Network Analysis of Disaster Response Routes for Flooding: the case of Cagayan de Oro City, Philippines

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Abstract: Impassable roads due to flooding is one of the main reasons for slow response of emergency units as a result of limited routes. This study will focus on creating a disaster response route and their corresponding maps to mitigate traffic congestion due to flooding in the Poblacion barangays in Cagayan de Oro. Further, the disaster response routes are assessed through a vulnerability assessment using Network Robustness and normalized using Network Vulnerability Indices. These indices are computed using traffic volume, travel time and serviceability of road links which are obtained through a planning tool, Equilibre Multi-modal/Multimodal Equilibrium (EMME) 4.0 software. The methodology involves traffic and transit assignment for a base scenario and two flood scenarios. Results of each scenario are compared using the resulting vulnerability indices which helps the researchers identify critical road links and potential alternative routes for disaster response. The study highly recommends the methodology for disaster route selection and scenario analysis in other cities prone to flooding.

Keywords: Multimodal Transport Planning Software, Network Robustness Index, Network Vulnerability Index, Flood Disaster

1. INTRODUCTION

Cagayan de Oro City is a first class, highly urbanized city in Northern Mindanao and the capital city of Misamis Oriental. Also, the city is dubbed as the “Gateway of Northern Mindanao” as it lies on the coastline of Mindanao, serving as the regional trade center for the entire Northern Mindanao. Problems are evident in the city’s fast progress. One of which is flooding, which is the main effect of heavy rainfall during rainy seasons. Flooding is usually one of the main reasons for slow response of safety rescuers and emergency units to the affected areas, since some roads are not accessible in times of natural calamities. Here in Cagayan de Oro, some areas are highly affected by flooding, which leads to the shutting down of road networks. The tragic consequences of this natural calamity clearly indicate the need to design effective physical and social programs that must be implemented in order to mitigate the impacts of flood. Understanding how a range of factors, such as demographic and socio-economic, as well as geo-physical factors are interlinked with flood and vulnerability can be an essential input in generating a sound flood mitigation program.

According to Fillone (2017), road networks are most likely to be vulnerable to natural disasters since its effects can cause a huge effect on travel conditions. In a sense, some roads are less accessible after the occurrence of natural disasters. For instance, bridges are closed after the occurrence of an earthquake and some roads are closed after the occurrence of heavy rainfall or flashfloods. With this, vulnerability assessments are conducted to easily determine which affected roads or areas could heavily damage the transmission of the entire response system, given that they are significant effects of natural disasters to travel conditions.

This study will focus on creating solutions for both transportation engineering problems and environmental engineering problems. For the transportation engineering, this study will focus on alternative transportation route for all the vehicles that wish to travel in and out of the city during rainy seasons.

The main objective of this study is to to develop a road network analysis of disaster route plan due to flooding. More specifically, this study aims: (1) To conduct an assessment on flood prone areas in Cagayan de Oro City. (2) To identify vulnerable routes on a road network using Network Vulnerability Index (NVI) values (3) To identify critical links on a road network using Network Robustness Index (NRI) values and EMME/4 simulations. (4) To develop a disaster response map through network vulnerability analysis.

According to Scott et. al (2006), a proposed network robustness index (NRI) calculates the change in cost when network becomes unstable. The cost of the base link (when not flooded), denoted by C, is defined as:

$$C = \sum i \ q_i t_i \tag{1}$$

Where t_i: travel time for link I, q_i: traffic flow for link i, and the network robustness index is defined as:

$$NRI = \ C_{after} - C \tag{2}$$

Where Cafter is the total cost of travel on the network under the flooded condition. A network vulnerability index (NVI) is a measure proposed by Balijepalli & Oppong (2014) calculates the vulnerability of the lane while considering the serviceability of each road link on the network. The NVI is defined as:

$$NVI = \ \sum_{i=1}^{n} \left[\left(\frac{q_i^{before}}{r_i^{before}} t_i^{before} \right) \right] - \sum_{i=1}^{n} \left[\left(\frac{q_i^{after}}{r_i^{after}} t_i^{after} \right) \right] \tag{3}$$

Where, r_i : serviceability of link i (i.e. total available capacity of link i / standard hourly link capacity per lane) and q_i, t_i : as defined in (2).

The serviceability of the link is reduced when the road link is affected by the flood as indicated by its flood level hazard. For this study, there is only one flood scenario (i.e. 5-year flood) and different capacity reductions were introduced within the transportation network depending on the hazard level on the road location. Increasing values of NVI and decreasing values of NRI makes the lane more robust and less vulnerable, which are to be identified through this research analysis.

The Philippines is no stranger when it comes to flooding. With its vulnerability to natural hazards especially flooding, the impacts of flooding can cause a disruption to our road networks which could then lead to traffic congestion. People living in low-lying areas are the most vulnerable to such flood hazards, especially those living near the river areas. With the disruption in a road network under flooding conditions, it would make it difficult for emergency vehicles to respond on time, especially with the presence of traffic congestion, in the road network. Hence, there is a need to conduct a research on vulnerability assessment on our roads and to develop a disaster response route in order to be able to respond to a certain flood event on time.

One of the major factors of the vulnerability on roads is flood hazards, robustness of a road link under flooded conditions and its serviceability. Flood hazard can cause a reduction of traffic capacity, which may overall affect the road network. Each road link has reduced capacity for each level of hazard, ranking from low, medium and high. The robustness of a road link determines how critical the road link is to the network. Serviceability on the other hand is described as the possibility of using that particular road/link/node during a given period. This factor also indicates how important this road link is towards the road network. For a road link to be described as vulnerable, the link must be both exposed to a flood hazard and at the same time be important to the network.

Flooding is a natural disaster which cannot be prevented, however, the impacts of flooding on our road networks could be reduced or controlled by vulnerability assessment and disaster route mapping using GIS and EMME/4 modeling applications and simulation. Vulnerability assessment is conducted on a road network in order to identify the level of vulnerability for each network link. Vulnerability is defined as the inability to resist to a hazard or to respond when a disaster occurs. The network robustness index (NRI) and the network vulnerability index (NVI) are vulnerability indicators used to describe the road links' vulnerability and accessibility, which could then guide the researchers on the selection of alternative routes. Not all road links on the road network could be assessed, hence choosing the critical routes on a road network where flooding normally occurs is an essential part in conducting the research.

Data which needs to be collected includes traffic flow, traffic time, traffic demand, road length, road capacity and the serviceability factor. Using GIS applications, it is also important to identify routes leading to the nearest hospitals, police stations, fire stations, shelter stations and other emergency buildings or evacuation areas for disaster response. This also includes different road links which may be used as an alternate route for disaster route mapping. For modeling and simulation, two scenarios are being used, one is the normal road network condition and the other is the disrupted road network due to flooding. A 5-year flood model (DREAM,) is used for the disrupted road network which is then used for simulation on the EMME/4 software. After which, network links are evaluated using the NRI and NVI values and a disaster route map is produced using GIS in order to reroute the path of vehicles to less vulnerable network links. Once data are analyzed and further evaluated, the disaster route map and the data on vulnerability assessment on selected road links are presented.

