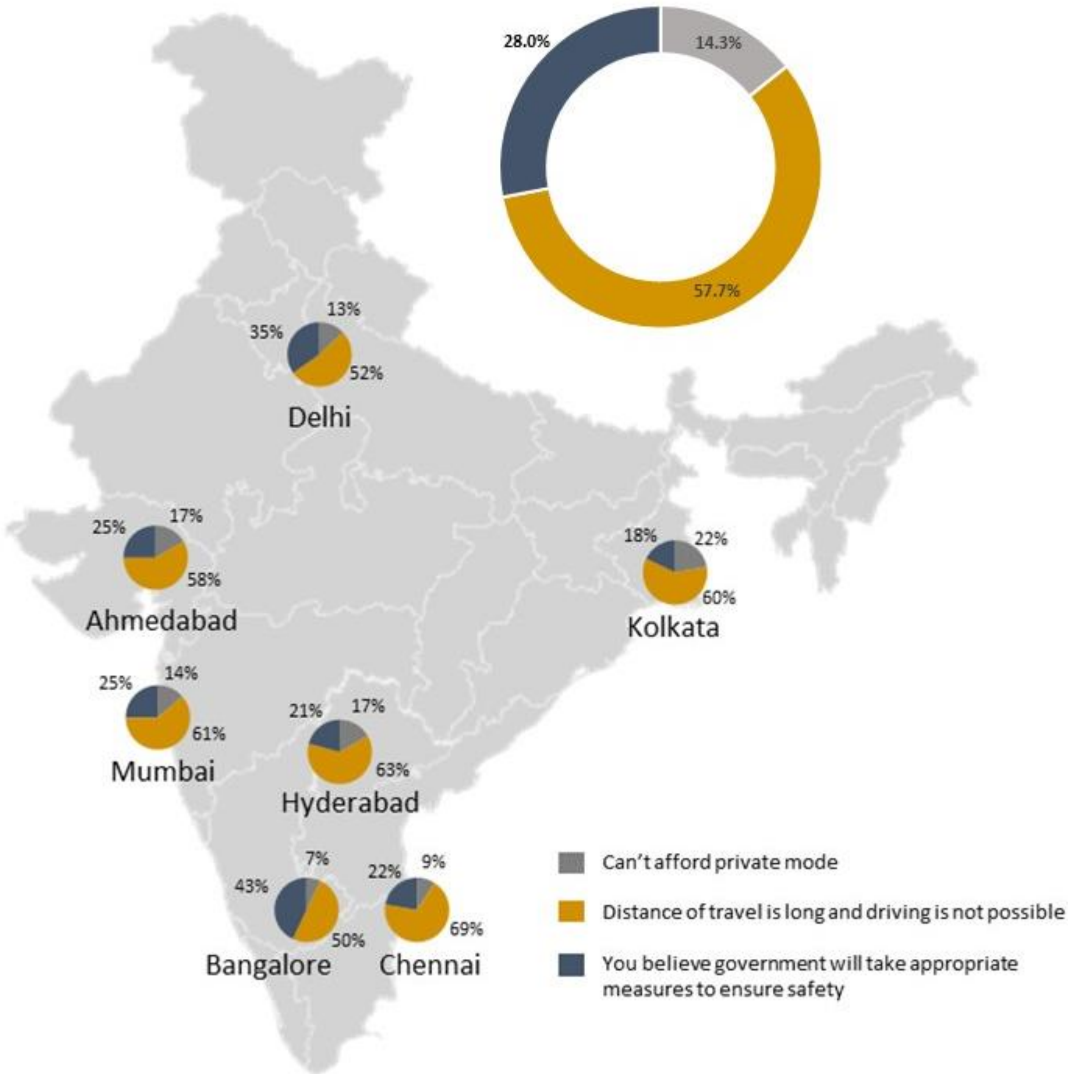


Figure 9: Reasons for continuing to use public transport post-lockdown

4.4 User expectation from bus operators

Public transport operators have a significant role in rebuilding the trust of public transport users. The impact of COVID-19 can be turned into an opportunity to overhaul the quality and function of public transport in Indian cities. This research study presents user expectations from the public transport agencies/operators. While there are innumerable measures to ensure safety, a set of 11 measures were outlined based on the literature review. These measures were presented to the respondents, who were asked to rate them in terms of effectiveness in reducing transmission of COVID-19 when using public transport. Figure 9 shows the rating of 11 different measures. According to the respondents, the 5 highest rated measures are i.) Provision of sanitizers at stops and inside the public transport (4.4) ii.) Not allowing people without a face mask inside the public transport vicinity (4.3) iii.) Cleaning and disinfecting the bus after every trip (4.1) iv.) Web ticketing (4) v.) Increased frequency of public transport (4) (
