Proceedings of the Eastern Asia Society for Transportation Studies, Vol.12,2019

Simulation of Metro Manila Public Transportation Network under Flooded Conditions

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Abstract: The proper functioning of public transportation networks is critical to areas where travelers heavily rely on transit services. This paper presents flooding scenarios affecting the existing transportation network of Metro Manila, Philippines during adverse weather conditions. Simulation modeling through a GIS software revealed that the flood would impair 32% and 20% of jeepney and bus routes, respectively and would make some cities highly susceptible to transit-related disruptions. Assignment results indicated that floods will increase travel times and trips made using only auxiliary transit but will decrease the number of transit lines taken per passenger because floodwaters may force travelers to take circuitous routes. Access to transit services would also be impaired in several areas because of the changing conditions as transport services adjust to flooding. The results reflect the need for the improvement of transport infrastructure and development of flood-free transit routes that would complement existing services affected by floods.

Keywords: public transportation, flooding, simulation, transit assignment

1. INTRODUCTION

Public transportation is essential in metropolitan regions as the services it offers provide a mobility option that benefits the general public (Cervero, 1998; Oswald & Treat, 2013; Tao, Corcoran, Rowe, & Hickman, 2018; Vuchic, 2005). The improvement of public transportation services is valuable to the environment and the economy because it addresses the issue of congestion by reducing the number of vehicles operating along major thoroughfares (Dewan & Ahmad, 2007; Houghton, Reiners, & Lim, 2009) and encourages shifting form personal car to more sustainable travel options (Cats & Jenelius, 2014).

Just like any network, public transportation networks face the threat of climate change and extreme weather events. Different studies have shown that natural disasters such as floods cause damage to transport facilities and infrastructure (Balijepalli & Oppong, 2014; Oswald & Treat, 2013) and make certain portions of the road network impassable (Berdica, 2002). Disasters disrupt the function of transportation networks and often result to loses in travel time (Balijepalli & Oppong, 2014; Berdica, 2002; Scott, Novak, Aultman-hall, & Guo, 2006), affect other parts of the network (Cats & Jenelius, 2016), burden other critical lifelines (Khademi et al., 2015), and impair the abilities of individuals to perform their daily activities like commuting, shopping, etc. (Cats & Jenelius, 2014).

Despite the importance and benefits of transportation services in the functioning of urban regions, most of the effects of the disruptions to transportation networks are still unknown (Suarez, Anderson, Mahal, & Lakshmanan, 2005). Transport planners, therefore, should be aware of the susceptibility of transit networks to disruptions so that the corresponding services can absorb and withstand its impacts and continue to function. In doing so, public transportation becomes a more attractive option for travelers because of its robustness.

Because of the potential issues posed by severe weather events to transportation systems, the authors are motivated to examine potential impacts of floodwaters to transit services in the capital region of Metro Manila in the Philippines. The authors believe that this is a study worth pursuing given that Metro Manila is frequently hit by meteorological disturbances that often disrupts the performance of the entire transit network. However, studies detailing the potential effects of such disturbances to the local transit network is scant. This study aims to gain insight as to how much transit services will deteriorate due to a flood event. Further analysis would provide the changes in public transportation trip characteristics when the network is simulated under various conditions. The study would, therefore, be able to provide what portions of Metro Manila would need to be evaluated further to make transit services less vulnerable to the disruptions.

The remainder of the paper is structured as follows. Section2 provides a review of studies on the impacts of severe weather on transit services. Section 3 provides a brief background on the study area and the existing transportation services. Section 4 describes the methodology. Sections 5 discusses the findings of the study. Section 6 concludes the paper and provides recommendations for local authorities and future work.

2. RELATED LITERATURE

Public transportation systems are affected by changes in weather conditions (Böcker, Dijst, & Prillwitz, 2013) because most transit-related infrastructure are often exposed to the environment (Miao, Feeney, Zhang, Welch, & Sriraj, 2018). Studies of transit performance during adverse weather conditions show that disturbances in operations lower service quality, degrade passenger satisfaction, and affect transit ridership (Changnon, 1996; Hine & Scott, 2000; Hofmann & O'Mahony, 2005; Kashfi, Bunker, & Yigitcanlar, 2016).

There have been different approaches in studying the impacts of disruptions to transportation networks. Most of the available literature about this topic typically focus on the vulnerability of transportation networks to different kinds of disturbances. Authors usually perform a vulnerability assessment to expose the weaknesses in the transportation network (Husdal, 2004). This section provides a summary of the studies that either assessed the impacts or the vulnerability of transportation networks to potential network disruption.

Most of the process involved in analyzing the impacts of disruptions to transportation networks usually performs scenario-specific assessments. The goal of these kinds of assessment is to answer "what if" questions regarding particular disruptions and compares these scenarios to a base scenario (Murray, 2013). This was evident in the processes used by Suarez et al., (2005) in the Boston Metro Area, Balijepalli & Oppong (2014) in providing alternate routes, Chang et al. (2010) in understanding the redistribution of flows in Oregon, USA, Rodríguez-Núñez & García-Palomares (2014) in determining the criticality and exposure of transport networks, and Selvaraj (2016) in measuring the effects of nuisance flooding. In most of these studies, they often use different indicators to measure the vulnerability of the transportation network. For public transportation networks, the common indicators used are transit time, total travel time, passenger distance, changes in ridership by mode/route (Dowd, 2015), betweenness centrality (Cats & Jenelius, 2014), among others.

In the Philippines, studies analyzing the effects of disturbances to public transportation services have mostly been limited to the analysis of travel behavior change. Ibasco (2016) studied the behavior of university students, while Sunga et al. (2017) studied the mode choice behavior of commuters in a central business district. Meanwhile, the previous work of Abad et al. (2016) investigated the relationship between reduced mobility and housing affordability. However, none of these works shifted their focus on the analysis of transit network performance in the event disruptions. This paper looks at this perspective to provide an insight into how changes in transport services caused by flooding would affect trips performed using transit.