2. REVIEW IF REKATED LITERATURE EXPERIMENTAL

2.1 Impact of Flooding to Traffic Conditions

In Cagayan de Oro, flooding is a major issue to tackle especially on rainy seasons, which is usually caused by heavy rainfall and overflow of creeks and rivers. Flood waters not only causes property damage and loss of life, but also influences the traffic network and can cause traffic congestion in an affected area (Abad and Fillone, 2017). Numerous studies over the last decade had dealt with the impacts of heavy rainfall especially on road networks. Hooper et al. (2013) conducted a study on a detailed analysis regarding the relationship between rainfall intensity and vehicle speed. It's clear that the precipitation could affect vehicle speed for varying rainfall intensities, yet such relation shown is very complex and requires much research to define a mathematical relationship between the two. Kyte et. Al (2007) on the other hand considers four environmental factors (wind speed, precipitation intensity, visibility and pavement condition) which could affect the free-flow traffic speed of a vehicle. However, studies related on the impacts of flooding on road networks have received such little attention because of two main reasons: the complexity of integrating two highly dynamic and uncertain systems; the need to assess flood impacts in monetary terms for the purposes of cost-benefit ratio (Pyatvoka et al., 2015). However, impacts of flooding on road networks can also have monetary dimensions, such as fuel consumption, additional operating costs and loss of time.

Due to limited literature relating flood impacts on road networks, certain assumptions are needed to be made in order to create a model or simulation on its effects. Pregnolato, et. al (2017) assumed the road to be closed when the water covers the crown of the road, regardless of its depth. Likewise, Suarez et. al (2005) assumes the road to be closed and impassable when flooded. Typical assumptions can also include the following; traffic volumes and speeds are assumed to correspond to regional (or even national) average statistics; a road is assumed to be completely closed when its crown is covered by water, regardless of depth; traffic on open roads continues to flow smoothly, perhaps at a slightly reduced maximum speed; traffic volumes do not exceed the design capacity of a road; traffic conditions do not change over the course of the day, or seasonally; and, diversion routes, and changes (or not) to driver behavior as a result of the flood, are often assumed without any clear rationale (TRB, 2010; Environmental Agency, 2010; Shand et al., 2011; Penning-Rowsell et al., 2013; Dicrete Fourier Transform, 2014b). In this study, flood heights and reduction to traffic volume capacity are to be assumed due to the level of hazard for each road.

2.2 Vulnerability Indicators

Road networks are vulnerable to natural disasters especially with flooding, which may cause a disruption in traffic flow and a reduction of its volume capacity. However, not all road links equally affect the travel conditions in a given network; typically, some links are more critical to the network functioning than the others (Balijepalli and Oppong, 2014). According to Berdica (2002) vulnerability is defined as the traffic network's sensitiveness to major incidents which decrease network serviceability.

In order to perform vulnerability assessments, vulnerability indicators are to be used to determine critical links that may affect the road network. Recent studies show the different uses of vulnerability indicators in a road network. Jenelius et. al (2006) uses the increase in generalized cost of travel (time, distance, money) as a factor of reduced network performance. In this case, links that are disrupted are assumed to be completely closed which forces the travelers to take other less advantageous routes. Tu et al. (2010) proposed a new network topology vulnerability indicator by introducing "minicuts frequency vector" assessment index to determine critical links on road transports in China. However according to Lu, et al. (2013) these vulnerability indicators falls short since these studies focuses more on the external traffic incidents and fails to recognize underlying factors, so they are unable to find out the relationship between disastrous incidents and road transport.

For this study, the researchers used the notation proposed by Balijepalli & Oppong (2014) and Scott et al., (2006) which includes the network robustness index (NRI) and the network vulnerability index (NVI) for the vulnerability analysis of road lanes in Cagayan de Oro. The NRI is defined as the change in total travel time over a given time interval resulting from the re assignment of traffic in the system when a specific link is removed from the network (Scott et al., 2006). This paper considers reduced serviceability due to flood hazard and varying serviceability of roads instead of assuming affected roads to be completely impassable. These values are acquired using simulations from the EMME/4 software.

2.3 Data Variables

Traffic Volume - According to Parvathi et.al (2017), the analysis of traffic characteristics which help in the decision of the geometric design of the road, along with traffic control for a more convenient movement of traffic and for the identification of the problem and for data collecting in the analysis of traffic characteristics which help in deciding the geometric design of the highway and traffic control, traffic volume is used. The number of vehicles detected at a certain section of the road for every period of time at any selected period is called traffic volume. Traffic volume is a quantitative measure of flow and vehicles per day and vehicles per hour are its commonly used units. To complete a study on traffic volume study, the distribution by turning movements and classification of different lanes per unit of direction and time and classified volume study by determining the volume of various classifications of traffic may be included. In this study, determining the traffic volume will help the researchers design a disaster response map which can distinguish roads that have less traffic congestion.

Travel Time - According to Konstantinidou et.al (2014), The impact of disasters on society and the economy has increased in the recent years; factors such as the size and density of modern communities and their dependence on sophisticated yet sensitive infrastructures, have critically contributed to populating effects of catastrophic events. Disasters can also affect the travel time of transportation vehicles. Disasters can delay and disrupt the flow of traffic in the area affected by a it. And because of that, the travel time of transportation vehicles in the affected area can increase and can result to queueing and heavy traffic. According to Chang (2002), The effects of disaster related damage are approximated through an arbitrarily set effective distance multiplier that is intended to reflect increased travel times. It is anticipated that poor weather and flood conditions would result to increases in travel time (Abad and Fillone, 2018).

Vulnerability - Due to the vulnerability of a road network on flooding and other disaster related events, numerous studies had been raised in order to identify or measure vulnerability of road links. According to Peeta et.al (2010), "disaster management is a multi-stage process that starts with predisaster mitigation and preparedness that focus on long-term measures for reducing or eliminating risk, and extends to post-disaster response, recovery and re-construction". The pre disaster planning phase therefore, according to Konstantinidou et.al (2014), involves strategic decision-making for risk assessment and infrastructure improvements to reduce vulnerability and enhance human and physical system resilience. A concept often used for investigating the sensitivity of a network against disruptive events is vulnerability. Vulnerability is susceptibility to incidents leading to reduced serviceability and mobility. According to Burgholzer et.al (2013), vulnerability is the reduction in network's performance in the case of a link disruption. For this research, vulnerability is determined using GIS wherein a 5-year flood model is used to measure the vulnerability of affected areas during the flood. Three levels of vulnerability are identified, high hazard, medium hazard and low hazard, which would be used in identifying critical road links and alternate routes in the road network.

Serviceability - Serviceability is a pointer that speaks the level of service a pavement gives to the clients. This abstract opinion is firmly identified with objective aspects, which can be estimated on the pavement's surface. The researchers need to assess and obtain the serviceability of road network during floods and disasters. Pavement Serviceability is a concept representing the level of service which streets and roads offer users riding vehicles, and it is part of the American Association of State Highway and Transportation Officials (AASHTO) design method of pavement structures (Solminihac et.al, 2003). According to Solminihac et.al (2003), Pavement Serviceability represents the level of services that pavement structures offer users. This indicator first appeared as a rating made by users with respect to the state of the road, particularly the road's surface. This rating is represented by a subjective index called 'Present Serviceability Rating' (PSR) and may be replaced by an objective index called 'Present Serviceability Index' (PSI). Level of Service (LOS) on the other hand is a term used to qualitatively describe the operating conditions of a roadway based on factors such as speed, travel time, maneuverability, delay, and safety. The level of service of a facility is designated with LOS A to LOS F, with A representing the best operating conditions and F the worst. The researchers need to know the serviceability of selected road links from barangay 1 to barangay 40 for computing the NRI values using EMME/4.