Figure 10). Adhering to the social distancing norm has been rated between the range of 'medium to high', representing users' desire for operators to maintain social distancing inside public transport vehicles. The low to medium (between 2-3) rating for queue-based entry and thermal screening of passengers reflects passenger behaviour patterns, as these measures would be time-consuming and affect travel time.

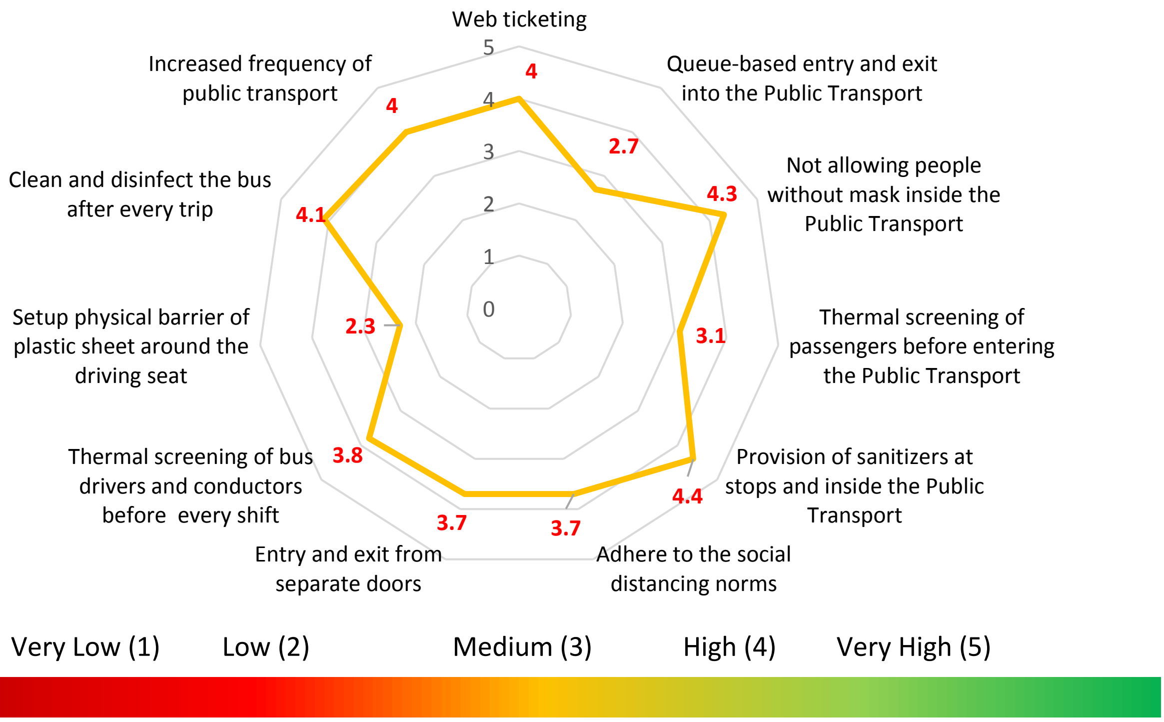


Figure 10: Rating for various measures to reduce the risk of COVID-19 while using public transport

4.5 Impact on Vehicular Ownership

Overall, 76% of the respondents are not willing to buy any new vehicle post lockdown. Of the 24% of respondents who indicated their willingness to buy new vehicles post lockdown, the percentage is highest in the income group between Rs. 25,000-50,000 (**Figure 11**). This is likely to be because this income group can afford a private vehicle but had preferred to use PT until now. Meanwhile, the high-income group already own a vehicle, hence they score highest in being the least willing to purchase a new vehicle**.** The vehicular segment corresponds both to income level and cost of the vehicle, as low- and middle-income groups are willing to buy a 2-Wheeler while the high-income group prefers the 4 Wheeler (**Figure 12**).