3. METRO MANILA: GEOGRAPHY, PUBLIC TRANSPORTATION NETWORK AND CONDITIONS

3.1. Climate and Geography

Metro Manila (National Capital Region), the seat of the Philippine national government, is composed of four districts with 17 local government units (LGUs). This metropolitan region is the smallest among the country's 18 regions in terms of land area (619 square kilometers) but contains 12% (or about 12 million) of the entire Philippine population. Metro Manila experiences a tropical climate characterized by high temperatures, humidity, and seasonal rainfall. The region experiences two seasons – wet (usually begins during the month of May and ends during October) and dry (from November until April). The region is also bounded by the plains of Central Luzon in the North, the mountain range of Sierra Madre in the East, the Manila Bay on the West, and Laguna de Bay on the South. Because of the topographical and climatic conditions of the region, some cities have high flood risks either because of its proximity to river estuaries or because they received mountain run-offs and overflows from bodies of water. Furthermore, some streets in Metro Manila have also become flood-prone (Lagmay et al., 2016) because these streets intersect creeks located at topographic lows. Combining this with the inadequate drainage facilities and poor solid waste management practices, this has resulted in frequent flooding events making the wet seasons worrying for Filipinos. Some of the notable flooding events which are caused by weather disturbances are listed in Table 1.

3.2. Public Transportation System

The public transportation needs in the region are addressed by buses (airconditioned and non-airconditioned), jeepneys, Asian Utility Vehicles (AUVs or UV Express), light rail systems (LRT1, LRT2, MRT3), and the heavy rail (PNR). The routes shown in Figure 1 are city routes and do not include provincial services (moving in and out of Metro Manila). The paper will only pay specific attention to road-based public transportation services in Metro Manila.

Both bus and jeepney services in Metro Manila operate fixed inter-city routes. Naturally, this is expected for buses as these are designed to operate long distance travels along major roads and to carry a higher number of passengers (average seating capacity is 60). As such, buses serve the longest routes and the highest vehicle occupancy rates (Japan International Cooperation Agency, 2015a) but operate at a relatively low speed not exceeding 20 km/hr during weekdays (Department of Transportation and Communications, 2012). Jeepneys, on the other hand, operate shorter routes (average service route length is 10.9 km) than buses. The body of the jeepney was transformed from old service vehicles during World

War II limiting operations to a lower seating capacity than buses. Jeepneys are popular and successful because of its local availability, its capacity, accessibility, familiarity, economical fare, and extensive networks (677 routes within the region) (Bayan, 1995; Ebata, 1996; Labastilla & Villoria, 1999; Okamura, Kaneko, Nakamura, & Wang, 2013). Unfortunately, operating speeds of jeepneys barely reach 15 km/hr because of delays caused by the frequent boarding and alighting at non-designated stops along its service route creating bottlenecks and worsening urban traffic situation (Chiu & Shioji, 2006; Department of Transportation and Communications, 2014).

Table 1. Severe Weather Disturbances and Flooding Incidents in Metro Manila (2009 - 2017)

Weather Disturbance / Date	Recorded Incidents
Ketsana / September 24 - 27, 2009 Max.24h rainfall: 556.1 mm (Science Garden)	Caused flooding in significant parts of Metro Manila, Central and Southern Luzon, and portions of Visayas and Mindanao. 239 barangays in Metro Manila were flooded of varying heights ranging from knee/neck to rooftop deep
Southwest Monsoon / August 7-11, 2012 Max.24h rainfall: 1007.4 mm (Science Garden)	Caused massive floodings in the NCR and Regions 4-A and 4-B Power and water interruptions occurred in San Juan, Navotas, and Malabon Marikina river overflowed 12 cities and 1 municipality in NCR were declared under a state of calamity
Habagat & Maring / August 17 - 21, 2013 Max.24h rainfall: 1120.2 mm (Sangley Point)	Flooded 10 cities in NCR 7 cities and 1 municipality were declared under states of calamity Office work and classes were suspended Varying rainfall warnings (orange to red) from August 18 to 21
Mario / September 17-22, 2014	Caused damages and flooding in NCR Suspension of all classes across all levels in Metro Manila Canceled and diverted international and domestic flights
Nona / December 15 – 19, 2015	Classes were suspended in NCR Domestic flights were canceled
Lannie & Maring / September 11 – 13, 2017	Flooded areas in Metro Manila. Work and classes were suspended in NCR

AUVs operate in a different manner compared to buses and jeepneys as these light commercial vans provide point-to-point (or express) services between residential areas and central business districts. AUVs are distinct in terms of their operations since they do not have fixed routes which allow them to operate at faster speeds (average speed ranging between 20 and 30 km/hr) than buses and jeepneys. Moreover, their success stems from filling the gaps left by bus and jeepney operations. The high patronage of these services resulted in a total of 290 routes mostly operating from the periphery of NCR towards the central portion of the region. Completing the transport mode hierarchy are tricycles (motorcycle-powered) and pedicabs (human-powered) which often serve residential areas and subdivisions and sometimes feed into other transport modes.

The current structure of public transport service gives the government a regulatory role through granting of franchises (Certificates of Public Conveyance) while operators (franchise owners) and drivers have free reign on vehicle dispatch and schedules (if any). The current structure, unfortunately, makes transit services more profit-oriented than service oriented (Department of Transportation and Communications, 2014) and highly competitive between operators, which could be problematic in disruption events affecting the transit network.