Network Robustness Index (NRI) - A network robustness index (NRI) is used in identifying critical links and evaluating the performance of a transportation system. It utilizes the change of the total network capacity as an assessment measure. According to Du et al. (2017), the NRI is a direct measure to reflect how vulnerable a single link is if it was completely removed. It also takes in account the spatial relationships and possible rerouting applications to the network's topography, Origin destination demand, and capacity of individual highway segments. The NRI is used on calculating the change in cost when a road network becomes unstable. According to Sullivan et al. (2009), the NRI is distinguished from other indices since it accounts for connectivity, link-capacity, network demand, and the presence of isolating links. It is proposed as an ideal technique for ranking network links over the volume-to-capacity (v/c) ratio and comparable local measures. Other applications for the NRI would also include measuring or estimating emissions from vehicles on a road network. Specifically, the NRI is expanded to include road emissions in the link criticality analysis process, resulting in the creation of an Emissions based NRI (ENRI), to be used in conjunction with the NRI (Reynaud, 2018).

Network Vulnerability Index (NVI) - Road networks are vulnerable to natural disasters such as floods, earthquakes and forest fires which can adversely affect the travel on the network that remains intact after an event. However, not all road links equally affect the travel conditions in a given network; typically, some links are more critical to the network functioning than the others. It is stated that the majority of the existing indices designed to measure vulnerability offer a desirable measure of network-wide accessibility in sparse regional networks, however they hardly ever consider the extent of serviceability of crucial hyperlinks in dense urban road networks (Balijepalli & Oppong, 2014). Network vulnerability index measures the vulnerability of a road link while considering the serviceability of each road link on the network.

2.4 Review on Methodologies

Centroids, Nodes and Links - The road network of Cagayan de Oro City is subdivided into

80 zones (barangays), which is represented by a centroid connected by a link to the road network where all trips coming to and from the zone are situated. Regular nodes are points in the network which connects road links which may represent as intersections, transit stops or ends of road links, allowing movement of traffic in the network. All trips originate and terminate from the centroid. A road link is a directional connection between two nodes which may be classified as one-way or two-way. There are four types of road classification in the network build represented by different colors, red (major highways), orange (minor highways), yellow (collector roads) and white (barangay roads) which is indicated in the base layer of open street map. Each has its designated road capacity depending on its classification.

Modes - are elements of the road network which defines the type of vehicle or means of transportation on a road link. Modes are classified into five types; auto, auxiliary auto, transit and auxiliary transit. Auto mode are used to specify road links accessible to all private vehicles. Only one auto mode can be defined in the network build and its speed is defined by a volume-delay function for each road link. Transit modes are modes that allows public transport such as buses, jeepneys, multicabs, vans and motorelas. Transit lines or routes can be defined using links that allows access for transit modes. Auxiliary transit modes are used to model access to transit lines and/or transfer between lines that do not pass the same node (e.g. pedestrians). Auxiliary auto modes are similar to auto modes, however some road links may be unaccessable to certain vehicle types or restricted to pass only on certain types of road links. Examples of these are trucks, high occupancy vehicles, taxis, motorcycles, sikads etc. In this study, there are a total of ten modes defined in the road network; private vehicles, jeepneys, multicabs, buses, motorelas, vans, motorcycles, trucks, taxis and walk/bike. Each mode is assigned on link segments depending on its designation.

Transit Lines - A transit line itinerary is defined as the sequence of nodes (stops) encountered by the transit line on its route. In order to simplify the coding, it is not necessary to specify all the nodes along a route. If nodes are omitted, the line is assumed to pass through the nodes on the shortest path between two specified nodes. The travel time of a transit line may be specified by an average speed or with transit time functions. These functions specify the travel time on each segment of the line and may be correlated to the travel time of the auto mode on the same link. Transit line itineraries may be displayed as required.

SOLA Traffic Assignment - The Second-Order Linear Approximation (SOLA) traffic assignment is an extremely efficient implementation of a variant of the linear approximation method. It is fast-converging to a finer solution than other linear approximation methods (including the Standard traffic assignment) and is parallelized to provide substantial performance benefits on multiprocessing systems. Relative gaps of the order of 10-6 for single and multiclass equilibrium assignments are easily obtained in practice. For well-converged solutions all results should be similar to those obtained with the Standard traffic assignment tool, but only unique results, that is, total link flows and O-D impedances will be identical for well-converged Path-based traffic assignments.

2.5 Evacuation Route Planning Method

Evacuation is a complex process which involves several consecutive phases such as the identification of an incident or a potential threat of an area due to the type of disaster, and the evacuation order for the residents of these areas. However, in an evacuation plan, there are several factors that needs to be addressed before the planning of an evacuation route. The probability of the occurrence of that particular disaster, providing adequate food and shelter for those affected, the distance between the relief locations from the affected area, the structural condition of the rehabilitation center, the availability of emergency vehicles and the traffic conditions of an evacuation route (Stepanov and Smith, 2009). In order to manage the evacuation process efficiently, a pre-made evacuation plan may be used for scenarios that are most-likely to happen, such as flooding (Alexander, 2002). Studies and simulations on maximizing or improving the planning and operation processes of evacuation routes may help maximize the utility of existing networks for disaster response (Han et al., 2006). Mali et al (2017) proposed an enhanced routing method using Dijska's algorithm and hierarchical processing. Seven factors being considered here are, road length, road width, road type, traffic volume, mass density, velocity limit and junction delay. With this, conventional methods are conducted for a safe and fast evacuation, where evacuation routes are based and done possible by considering the shortest time possible for evacuation and geographic proximity. According to Kovacs and Spens (2007), evacuation prior to the natural disaster can be done by pre-warning of sudden-onset disasters, which will also depend on the disaster type. Campos et al. uses the heuristic algorithm for finding two independent paths from disaster area to shelter with the smallest travel time. In this study however, vulnerability assessment on the road network is to be conducted in order to identify critical links, vulnerable routes and alternative routes which could help aid the researchers on creating a disaster response route.

3. METHODOLOGY

3.1 Research Design

Due to geographic location and the rising effects of climate change, Cagayan de Oro city has been prone to multiple natural hazards especially flooding. As such, traffic congestion has been a major issue especially in clogged or impassable roads in Cagayan. The need to divert or reroute vehicles in order arrive towards their destination safely and to develop a disaster response route where emergency vehicles could respond to a given flooding event more efficiently are the focus of this study.

This study involves four main phases as illustrated in figure 1, the primary data collection, secondary data collection, data analysis and discussions and conclusions /recommendations. (1) The first is the secondary data collection in which researchers acquire existing data for traffic conditions in Cagayan de Oro city, which includes vehicle classification, vehicle fleet, road classification, road capacity and traffic demand based on zone to zone travel. Data are collected from the Land Transportation Franchising and Regulatory Board (LTFRB) and the Department of Public Works and Highways (DPWH). Part of the primary data collection is to request permissions from the Local Government Units (LGU's) in order to conduct the research. Aside from traffic data, flood hazard maps are collected from the UP Disaster Risk and Exposure Assessment for Mitigation (DREAM) program. (2) The second is the primary data collection which is obtained through EMME simulation. Data that are required for vulnerability assessment includes the following: travel time; traffic flow and serviceability. The flood hazard map is developed using project UP DREAM, a program which identifies the level of hazard of specific areas due to flooding, and the capacity reductions based on the flood hazard level. The researchers used a 5-year flood and 25-year flood as a model for the flood hazard map and specific areas in CDO are identified by the researchers. Once developed, transportation networks that are disrupted during flooding are identified and its volume capacities are reduced depending on the level of hazard for each road. Travel time t_i, traffic flow q_i and serviceability r_i are identified by EMME/4.4 after running the analysis. Travel demand per vehicle classification is expressed in a form of a full origin-destination matrix provided by the RTA. (3) The third phase is the data analysis and further discussion of results. Critical links, vulnerable links and alternative routes are identified using the computed NRI and NVI values, which would aid the researchers in the mapping of the disaster response plan. For routes, the researchers will focus on road links that are closely situated near hospitals and evacuation centers. (4) Lastly, recommendations which also includes the proposed disaster response route and alternate routes are then presented to the local government for further discussions, suggestions and implementation of the disaster route.

