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Optimizing Link Capacities in the Traffic Network Surrounding the Commercial Business District (CBD) of Cagayan de Oro City, Philippines

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Abstract

Traffic congestion has become one of biggest problems brought about by modernization and has greatly affected big cities all over the world. Various strategies, such as the creation of new or alternate routes, have been explored by road management agencies in order to reduce delay. However, in order to achieve effective traffic management, it is important to know the link capacities in the traffic network. Cagayan de Oro City, tagged as the city in bloom, in blossom and in boom, continues to prosper and with it, transport vehicles, including public utility jeepneys (PUJs), in the city are also continuously increasing, thus causing traffic congestion in the city especially around its commercial business district (CBD). In this paper, a mathematical model is formulated and solved to provide guidance on how to allocate congestion in the traffic network surrounding the CBD of Cagayan de Oro City, Philippines, in an equitable manner such that the overall network congestion or delay can be minimized.

***Keywords**:* traffic congestion, traffic management, link capacity

1. Introduction

Traffic congestion leads to long and unpredictable commute times, environmental pollution and fuel waste. The travel time spent in traffic networks is one of the main concerns of the societies in developed countries. Traffic congestion has become one of the greatest plagues that impacted modern cities around the world. Due to continuing development, time spent being stuck in traffic has considerably increased and has miserably caused unwanted delays and extra travel costs to commuters. Monitoring traffic density and speed helps to better manage traffic flows and plan transportation infrastructure and policy.

Study of the various characteristics of road traffic is immensely useful for planning and design of roadway systems and operation of road traffic. Understanding the real traffic behavior requires quantification of some of the basic traffic flow characteristics such as speed, flow and density. Generally, motorists perceive lowering of the quality of service when the traffic density on the road increases. In other words, for a given roadway, the quality of flow changes with the traffic density on the road. Thus, the measure 'density' provides a clear indication of both the level of service being provided to the users and the productive level of facility use. Hence, there is a need for in-depth understanding of traffic flow characteristics with specific reference to density.

Speed and travel time are the most commonly used indicators of performance for traffic facilities. Network travel time contours, speed trends, maps of link speed, and various displays in transportation management centers emphasize the importance of these two parameters to the public and to the profession. When facilities are congested, the amount of delay and the extent of the congestion are common supplemental indicators. The terms "delay" and "congestion" are almost always synonymous with each other and are commonly used in existing literature on traffic studies (Daganzo *et al.*, 1999; Tong, 2005; Varaiya, 2005). There are many kinds of "delay" that can be defined and measured. Similarly "congestion" has many interpretations. For some "point" facilities, such as intersections, average delay is the defined level of service indicator. For arterial streets, the average travel speed of the vehicle is the defined indicator, although the data is often taken by means of travel time run. Even for freeways, where density is the defined level of service indicator, speed, delays and related travel times are also critical measures when describing congestion. Travel time has the advantage that successive trip segment can be added directly, without concerns for weighted averages. Speeds, on the other hand, do not have to be linked so directly no trip length in the presentation, and are often used to describe performance at a particular point or short segment of a facility (Roess *et al*., 2011).

Traffic congestion has no real concrete definition, but it can be best described as vehicle density, vehicle speed, and traffic volume. Vehicle density refers to the size of the vehicles on the road. Vehicle speed is the rate at which the flow of traffic is moving while traffic volume deals with how many cars are on the road during a certain time, say, in 1 hour. There are essentially two types of traffic congestion. It can either be recurrent or non-recurrent. Recurrent congestion is every day rush-hour stop and go traffic, occurring when the capacity of the freeway is exceeded. The initial cause of this type of traffic is that there are too many people rushing along our highways usually alone in their cars during the peak traffic back-up hours, hence the name ‘rush-hour’. These hours range from 7 to 9 A.M. and from 4 to 6 P.M., the time when people are traveling to and from work, respectively. This recurrent congestion deals with the everyday drivers who usually know how to handle the problems or situations that might occur in a traffic jam. This is an important consideration when dealing with an efficient way of getting out of the traffic jam. The more equipped the drivers in the traffic are with the skills and knowledge of dealing with this situation, the easier and quicker the traffic will dissipate (Roess *et al.,* 2011). Non-recurrent congestion, on the other hand, is the unexpected or unusual congestion caused by an event that was unexpected and transient relative to other similar days. These can be caused by a variety of factors such as lane blocking accidents and disabled vehicles, construction lane closures, inclement weather, and significant increases in traffic volume in comparison to “normal” traffic volumes.