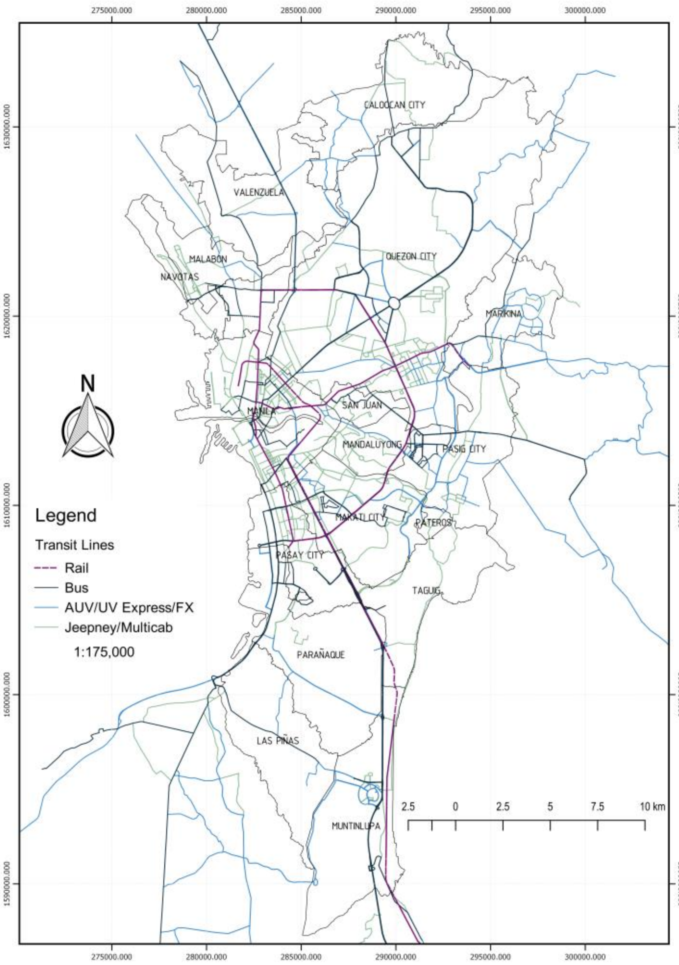

Figure 1. Public Transportation Network Coverage

This paper will explore the potential effects of flooding to road-based public transportation services as simulated thru different flood scenarios. The analysis would focus on the affected city buses and jeepney services. The analysis would focus on the changes in transit indicators (lines per passengers, passenger-hours, impedance). Finally, the paper extends its analysis to the changes in access (from origin to initial boarding) and egress (final alighting to destination) distances. The main aim of the paper is to describe the impact of a 5-year flood affecting the entire region to the transportation network. In the end, policy recommendations are envisioned to be able to cope up with the potential impacts of flooding.

4. METHODOLOGY

4.1. Data Preparation

The transportation network and its properties were developed using a transportation modeling software – EMME/4. The zoning system adopted in this study is in conjunction with the zoning system used in government studies. The network of Metro Manila is divided into 268 zones based on the household interview surveys during the MMUTIS Update and Enhancement Project (JICA, 2015). Each zone is represented in the network with a centroid and is connected by a link to accommodate trips coming in and going out of the zone centroid. The public transportation routes were collated from various studies and surveys (Department of Transportation and Communications, 2009, 2014; Roquel & Fillone, 2015). The origin-destination (OD) matrix represents the trips made between each pair of zones during a typical weekday peak hour. The peak hour period considered in the study considers the trips in the morning.

The flood maps indicating the level of hazards of all the LGUs within Metro Manila were downloaded from an online repository (DREAM, 2016). The flood hazard maps and road/public transportation network was exported into ESRI shapefiles. GIS software (QGIS) was used in determining the affected portions of the road network. Specifically, the authors made use of several processing tools to prepare the flood hazard and road network layers for analysis. The actual steps in preparing the shapefiles for analysis are similar to the methodology of Oswald & Treat (2013):

Prepare flood hazard layers:

1. Clipping of overlapping flood hazard layers (for flood hazard layers that cover similar areas).
2. Dissolve the individual flood layers to return three distinct levels of flood hazard.
3. Merge the dissolved layers to have one flood hazard map for the entire study area.
   3.1. As an aside, the flood hazard map was split according to its level of hazard

Intersect flood hazard layer with transit segments:

1. The intersection of the public transportation network and the individual flood hazard layers was determined using the *Line-Polygon Intersection* processing tool of QGIS. The selection of flood-affected network nodes was performed using the *Clip Points with Polygons* processing tool of *SAGA*.
2. Individually the transit routes for any errors.
3. Calculate the route lengths affected by the flood.

4.2. Modeling Assumptions and Scenarios

Some of the assumptions in the study are as follows:

1. People attempt to perform their regular trips (Dowd, 2015). This paper models a situation wherein transit users will attempt to complete the trip despite the disruption caused by floodwaters. In addition, it is assumed that travelers have full information on flooded roads.
2. Fixed trip distribution (Dowd, 2015). The paper assumes that the distribution of the trips remains the same since travelers will have made their decision on the trips that they will make. Further, this assumption covers types of trips whose destinations cannot be easily altered (e.g., location of work, school, or home). This assumption is justifiable since the focus of the study is the redistribution of the flows to other routes (Chang et al., 2010).
3. Passengers would choose the path that would provide the shortest travel time between their origin and their destination (Rodríguez-Núñez & García-Palomares, 2014).

4. Links affected by the flood are limited in terms of operability. Assumed capacity reduction factors are used based on the level of hazard that affects the link.

The modeling scenarios in this study are defined as follows:

1. **Base scenario (Scenario 601).** This is the model scenario representing normal conditions as a point of reference for the next flood scenarios.
2. **Reduced link capacities (Scenario 602).** This is the model scenario representing a flooded network scenario wherein capacities of links intersecting with the flood hazard map are reduced. The reduction in link capacities is assumed based on the level of flood hazard affecting the link.

   A link would retain its original capacity if not affected by the flood. If affected by the flood, the original capacity would be reduced depending on the flood hazard level. For instance, a type-1 link that intersects an area with low flood hazard would have its link capacity reduced by 10% (from 800 to 720 vehicles per hour per lane or vphpl). The capacity reductions were based on the authors' perception of the type of vehicles that would be affected based on the estimated flood heights. These reduction capacities are used to reflect the smallest possible change in capacity for a given road link that would still reflect the impact of flooding. However, these capacities still need some calibration and applicability to real-world scenarios. Table 2 shows the road classification and its corresponding characteristics adopted in the model. Figure 2 shows the network with the flood hazard map to identify flood-affected roads.

Table 2. Road Network Characteristics under Normal and Flooded Conditions

Type	**Description**	**Original Capacity**	**Reduced capacity per flood hazard**		
			Low (10%)	**Medium (50%)**	**High (80%)**
1	National Roads	800	720	400	160
2	Expressways	1000	900	500	200
5	Local roads (inner roads)	600	540	300	120

3. **Restricted boarding and alighting (Scenario 603).** This represents events wherein flood affected transit segments restrict passenger movement like boarding and alighting. This scenario highlights the possibility that individuals would find it difficult to board or alight a vehicle when it is located in a flooded segment. Naturally, travelers would want to board or alight at areas free from floodwaters. This scenario also adopts the previous scenario (Scenario 602), wherein network elements affected by floodwaters have reduced capacities.