3.2 Research Setting

Cagayan de Oro City is dubbed as the "Gateway to Northern Mindanao" because of its geographic location, whereas it lies on the coastline of Northern Mindanao. Given its location, during heavy rain seasons, flooding usually occurs on areas lying along the coastline and on areas surrounding rivers and creeks in the city. One notable disaster within Cagayan de Oro City is the flooding last January 2017. As stated by Philippine Information Agency (PIA) and City Disaster Risk Reduction and Management Department (CDRRMD), heavy rainfall, overflowing creeks, blocking huge scale vehicles and watering hole areas are few causes of street flooding in the city.

3.3 Research Instrumentation

There are different measures in determining the vulnerability indices. This study will require the use of different transportation applications, such as the Equilibre Multimodal Multimodal Equilibrium (EMME), which empowers some of the world's most complex transport models with trusted step by step procedure made to work on a larger picture. This application allows the development of transportation network and its properties. With this, a diagram of disrupted networks was shown by overlaying a flood map on the shown networks. Another application is the Quantum Geographic Information System (GIS) version 3.10, which is a system programmed to capture, store, analyze, manage and show all kinds of geographic data. GIS applications are tools that allows users to edit data in maps shown and present the results. This tool is essential for hydrology engineering to help engineers imagine the real situation of flood events and easily plot a solution for a rational and accurate decisions.

4. RESULTS AND DISCUSSIONS

4.1 Barangay 1 to Barangay 40 Road Network

Shows the all nodes, links and centroids in the road network. The yellow lines represent links in which vehicle modes may access to while the green lines represent link connectors to centroids. Centroids (green) are assigned on all barangays, which are placed on areas that are densely populated. Regular nodes (red) represents intersections or turning points of road links and connector links which allows movement of traffic. There are a total of 2874 nodes and 6984 links being used. The network build extends to all 80 zones in Cagayan de Oro city including all transit routes and vehicle types. The shape file for the map layer of Cagayan de Oro city zoning, barangay boundary and roads are obtained from the Engineering Resource Center (ERC). Lane capacity for each link depends on the classification of the road, if it is a national road or local/barangay road. National roads such as C.M. Recto and Apolinario Velez St. have a link capacity of 900 veh/hour/lane. On the other hand, inner roads such as collectors and barangay roads have a link capacity of 750 veh/hour/lane.

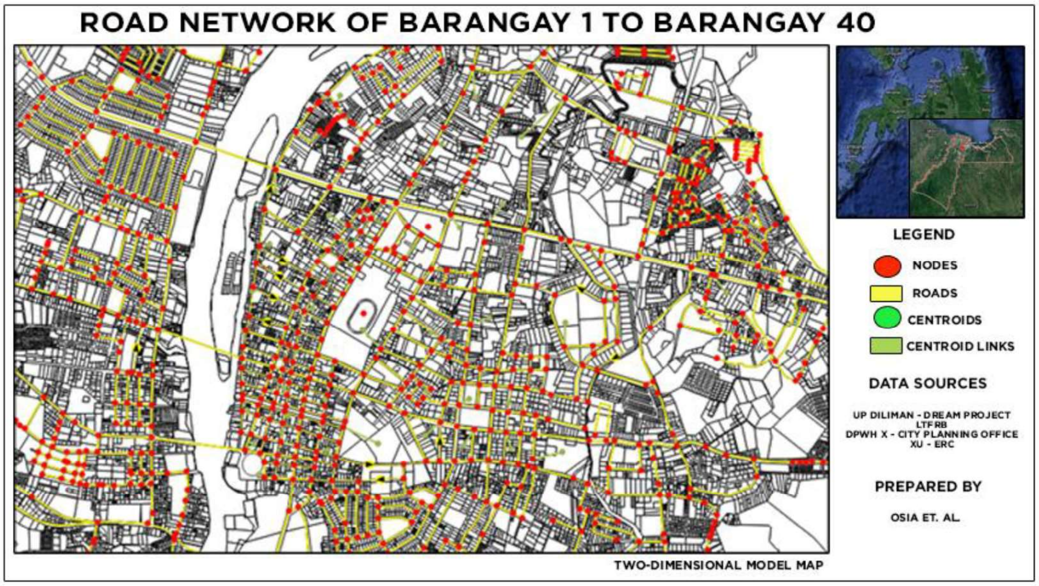

Figure 1. Road Network of Barangay 1 to Barangay 40

4.2. Barangay 1 to Barangay 40 Flood Hazard Profile

Flood hazard maps are provided by DREAM which consists of two flooding scenarios, 5-year flood and 25-year flood. Flood hazard levels are indicated in red (high hazard), orange (medium hazard) and yellow (low hazard). Flood water heights and reduction on link capacities may vary by hazard level with low hazard at 0-0.5 meters (10% reduction), orange hazard at 0.5-1.5 meters (50% reduction) and high hazard at 1.5 meters and above (80% reduction). Road capacity reductions are applied to all roads in Barangay 1 to Barangay 80, however, only roads within Barangay 1 to Barangay 40 are investigated on the analysis and selection of routes.
In 5-year flood Camaman-an, Barangay 31 and Lapasan are the three Barangays that are prone to high hazard flood. Also, in 25-year flood Consolacion, Camaman-an, Lapasan and Puntod are the four Barangays that are prone to high hazard flood. Shows most areas within the poblacion area is affected by flood, but in between low to medium flood hazard. Barangay 31, which is situated along Limketkai Avenue, is affected by low to medium flood. Also, some areas within Barangays 22, 24 and 26 along CM Recto Avenue and Corrales Extension are severely affected by medium level flood. This is because these areas are located along Bitan-ag Creek, one of the most hihgly flooded creeks in the city during flood season. The flood within the scope of the study in the given period of time is not as high as expected but will still cause disruption of road networks. In this scenario, mostly minor roads within the scope are identified to be vulnerable in terms of flooding.