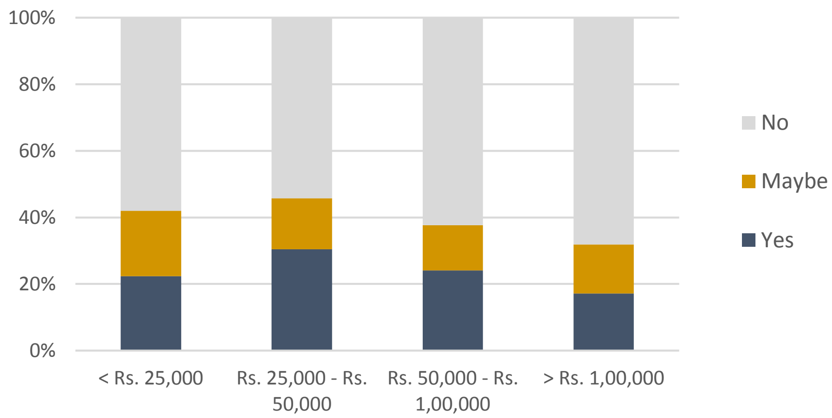


Figure 11: Income-wise percent distribution of sample for willingness to buy new vehicle

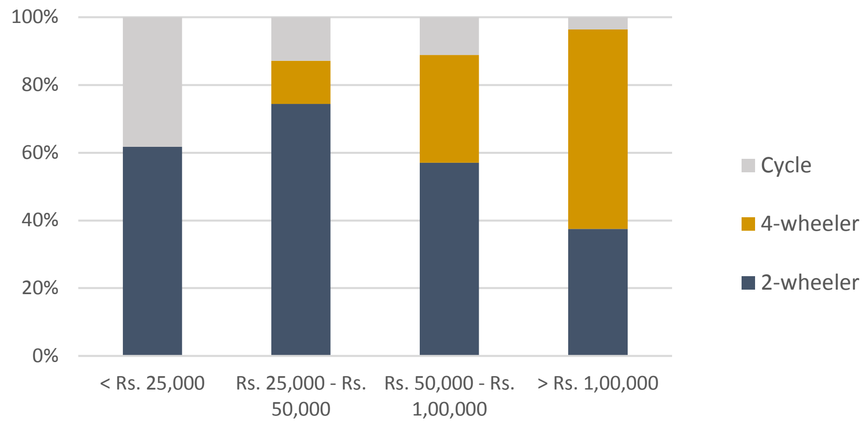


Figure 12: Income-wise percent distribution of sample for preferred mode of new vehicle

5. DISCUSSION

Despite the easing of lockdowns around the world, it is clear that, at least in the short- to medium-term, physical distancing will continue to be the norm. The current supply of public transport in Indian cities means that such physical distancing will pose a significant challenge. As suggested by the responses received, public transport is likely to be negatively impacted in the short-term. There is also a possibility of increased vehicular ownership post lockdown. This shift away from public transport to private modes will lead to increased demands on an already congested road space. Increased traffic, vehicular pollution, road safety and noise pollution are major concerns. It is clear that there is therefore an urgent need to develop a comprehensive strategy, one which addresses the immediate impact of COVID-19 as well as the bigger challenge of the global climate crisis.

Restoring public trust in using city buses and addressing the health-related risks of doing so are both essential. Web ticketing, demarcating seats to maintain the physical distancing, disinfecting the bus after each trip, installing handwash stations at bus stops, face shields and regular thermal screening for drivers and conductors, and entry from the rear gate and exit from the front gate, can all help in building trust in riders (GIZ India 2020). Moreover, improving the supply of buses by fleet expansion, making PT fares more attractive, and ensuring high levels of safety will help re-establish passenger trust (Thakur et al. 2020).