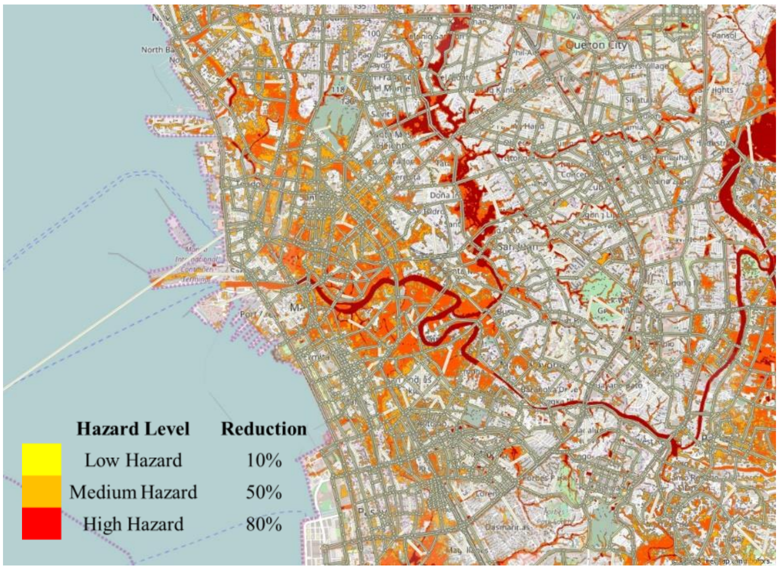

Figure 2. A portion of the road network with flood hazard map (Source: DREAM, 2016)

4. **Remove heavily affected transit services (Scenario 604).** This scenario represents instances wherein profoundly affected transit services are removed. Transit services wherein 80% of its transit routes are affected by a flood are removed under this scenario. The scenario implies that services would cease to operate if the majority of the service route would be inundated with floodwaters. This is a reasonable assumption since it would be difficult for services to continue when most of the route is inundated with floodwater. The scenario also adopts the previous scenario (Scenario 603) wherein restrictions in boarding and alighting and reductions in capacity for flood-affected network elements are observed.

4.3. Model setup and network performance evaluation

All the network modeling simulations were done in the transportation modeling software-EMME/4. The EMME/4 software offers a variety of transit assignment tools for analyzing transit demand. Specifically, the authors made extensive use of the *Extended Transit Assignment* module of the software, which is based on the developed concept of *strategies* (Spiess, 1984; Spiess & Florian, 1989). The *strategies* assume that the traveler behaves in a way that minimizes their total expected travel time, which is the sum of the expected walk, wait, and in-vehicle time. Using the extended transit assignment, the modeler can force travelers to leave a centroid of a traffic analysis zone using the best connecter, choose among transit lines/routes with the least *penalty* or cost (fare and travel time). The procedure of the optimal strategy assignment model is composed of two parts:

1. Define the optimal strategy and the total expected travel times from each node to all destination nodes
2. Assign the transit demand to the network (from all origins to the destination) according to the optimal strategy

The use of the optimal strategy assignment is justifiable since the authors assume that any form of disruption to the network would result in travelers seeking the *least costly* way to get to their respective destinations.

The evaluation of the network performance was performed by comparing the performance of the flooded scenarios (Scenarios 602, 603, 604) to the base scenario. First, comparisons between the extended transit assignment results will be presented. These values are expressed in terms of changes in *auxiliary transit demand only*, *lines per passenger*, and *passenger-hours* to the destination zone. Auxiliary transit demand refers to trips made by walking or by using human-powered pedicabs and tricycles. *Lines per passenger* refers to the number of transit services or lines that the passenger takes for their trip between an origin and destination pair. Finally, *passenger-hours* is often used to measure the performance of a transport system. This indicator is taken as the product of the number of passengers and the time it takes for these passengers to travel through a transit segment. An increasing value usually indicates either an increase in passenger load or travel time in a segment.

The research then focuses on the changes in *access* and *egress* distances in the event of a flood. In doing so, the first and last portions of each trip will be analyzed as it may affect travelers significantly. The analysis was performed by doing the *extended transit analysis* module of EMME/4. The procedure can be described as follows:

1. Run the optimal strategy assignment model to the scenario
2. Conduct extended transit assignment analysis (path-based analysis)
3. Select *origin to initial boarding* (for access distance) and *final alighting to destination* (for egress distance) as the path to be analyzed.
4. Set the length thresholds from *lower = 0* to *upper = 99999* to select all access and egress links.
5. Save the calculated access and egress distances to a full matrix.

The results are presented in map form to reflect spatial differences and to pinpoint which zones are most affected by a flood.

5. RESULTS AND DISCUSSION

5.1. Affected Nodes and Transit Segments

Figure 3 shows the extent of the nodes that are affected by a 5-year flood affecting the entire metropolitan region. Majority of the nodes are found at the western portion of the region focusing on the cities of Manila, Pasay, and Parañaque. Specifically, the locations of these points are concentrated on those within proximity of the Pasig River.