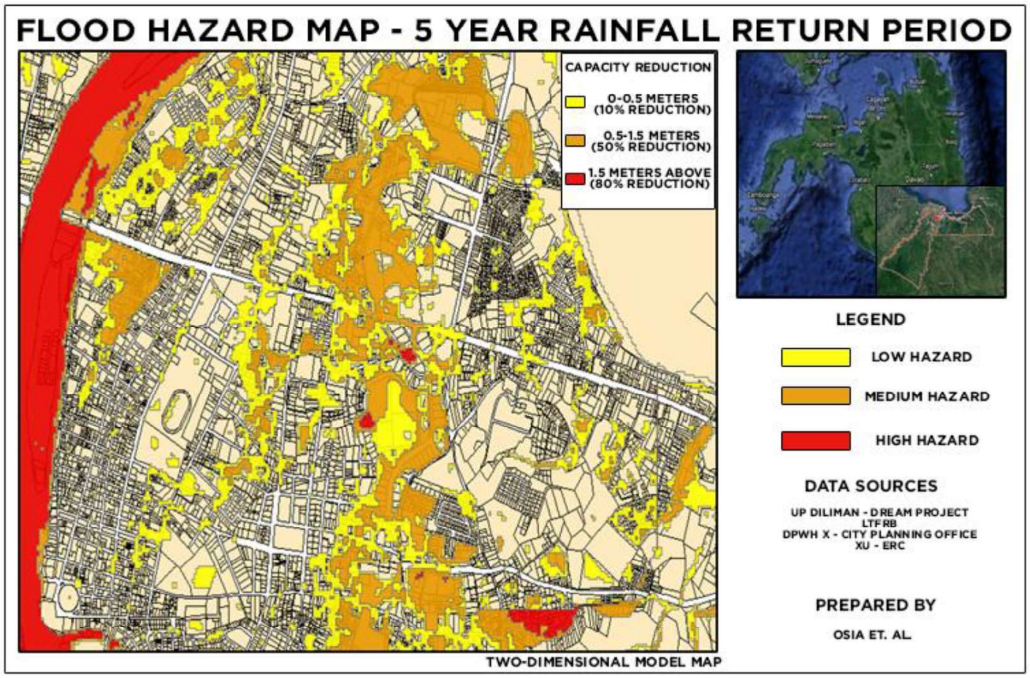

Figure 2. Flood Hazard Map for 5 Year Rainfall Return Period

Shows that barangays lying near Cagayan de Oro River have high chances of high flood hazard, and almost half of the barangays within the poblacion area is covered with heavy flooding. For some areas that lie not close to the Cagayan River or Bitan-ag Creek with high flood hazard, one probable reason for high flood hazard is the geographical state of the area. They may be areas that serve as “catch basin” of floodwater.

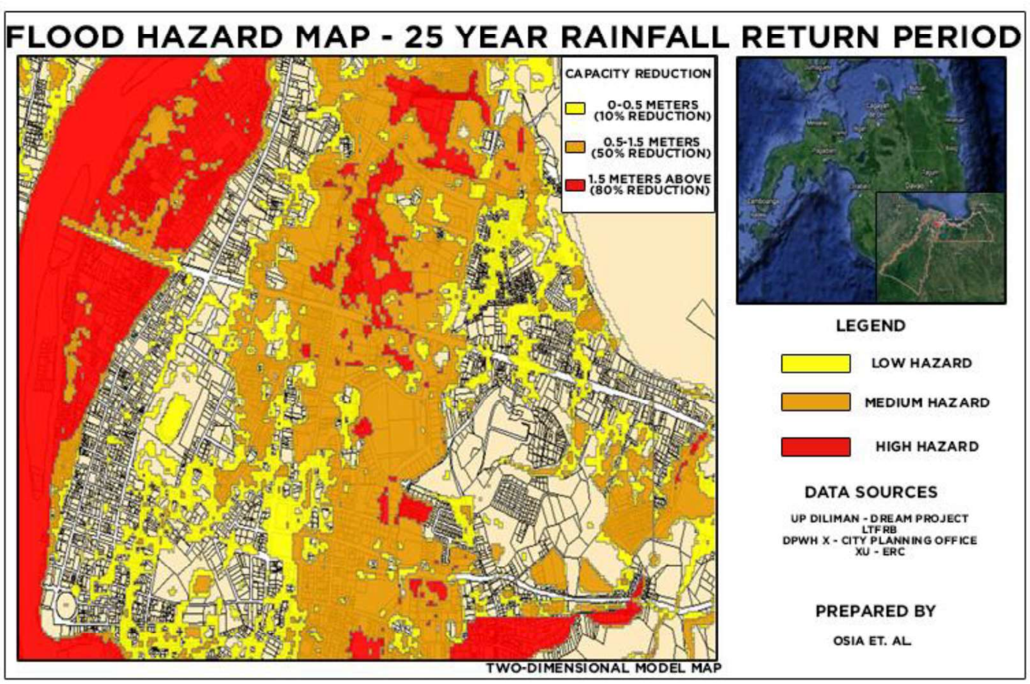

Figure 3. Flood Hazard Map for 5 Year Rainfall Return Period

4.3. Baseline Scenario

Shows the link volume of barangays 1-40 of Cagayan de Oro City when not flooded. The bar values in the figure represents the total volume of traffic in the road links. Results are based on the output of EMME/4 using traffic and transit assignments via EMME modeler. Extra attributes and functions are defined for computing the traffic volume and travel times. Travel demand is based on the jeepney matrix provided by the RTA, which comprises of the demand for all 80 zones in Cagayan de Oro city. Based on the figures above, traffic is heavily focused on areas in Divisoria and Cogon, especially since the Cogon area has the highest travel demand among between the 40 barangays within the city proper. Cogon road, Ysalina bridge and CM recto highway has the highest traffic volume having 2,292 veh/hr, 1,718 veh/hr and 1,562 veh/hr respectively. The number of vehicles detected at a certain section of the road for every period of time at any selected period is called traffic volume. This is used in the decision of the geometric design of the road, along with traffic control for a more convenient movement of traffic. Also, traffic volume is needed to identify roads that can be accessed in times of disasters such as flooding.

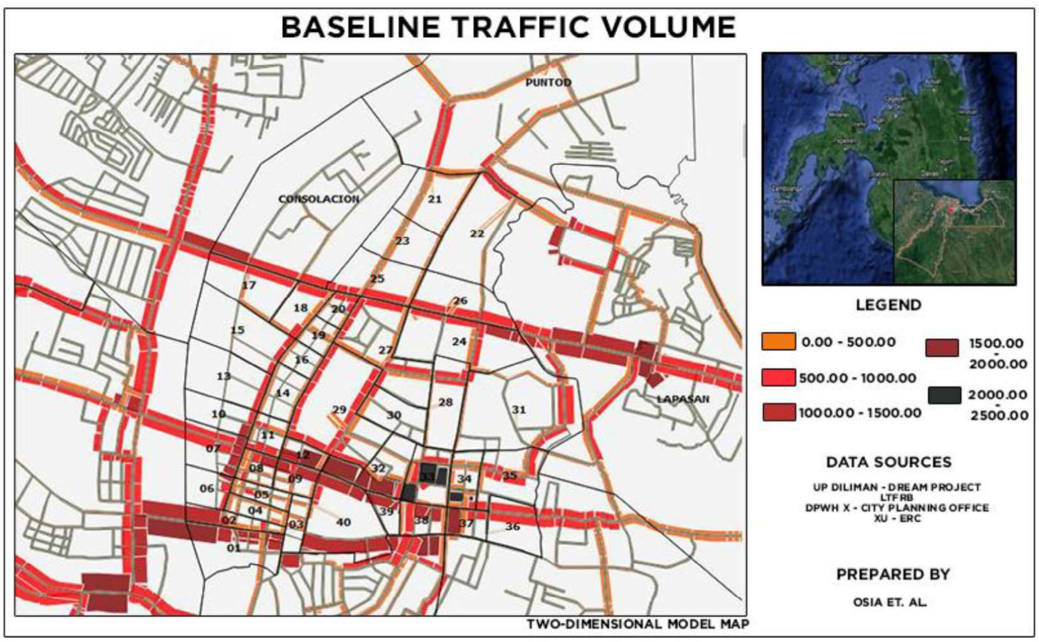

Figure 4. Baseline Traffic Volume

4.4 Traffic flow for 5-Year Flood

It shows that Barangay 31, which is situated along Limketkai Avenue, is affected by low to medium flood hazard. Also, areas near Barangays 22, 24 and 26 along CM Recto Avenue and Corrales Extension are severely affected by medium to high hazard flood. With this given, traffic volume continues to rise along roads which is located on a barangay severely affected by the flood, such as Gaabucayan Street along Barangay 22. As observed, the traffic volume in Marcos Bridge and Rotunda is much greater than the traffic in Puntod-Kauswagan Bridge and JR Borja Bridge, that is because of the occurrence of flood that closed the roads surrounding the said bridges.