In addition, staggering office timings in metropolitan cities can help to flatten the peak rush hours (MoHFW 2020). In order to provide adequate supply of buses, all inter-city buses can be used for city services irrespective of the kind of contract buses hold, while still ensuring physical distancing (Suman, Agarwal, and Bolia 2020). The extraordinary situation that COVID-19 has brought upon the world has also provided an opportunity to address India’s existing institutional challenges. Enhanced technology, such as the sharing of bus on-board occupancy and the real-time information of bus positions through web-based applications and on the digital boards of bus stations, can also be effective strategies. Additional funding can be pulled from central and state governments to cover the shortfalls due to reduced farebox revenues. Exemptions can be made in motor vehicle tax for the months when services are limited and ridership is poor, as this will help reduce the monetary burden for operators (UITP 2020).

As previously mentioned, the challenges posed by COVID-19 can be taken as an opportunity to refurbish the urban transport sector and steer it toward a more desirable future. Technology and sustainability can be used to demarcate a better future for urban mobility. As the government proceeds toward a phased unlock, urban mobility can progress towards a more desirable ‘new’ normal. This new normal mobility can be defined as a system where streets are for all, congestion and pollution are less, public transport is safe and non-motorised transport is extensively used. To achieve the desired normal for urban mobility in cities, the focus must be on dedicated non-motorised transport infrastructure, land use and transport integration, promotion of electric vehicles across all modes, and institutional unification to ease and accelerate the implementation of transport policies, programs and schemes. A collective effort from the community and authority can bring this desirable change in the urban transport sector. While strategies are many, financial support to implement these strategies is the key. Public transport has been widely regarded as a social obligation for a long time. The pandemic is an opportunity to make the proposed measures to improve PT a reality. PT users are not the only ones whom stand the gain from such improvements: non-riders and property owners, indeed the whole of wider society, will benefit from an overall enhanced quality of life, reduced congestion, a decline in road accidents, and better air quality due to lower GHG emissions. A comprehensive plan to attain revenue from all these sources (carbon taxation from 4-wheeler and congestion pricing) is crucial. This revenue can therefore be diverted to help improve the bankability of State Transport Undertaking's, with a revised focus on fleet expansion and desired service.

The lasting legacy of the pandemic has brought about a realisation that the larger crisis we face - climate change - could lead to similar disruptions of the same magnitude in the near future. Addressing climate change by adopting decarbonized modes, implementing awareness initiatives among communities and working towards resilience for such a crisis can hugely help cities peddle towards a greener future.

6. CONCLUSION

As the world's population increases and urbanisation expands, the needs of urban mobility have become increasingly urgent. The disruption that has resulted from COVID-19 has significantly impacted the mobility sector across the globe. This research paper attempts to capture the influence of COVID-19 on various aspects of mobility. The perception study suggests that mode choices will probably be altered post COVID-19, with a marked shift away from public transport to walking, cycling or personalised modes expected, at least in the short term. The study suggests that Mumbai, Delhi, and Kolkata may experience comparatively smaller shifts from public transport modes as compared to Ahmedabad, Chennai and Hyderabad. Various implementable measures have been rated by the respondents towards addressing the concerns while traveling through public transport. The analysis depicts that web ticketing and improved supply of public transport are two prime demands of the respondents. Vehicular ownership is another parameter that has been explored through the perception study and 24% of the samples are planning to buy new vehicles. Interestingly, the respondents belonging to the income category of INR 25,000-50,000 per month are more likely to buy new vehicles as compared to other income categories.

The pandemic has resulted in notable improvements in local air quality in cities globally and a glimpse, perhaps, of a greener future. We now have an opportunity to transform the urban mobility sector by promoting sustainable and decarbonised transport. Public transport is widely considered to be the pillar of sustainable mobility. Reviving the sector with public health interventions, better frequency and coverage, and scalable infrastructure could help make great gains in addressing the rise in GHG emissions and the ever-increasing congestion in Indian cities.

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