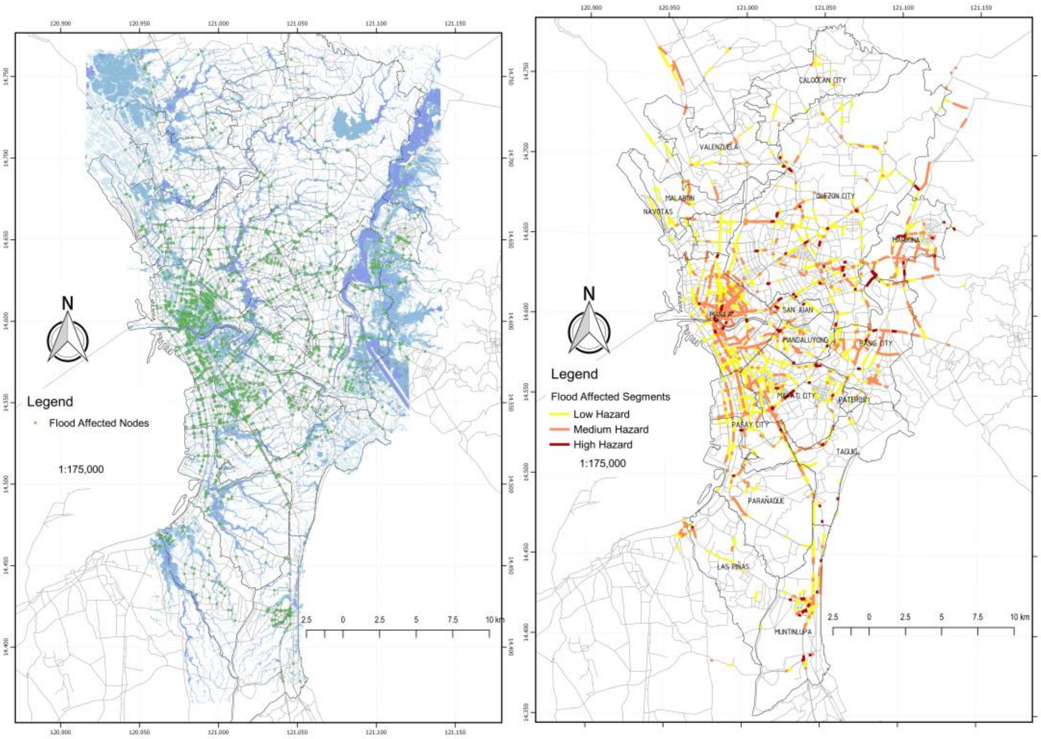

Figure 3 (left) Flood Affected Nodes (right) Flood Affected Bus and Jeepney Services

The figure on the right shows the extent of the flood hazard map when it intersects the available transit segments. The analysis of the affected transit service routes focused on the jeepney and bus services as these operate on fixed routes. The figure shows that services that operate within the central portion of Metro Manila (Manila, Pasay, portions of San Juan, Mandaluyong, Makati, and Pasig) would be severely affected by the assumed flood. However, the figure clearly depicts that most bus and jeepney services in Manila pass through areas that have medium hazard. This is significant since there are many educational and government institutions that can be found within this location.

Jeepney services are most affected in the event of a flood all over Metro Manila. Analyses showed that about 36% of the segments along its service routes would be affected by floods of varying hazards. On the other hand, only about 20% of the segments along bus service routes will be affected. The impact on bus services is less than jeepney services as most bus services operate along major roads that are away from flood-prone roads.

Analysis of the individual transit service routes revealed several jeepney routes are severely affected by a flood that would affect the city of Manila. The routes and the proportion of the affected route lengths are shown in Figure 4**.** The routes shown in the figure was the basis for Scenario 604 wherein these service routes were removed since at least 80% of their service routes is affected by a flood.

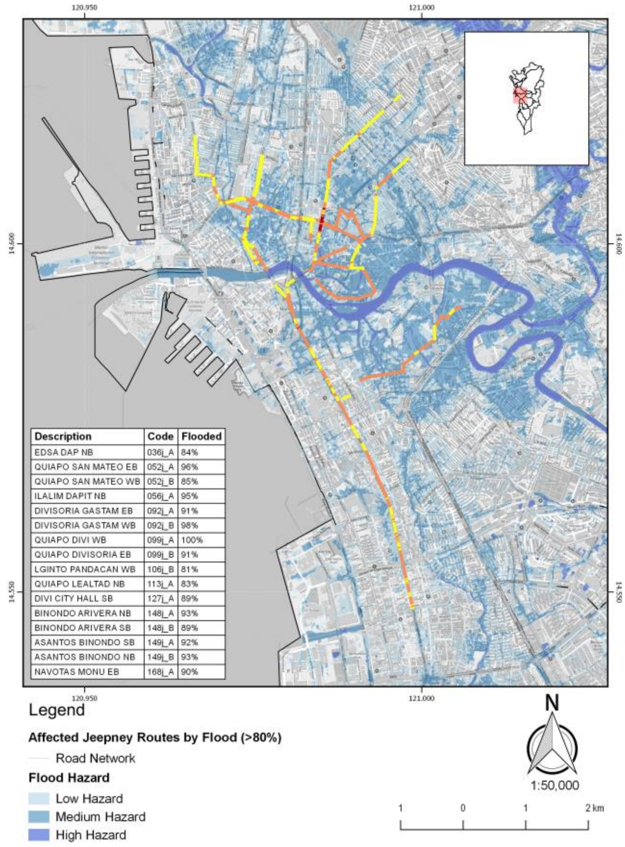

Figure 4. Heavily Affected Jeepney Services

5.2. Transit Assignment Results

The results of the extended transit assignment are presented in this section. Firstly, the comparison of the aggregated assignment results to the destination zone is shown in Table 3. The findings in the table suggest that there is no difference in transit assignment results for Scenarios 601 and 602. This may indicate that the effect of reducing the link capacities to the assignment of transit trips is unclear because there was no direct change in the service operating characteristics of the transit network. Hence, the changes in road link capacity would have more effect on the assignment of private car trips, which is outside the scope of this study. Further analysis, therefore, would focus on the changes as a result of scenarios 603 and 604.

Table 3. Summary of Extended Transit Assignment Results (Scenarios 601 - 604)

Scenario	**Auxiliary transit only demand**	**Total boardings**	**Average lines per passenger**	**Mean impedance**
601	30735	9344201.93	4.21	5544.41
602	30735	9344201.93	4.21	5544.41
603	33514	9173389.45	4.13	5645.16
604	34377	9146553.68	4.12	5649.62

Figure 5. Change in Auxiliary Transit Trips for Scenario 603 (left) and Scenario (604)

The changes made in the transit network to simulate the disruption caused by flood led to an increase in auxiliary transit only demand, decrease in total boardings and average lines taken by each passenger, and an increase in mean impedance (time measured in minutes). The increase in auxiliary transit demand reflects the difficulty to continue traveling using available transit modes because of the restriction in boarding and alighting or the removal of affected service routes. As a result, auxiliary transit modes were more attractive than the usual transit services. Figure 5 shows the changes in auxiliary transit trips going to destination zones in the study area. It reveals that the restrictions in boarding and alighting and the ceasing of operations of severely affected transit services would lead to an increase in auxiliary transit trips towards the city of Manila.