Cogon road, CM recto highway, Marcos bridge and Ysalina bridge has the highest traffic volume having 2,040 veh/hr, 1,526 veh/hr, 1,461 veh/hr and 1,452 veh/hr respectively. Traffic volume is lesser than expected in Puntod-Kauswagan bridge since the roads surrounding the bridge does not hold heavy traffic volume. This means that flood is not that severe along the area, compared to the given barangays with medium to high hazard flood. Since most roads along barangay 1 to barangay 40 are one-way lanes, when these roads are closed, it can cause extreme traffic congestion in other connected roads within Cogon area, since road networks are vulnerable to natural disasters, especially during flooding. These can cause major disruption in traffic flow and reduction of its volume capacity. In a study conducted by Abad and Fillone (2017) on re-routing scheme in Metro Manila, they stated that flood waters not only cause property damage and loss of life, but also influences the traffic network and can cause traffic congestion, in an affected area. Comparing the 5-year flood hazard map with the 5-year traffic volume, some roads are adversely affected by heavy traffic congestion caused by flooding. Also, there are areas where traffic volume within the 5-year flood map remain same, or may be assumed to have a slight increase since minor roads are not accessible due to low flood hazard. Specifically, Barangays 36, 37, 38, 39 and 40 may have a slight increase in traffic volume since roads in Barangay Nazareth are inaccessible.

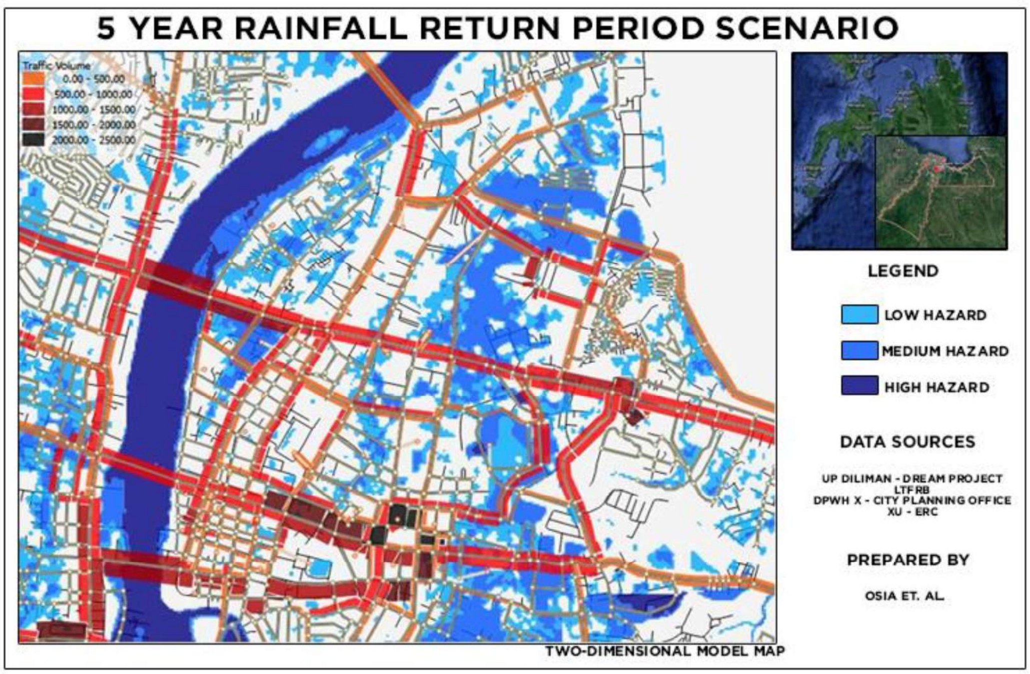

Figure 5. Traffic Volume for 5 Year Rainfall Return Period Scenario

4.5 Traffic Flow for 25-Year flood

Comparing the scenario of traffic volume within the 5-year map and 25-year map, only a slight increase of traffic volume is detected. For example, there is a slight increase in traffic volume on Corrales Extension. This may be caused by vehicles passing through the road caused by inaccessible minor roads near the area. Also, barangays surrounding the Cogon area, such as Barangays 32, 33, 34, 35 and 36, carry the same traffic volume compared to the traffic volume estimated on the 5-year flood map.

Cogon road, CM recto highway, Ysalina bridge, Marcos bridge and Agora has the highest traffic volume having 2,028 veh/hr, 1,427 veh/hr, 1,368 veh/hr, 1,133 veh/hr and 1,177 veh/hr respectively. That is because some areas in Cogon are prone to heavy flood hazard where some roads are not accessible, especially roads accessed by PUJs, which makes some roads, such as Hayes Street, to be accessed as an alternative road, which also causes major traffic congestion.

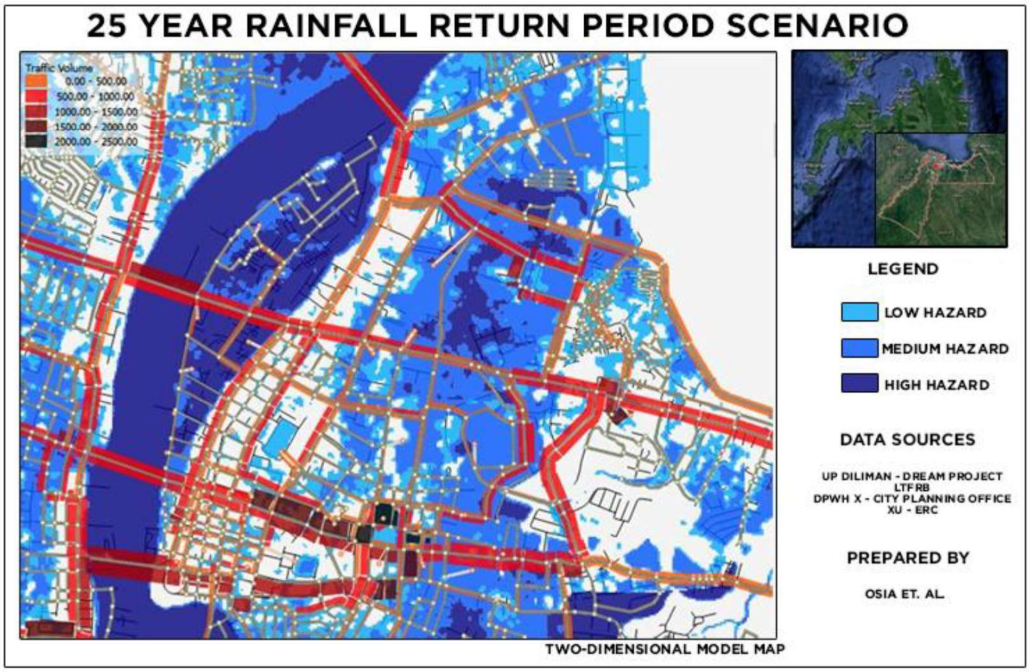

Figure 6. Traffic Volume for 25 Year Rainfall Return Period Scenario

Table 1 shows the traffic volume and travel time on each route under base scenario, 5-year flood and 25-year flood scenario. Based on the table below, changes in link capacity resulted to significant changes in traffic volume and travel times. In Ysalina bridge, travel time computed increased from 3.32 mins to 74.6 mins on 5-year flood and to 74.83 mins on 25-year flood. This is likely due to significant reduction of link capacity (80%) on the bridge, which resulted to higher travel times, despite having smaller changes in traffic volume. Likewise, Marcos bridge and JR. Borja has significantly increased travel times in both flood scenarios. It is because the bridge structures are the only means of access from one district to the next and roads are congested with the given flood scenarios, resulting to a decrease in traffic flow, but increase in travel time in its route. When flood happens two factors are considered: more delayed in time and lesser frequency of veh/hr (more congested area).