Furthermore, the decrease in total passenger boardings and average lines per passenger may hint at situations wherein travelers would take circuitous routes because of the restrictions in boarding and alighting at flood-affected transit segments. Naturally, the restrictions in boarding contributed a sharp decrease in total boardings from the base scenario. The resulting effect of the restrictions led to longer travel times because travelers affected by disruptions may have to take routes that avoid flooded areas which may be indirect or longer (Suarez et al., 2005). However, the resulting changes in average lines per passenger vary depending on the destination zone, as shown in Figure 6. The figure shows that effect of the flood to transit services led to a decrease in the average number of transit lines a passenger takes when going towards the central portion of Metro Manila. This indicates that travelers are sensitive to making transfers than in the unflooded (base) scenario because they would be exposed to floodwaters. However, travelers going towards the Northern or Southern portions of Metro Manila may have to perform more transfers to avoid the effects of disruption caused by a flood. The figure highlights the spatial differences of certain destination zones as a result of a flood disruption.

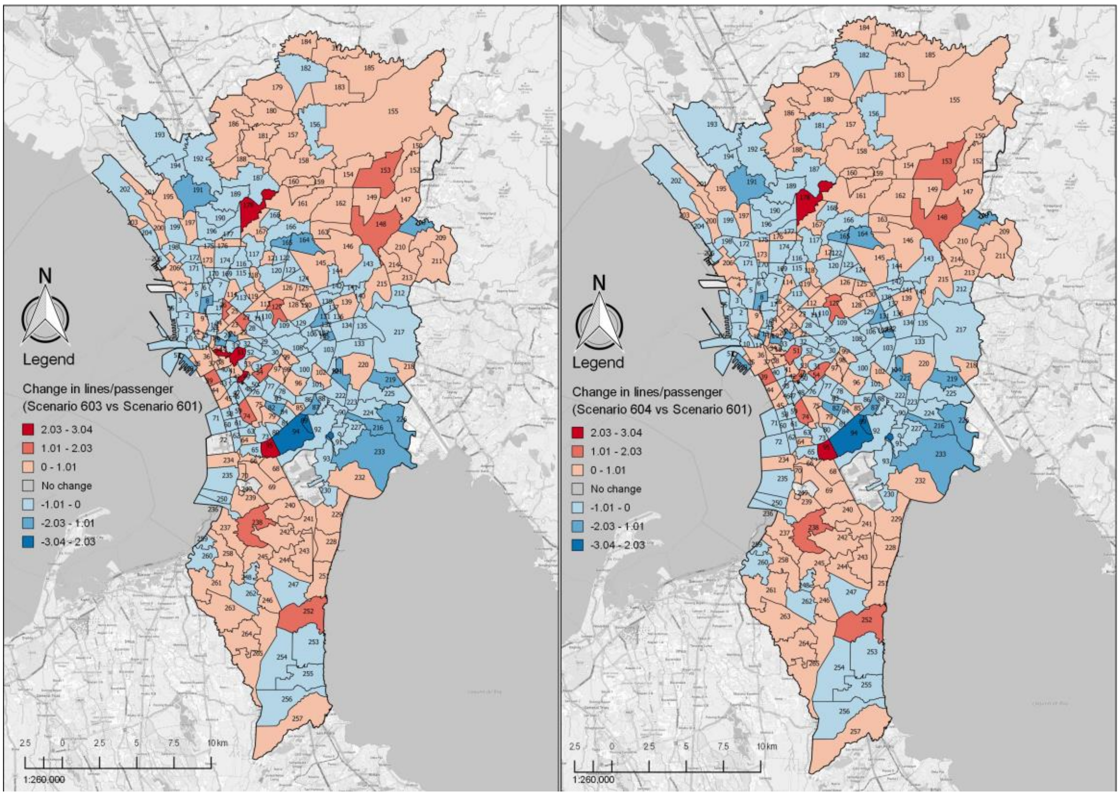

Figure 6. Changes in average line per passenger taken for Scenario 603 (left) and Scenario 604 (right)