Table 1. Traffic Volume and Travel Time for each Route

	Traffic Volume (veh/hr)			Travel Time (mins)		
Routes	Baseline	5-Year	25-Year	Baseline	5-Year	25-Year
Corrales Ave	10,056	6,150	7,362	2.89	2.84	2.86
Gen Antonio L. St.	5,503	6,488	4,930	2.65	2.64	2.69
Gen. Capistrano	20,432	19,447	18,379	4.1	4.06	4.06
JR Borja Bdg.	33,482	32,127	32,491	7.01	13.46	17.41
Marcos Bdg.	22,147	20,444	15,475	10.72	16.08	24.14
Velez St.	13,729	14,914	15,416	5.85	5.87	5.95
Yacapin St.	3,159	2,918	2,869	1.24	1.24	1.24
Ysalina Bdg.	8,716	8,132	8,118	3.32	74.6	74.83

The theoretical travel time through network simulations and actual travel time by measuring the travel time from starting point to the end point of a route using a vehicle and stopwatch. Actual travel times (also present normal condition) are measured during non-peak hours (6-8am) and peak hours (5-7pm). Base on the results we gathered, some values from peak hour travel time are greater than travel time obtained from the program. It is because the volume delay function of the road networks is assumed to be uniform (equivalent to 1) on all road links despite the fact that in actual, it varies differently on each link. JR borja bridge, Marcos bridge and Ysalina bridge shows a huge difference between theoretical and actual value since bridges are the busiest within the city proper.

4.6 Summary NRI and NVI Indices

Each table shows the NRI and NVI values for each scenario, which are ranked accordingly in order to guide the researchers in identifying routes that are vulnerable to the impact of flooding and sudden changes in link capacities. Higher value of NRI and lower value in NVI means that the route is more vulnerable. Among the eight routes, General Antonio lunast., Marcos bridge and Velez street are amongst the most vulnerable disaster routes. This is likely due to the sudden decrease of road capacity in road links that are affected by flooding. In terms of robustness, Ysalina bridge is the most critical among the eight routes, however it is also the least vulnerable has a higher cost of travel on the base scenario, making it viable as an alternate route.

Table 2. NRI and NVI Values for 5-year Flood

Routes	C after	C before	NRI	Rank	C after	C before	NVI	Rank
Corrales Ave	1383.32	841.38	-541.94	8	2046.39	1070.234	976.1564	6
Gen Antonio L. St.	1086.46	1218.62	132.16	5	1511.182	1648.686	-137.504	3
Gen. Capistrano	2104.35	2004.04	-100.31	7	3716.46	3190.819	525.6409	5
JR Borja Bridge	7153.93	11216.92	4062.99	3	42178.14	-396204	438382.4	8
Marcos Bridge	9039.06	14701.01	5661.95	2	15147.47	32940.57	-17793.1	1
Velez Street	2004.78	2141.72	136.94	4	4465.363	4719.567	-254.204	2
Yacapin Street	421.26	390.74	-30.52	6	654.6154	599.6568	54.95853	4
Ysalina Bridge	4453.68	100469.6	96015.92	1	45713.22	-32242.2	77955.45	7

For 25 year flood, the most vulnerable routes are JR borja bridge, Marcos bridge and Velez street. Due to heavy flooding in Corrales avenue, there is a decrease in road capacity, traffic volume and speed making the route more vulnerable. Based on both figure, the least vulnerable routes include Ysalina bridge and JR Borja bridge, since both figures show lesser costs and has less impact on flood hazard.

Table 3. NRI and NVI Values for 25-year Flood

ROUTES	C	C before	NRI	RANK	C after	C before	NVI	RANK
Corrales Ave	1383.32	1020.71	-362.61	8	2046.39	1460.547	585.843	6
Gen Antonio L.	1086.46	968.42	-118.04	6	1511.182	1660.52	-149.338	4
Gen. Capistrano	2104.35	1875.05	-229.3	7	3716.46	2876.381	840.0787	7
JR Borja Bridge	7153.93	15183.11	8029.18	2	42178.14	1102152	-	1
Marcos Bridge	9039.06	15503.4	6464.34	3	15147.47	63909.73	-48762.3	2
Velez Street	2004.78	2244.9	240.12	4	4465.363	5492.575	-1027.21	3

Yacapin Street	421.26	384.62	-36.64	5	654.6154	596.9767	57.6387	5
Ysalina Bridge	4453.68	100754.5	96300.84	1	45713.22	-40394.4	86107.58	8

4.7 Disaster Response Map

It shows all disaster routes within the city proper. Different colors indicate different routes which are selected to be vulnerable. After computing and ranking for both the Network Vulnerability Index and Network Robustness Index values for all the selected roads, it is shown in the vulnerability analysis that Ysalina Bridge (highlighted in light brown), Yacapin Street (highighted in yellow), Corrales Avenue (highlighted in dark brown) and Gen. Antonio Luna Street (highlighted in sky blue) are the most vulnerable routes. Despite the fact that the route of Marcos Bridge (highlighted in
dark blue), along the CM Recto Major highway, is the route that is most heavily affected by the flood, it still prevails as the least vulnerable among the eight routes, however has higher travel costs making it lest viable for disaster response.
After identifying and analyzing the selected roads, alternate routes will then be created during flooding. These alternate routes will help commuters access roads after the creation of a new road network in case of flood. These alternate routes will also help drivers avoid flooded roads to mitigate traffic congestion.

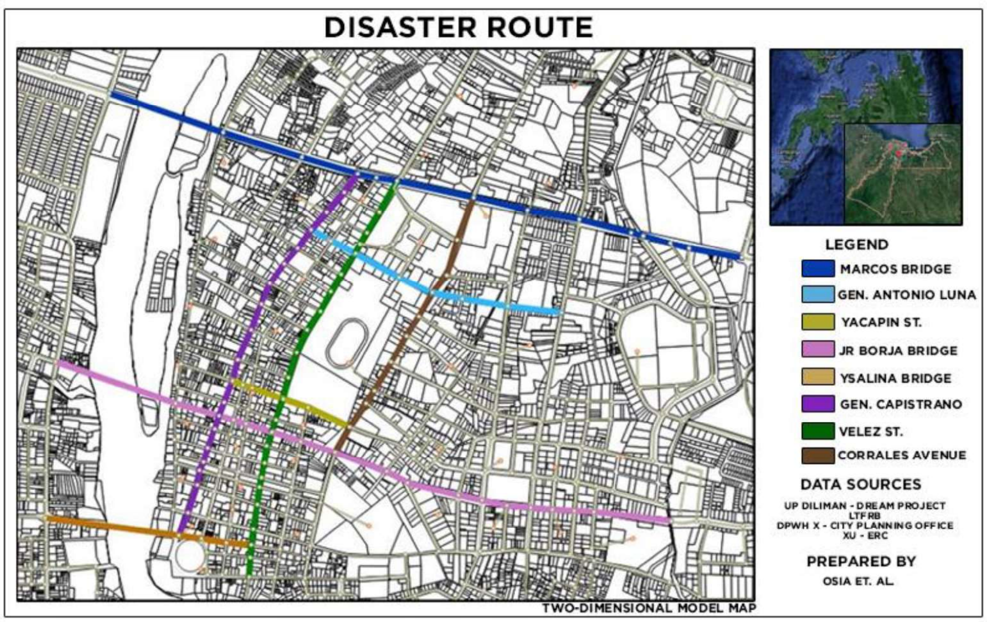

Figure 7. Disaster Routes

4.8 Synthesis

Objective 1: An assessment on flood prone areas in Cagayan de Oro City

The collection of the baseline data regarding the physical characteristics of the transit buses is done. The shape file used as baseline map of the zoning of Cagayan de Oro City and the barangay roads and boundaries for the identification of the road networks and transit lines were obtained from the Xavier University – Engineering Resource Center. The map shows all the nodes, links and centroids used, where are a total of 2874 nodes and 6984 links used in this scenario. The determination of the lane capacity for every link will depend on the classification of the road, whether it be a national road or a secondary road. The national road situated in Cagayan de Oro, which is CM Recto Avenue, have a link capacity of 900 vehicles per hour per lane, while local roads have an estimated link capacity of 750 vehicles per hour per lane. Also, travel demand per zone were provided by the Roads and Traffic Administration (RTA) where there were ten (10) matrices used in the study. For barangays 1-40, Barangay 33 has the most number of trips entering and leaving the zone, while for barangays 41-80, Barangay Carmen has the most number of trips entering and leaving the zone. Transit lines were also created to allow passage for transit modes. The values for the passenger capacity and vehicle fleet were obtained from the Roads and Traffic Administration (RTA) and the Land Transportation Franchising and Regulatory Board (LTFRB). Within Cagayan de Oro City, there are 32 lanes for jeepneys, 8 for multicabs, 2 for vans and buses. Also, there were restrictions for some modes and transit lines, such as motorelas, where Barangays Agora, Macasandig, Carmen, Consolacion and Camaman-an were restricted.

Objective 2 and 3: NRI and NVI values

The selection of the roads for the researchers to be able to compute for their Network Vulnerability Index (NVI) values and Network Robustness Index (NRI) values were based from the criteria presented. With that said, eight (8) roads were selected, which are as follows: Velez Street, Marcos Bridge, Capistrano Street, Ysalina Bridge, Yacapin Street, Corrales Avenue, A Luna Street and JR Borja Bridge. Having the highest values of NRI and lowest values of NVI in two different scenarios, the most vulnerable roads were selected. For a 5-year flood, the most vulnerable roads are Ysalina Bridge, Yacapin Street and A Luna Street. For a 25-year flood map, the most vulnerable routes are Ysalina Bridge, Yacapin Street and Corrales Avenue. They are among the most vulnerable routes selected, which is due to decrease of road capacity caused by flooding. In terms of its robustness, Marcos Bridge has the highest value.

Objective 4: Disaster Response Map of Barangay 1 to Barangay 40

From the vulnerability analysis done, the most vulnerable routes within the scope are Ysalina Bridge, Yacapin Street, Corrales Avenue and A Luna Street. These selected roads are easily accessible by public transportation vehicles and are also located near hospitals and evacuation sites within the scope, which affirms to one of the criteria for the selection of the most vulnerable routes. Also, the selected roads are located within the scope of the study. Lastly, the selected roads are most likely to have limited access to districts. With the selection of the roads that allows safe and coordinated movement for emergency respondents to respond to the affected area, the roads are considered to be the most vulnerable routes. With this given, accessibilty to hospitals and evacuation sites should be further studied and planned to improve the run of disaster response within the area during flooding season.

On the other hand, Marcos Bridge appears to be the most affected road during the flood season, but it turns out to be the least vulnerable road among the selected roads but still has a high travel costs, which makes it the least viable road for disaster response.

5. CONCLUSIONS AND RECOMMENDATIONS

The result shows changes in network traffic flows, speed and travel time due to link capacity reductions from the occurrence of a 5-year and 25-year flood. With the help of the Flood Hazard Map provided to us by the Engineering Resource Center (ERC), the researchers were able to achieve our first objective (1) which is to conduct an assessment on flood prone areas in Cagayan de Oro City. There are eight routes used in the study for disaster response, which are closely situated near evacuation centers and hospitals. These routes include Corrales Avenue, Gen. Antonio Luna street, Gen. Capistrano Street, JR Borja bridge, Marcos Bridge, Velez street, Yacapin street and Ysalina bridge. Network links and properties are developed using EMME 4.4 and reductions of road link capacities are caused due to the overlaying of the Flood Hazard Map to the Basemap and manually reducing each road link capacity according to its Flood Hazard Level.

By using specific vulnerability indices adopted in this paper by Balijepalli and Oppong (2014) and Scott et al., (2006), the researchers were able to achieve the second and third objective (2) which is to identify vulnerable routes on a road network using Network Vulnerability Index (NVI) values and (3) to identify critical links on a road network using Network Robustness Index (NRI) values and EMME/4 simulations. Resulting NRI and NVI values are compared for each route stated above in order to identify vulnerable links and potential alternate routes which helps the researchers achieve the fourth objective (4) which is to develop a disaster response map. Results show that the most vulnerable routes for a 5-year flood event are Gen. Antonio Luna street, Yacapin street and Ysalina bridge. For 25-year flood, the most vulnerable routes are Corrales avenue, Yacapin street and Ysalina bridge. This is due to drastic changes in traffic volume and travel time that caused higher vulnerability indices on these routes. In the case of Ysalina bridge, higher travel time and lower traffic flow and speed indicates that the route is congested, due to the impact of the flood hazard on this route. The least vulnerable route is Marcos bridge on both scenarios despite the fact that its links are more impacted by the flood hazard, however this resulted to higher costs making it less viable as an alternate route. Results also show that Velez street and Gen. Capistrano street are less vulnerable and more robust, with lesser cost on links making it viable as an alternate route for the utilization of emergency vehicles. These resulting models would serve as a guide for emergency responders for disaster response.

Further study is recommended since the study is only limited to Barangay 1 to Barangay 40 within Cagayan de Oro city and evaluates a limited number of modes (e.g. Private cars, Jeepneys, Taxis and Motorelas). Further study that could cover the entirety of the city is recommended by the researchers to improve data results on this study, as well as consideration of other disaster scenarios such as earthquakes, landslides, volcanic eruption etc. Also to establish maps of an identified shelters, evacuation centers, hospitals and fire stations outside the vulnerable area. For transportation planning, it is recommended to propose strategies in order to divert traffic to less vulnerable and more robust routes in the road network. Proposed disaster response map may be used for similar flooding scenarios for the utilization of emergency vehicles. For engineering application, it is recommended to increase lane capacity in order to accommodate more vehicles on critical areas, hence reducing the vulnerability of the road link. Flood mitigation may also help reduce the risk for flood hazards. Also, the study recommends to do road clearing, improvement on bridge design and bridge retrofitting, proposal of new bridge within the city.

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