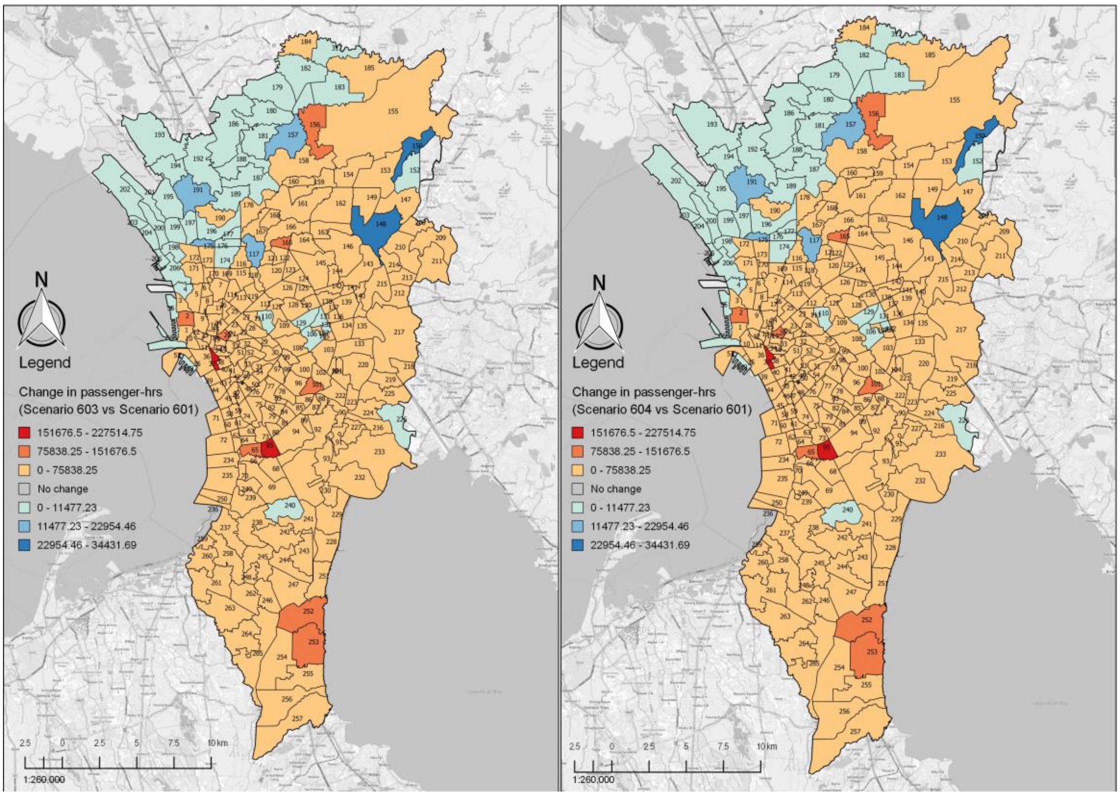

Figure 7. Changes in passenger-hours for Scenario 603 (left) and Scenario (604) right

The resulting changes in the transit network as evaluated in the scenarios led to an overall increase in travel times for the majority of the trips in Metro Manila as indicated in the results in Table 3 and in the changes in passenger-hours shown in Figure 7. The results in the figure indicate that the flooding scenario shows an overall increase in passenger-hours to almost all the destination zones in Metro Manila. However, the changes in Scenario 603 and 604 are almost close to none which may indicate that removing service routes resulted only to a minuscule increase in passenger hours compared to the scenario wherein passenger boarding and alighting were limited.

5.3. Impact on Access and Egress

The paper extends to an analysis of the *access* and *egress* portions of the trips performed under flooded scenarios. In particular, the analysis would like to reveal which zones would have significant changes in access (from origin to first boarding) and egress (from final alighting to destination) distances. The role of access and egress distance is significant, especially in flooded conditions as it may already show the difficulty to travel even during the first- or last-mile of the trip.

First, the paper analyzes if there are significant differences between the changes in access and egress distances for all zones in Metro Manila. The results in Table 4 confirm that the flooded scenario resulted in significant differences in access and egress distances to the base scenarios. The average distance changes were both negative in both instances, indicating that access and egress distance, on the average, have increased in both scenarios 603 and 604.

Table 4. T-test results of changes in access and egress distance from the base scenario

Metric	**Scenario 603**	**Scenario 604**
Access distance change (t-stat)	-5.5033	-5.5512
Egress distance change (t-stat)	-5.8693	-6.0562

**critical t-value at α=0.05 is +/-1.9689*

Second, the paper shows if the resulting changes in access and egress distances are similar under the flood scenarios. Results in Table 5 indicate that there are no significant differences between the resulting access and egress distances in the flooded scenarios. Presumably, the flood scenarios may have reduced the paths of travelers entering or leaving the zone. Hence, transit users would experience similar difficulties in traveling whether they are leaving from or going to a zone in a flood event. The results in Table 5 are visualized in Figure 8. The figure replicates the t-test findings wherein the changes in access and egress distance are similar under the same flood scenarios. The results are consistent with the findings in the previous section, where travelers towards the cities of Manila, Pasay, and Parañaque will be affected by floods. It is also worth noting that a zone south of Metro Manila (Alabang, Muntinlupa) would have increased access/egress distances (above 754 meters). This is a significant finding for the study area considering that it is a central business district (Boquet, 2017) and serves as a transit hub connecting provinces and cities south of Metro Manila to the metropolis. Increased access and egress distances in this area, therefore, expose potential issues on mobility.

Table 5. Differences between access and egress distances under similar flood scenarios

Metric	**Scenario 603**	**Scenario 604**
Difference between access and egress distance change (t-stat)	0.618	-0.241
t-critical (two-tailed)	+/- 1.9689	+/- 1.9689

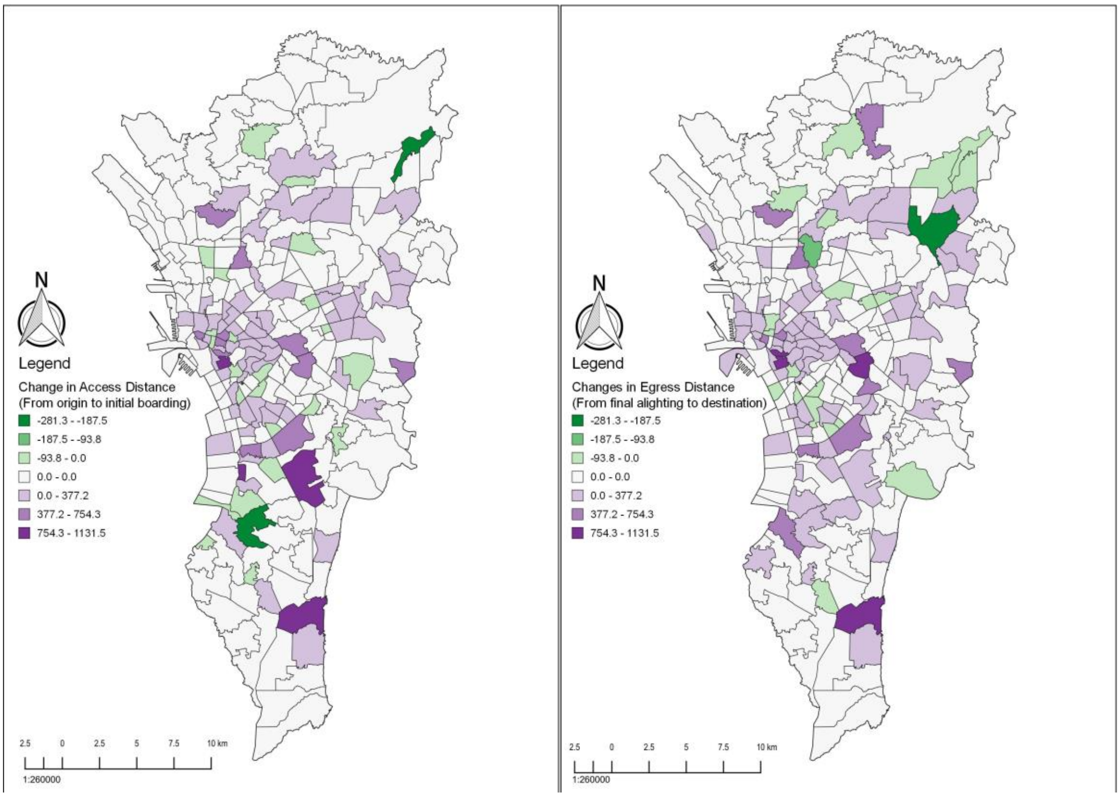

Figure 8. Changes in access and egress distance from the base scenario

The results shown in Figure 8 shows the change in access and egress distances for travelers coming from and going to the zones, respectively. A positive change in access or egress distance indicates an increase in the distance the traveler makes using auxiliary transit (walk, tricycle, pedicab). It can be found in the figure that areas that are significantly affected by floodwaters would result in an increase in access/egress distances. The findings hint that travelers would have to walk or ride the tricycle or pedicab for longer distances to access public transport services. The numerical results corroborate the transit assignment results indicated in Table 3. Specifically, the floods have limited access to transport service by restricting boarding and alighting and discontinuation of transit service. The resulting effects include an increase in the use of auxiliary transit modes for longer distances. In return, the number of boardings and average lines each passenger takes decrease while the increase in auxiliary transit use translated to an increase in passenger-hours.

The difference between the change in access and egress distances for both scenarios were consistent to most zones. However, in some zones, there had been a disparity in findings in access and egress distances. Specifically, in some zones, the modeled flood disruption led to a higher access distance and a decrease in egress distance. The discrepancy between changes in access and egress distance may be a result of the change in trip patterns of individuals. As mentioned before, travelers would seek the optimal paths given the flooded condition. Part of this may include finding paths or areas that are not inundated or affected by floodwaters. In doing so, trip makers may have to take different paths in leaving or entering a zone. However, this assumes that travelers are willing to use a different route or use a different mode in order to complete their trips. It also reflects the assumption that travelers are knowledgeable of the changes in travel conditions and the remaining available transit services which may not entirely represent actual disrupted conditions of the transportation system.

6. CONCLUDING REMARKS

This paper presents an analysis of the transit network performance under various flood scenarios. Three (3) flood scenarios were presented in the study – reduced link capacities, restricted boarding and alighting, and discontinued transit services for those routes that are affected by a flood that has a 5-year annual exceedance probability (AEP).

The analyses used a combination of GIS (QGIS) and transportation modeling (EMME/4) software. QGIS was used in determining affected transit network components and service routes. It was revealed that most network elements located mostly at the capital city of Manila. Further analysis showed that jeepney services are the most affected as 32% of its transit segments intersected the flood hazard maps. Specifically, there are 16 routes wherein 80% or more of its service route that would be flooded. Again, these 16 routes operate within the city of Manila near major trip attractors like government and educational institutions, health facilities, among others.

Analysis of the impacts of various flood scenarios was measured by comparing the flood scenarios to the base scenario. Aggregated transit assignment results using optimal strategies revealed that the average lines per passenger, trips made using auxiliary transit only, and the number of passenger boardings decreased because of flooding. In effect, passenger hours and mean impedances for trips using transit have increased. Extended analysis on the access and egress distances was performed to show how flood conditions affect the *first*- and -*last-mile* portions of transit trips. It was then revealed that most zones in Manila, Makati, Pasay, and Parañaque, and in Alabang, Muntinlupa had increased access distances. Likewise, t-test results indicate that there is no significant change between the change in access distance and the change in egress distance. The implication is that planners could then focus their analysis on either the beginning or the end of the trip (i.e., improving the access of a zone will also improve the egress towards the same zone). However, there were instances wherein the change in access, and egress distance was not consistent within the same zone. This may be a result of the assumption in the modeling phase.

The analysis performed in the study revealed the transit services and the areas whose travelers would have trouble in traveling because of a 5-year flood occurring over the entire Metro Manila. Recommendations in reducing the impact of such floods could be then implemented on these areas. Specific recommendations could include a combination of traditional engineering approaches and green infrastructure strategy to manage the impact of floods on the transportation network (Pregnolato et al., 2016). Specific attention is recommended in areas where access distance has increased. Local authorities are recommended to evaluate the current condition of street drainages and walking facilities (i.e., sidewalks). Any form of improvement for these two would benefit travelers by providing easier, safer, and more convenient access to public transportation services from their origin and vice-versa. Further, transportation authorities are recommended to plan emergency transportation services that avoid areas affected by floodwaters. This could provide travelers an alternative means of travel in the event of a flood and increase their adaptive capacities.

Recommendations for future studies include addressing the assumptions presented in the study. First, it was assumed that people would continue their trips regularly without making any adjustments. Future work can model scenarios wherein the variation of the number of trips made during the flood event will be considered since the travel behavior of individuals may differ with one another. Second, the changes in the transportation network characteristics should include a change in operating speed, headway, and frequency. The scenarios presented in the study assumed that transit operating characteristics remain the same. However, because of the changes in traffic conditions, service operations would be affected. It would be interesting to show how these changes in transport operating conditions would have an impact on the assignment of transit trips. Third, vulnerability analysis of actual transit routes could be evaluated to see determine which routes would be severely affected. Fourth, with regards to the analysis of removed transit services, it would be interesting to show how these trips would be displaced to other transit routes. Fourth, a continuing study on the changes in access and egress distances for zones vary from one another. Finally, the greatest limitation of studies simulating disruption scenarios of a transportation network is the validation of the results. The researchers admit that the simulation model cannot be described as a true scenario in the real world. However, the results could guide transport planners and policy makers to prepare for possible future disruptions caused by flooding. It is strongly recommended, nevertheless, to find ways that will validate the assumptions claimed and results gathered from this study.

ACKNOWLEDGEMENT

The authors would like to extend their sincerest gratitude to the Department of Science and Technology – Engineering Research for Development and Technology for providing financial grant to conduct this research.

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