Cagayan de Oro, considered as the regional center in Northern Mindanao, Philippines and the most populous highly-urbanized city, is noted for its accessibility, business growth and tourism attractions (Deveza, 2011). As the city continues to prosper, utility vehicles in the city are continuously increasing too. Brought about by its urbanization, Cagayan de Oro faces another problem which is traffic congestion.

Traffic density is defined as the number of vehicles occupying unit length of roadway at any instant of time (Morarescu and De Wit, 2011). Link capacity, on the other hand, is the maximum number of vehicles that can be accommodated on a particular link at a given time. Traffic density provides an indication of the level of service being provided to the road users. Hence, there is a need to study the traffic flow characteristics with specific reference to density and link capacity. In computing for the link capacity of each link in the traffic network under consideration, the size of the vehicle plus the spacing value, the duration of lane change maneuver, average driver reaction time, time for successive lane changes, deceleration at start of lane change maneuver, among others must be considered (Li, *et al.,* 2007).

In this study, a mathematical model is formulated and solved in order to provide guidance on how to allocate congestion in a traffic network surrounding the commercial business district (CBD) of Cagayan de Oro City in an equitable manner such that the overall network congestion or delay can be minimized. In the following section, some preliminaries needed for better understanding of the topic at hand is provided.

2. Methodology

2.1 Preliminaries

If each class of driver drives at its desired, "free-flow" speed, the observed uncongested flow-density relationship is a weighted average of the desired speeds. Assuming such behavior, a "i" yields estimates of free-flow speeds for these classes. Under uncongested conditions, the total uncongested flow q_v is given by

$$q_v = \sum_i v_{free,i} p_i k \tag{1}$$

where $v_{free,i}$ is the free-flow speed for each vehicle class i, $p_i k$ is the density of vehicle class i per unit length of roadway, p_i is the proportion of vehicles of vehicle class i, $k = \frac{1}{\sum_i p_i s_i}$, s_i is the inter-vehicle spacing (front to front) (Kockelman, 2001). However, under congested conditions, the driving situation becomes very different. Speeds are no longer constant for rising densities, and drivers can no longer choose their free-flow speeds. Instead, each class of driver is able to control the spacing at which it follows the preceding traveler. One behavioral assumption used in various studies is that spacing s_i for each driver class *i is* a linear function of speed (Daganzo, 1999).

In the Philippines, public utility jeepneys (PUJs) are the most common means of public transportation. According to the Land Transportation Office (LTO) Administrative Order (AO-2009-018), the standard size of a PUJ in the Philippines must be 11m in length, 4m in height and 2.5m in width. In this study, flow rate of vehicles is set at an average of 10 km/hour as observed during peak hours.

Currently there are 23 PUJ routes that pass through the CDB of Cagayan de Oro City. The southbound PUJs are usually not allowed to enter the CBD, hence are not included in this study. There are 4 routes for Eastbound PUJs, namely Bugo/Puerto, Lapasan, and Gusa/Cugman (RC and RD). Eleven routes for Westbound PUJs, namely NHA (RA and RB), Patag (C2), Apovel, Carmen (R1 and R2), Iponan (RA and RB), and Bulua (B1, B2, and B3) and 8 for Northbound PUJs which include Pier (RA and RB), Kauswagan (RA and RB), Bayabas (RA and RB), and Bonbon (RA and RB). The total number of PUJ units operating on these PUJ routes is shown in Table 1.

Table 1. Total number of PUJ units operating in the Eastbound, Westbound and Northbound routes of Cagayan de Oro.

PUJ Liner	Total Number of PUJ Units Currently Operating	PUJ Liner	Total Number of PUJ Units Currently Operating
Bugo/Puerto	238	Bulua (B1)	25
Lapasan	112	Bulua (B2)	11
Gusa /Cugman (RC)	127	Bulua (B3)	76
Gusa /Cugman (RD)	156	Pier (RA)	121
NHA (RA)	38	Pier (RB)	114
NHA (RB)	36	Kauswagan (RA)	13
Patag (C2)	58	Kauswagan (RB)	13
Apovel	41	Bayabas (RA)	20
Iponan (RA)	64	Bayabas (RB)	19
Iponan (RB)	57	Bonbon (RA)	52
Carmen (R1)	59	Bonbon (RB)	53
Carmen (R2)	79	Total	1582

Source: Land Transportation and Franchising Regulatory Board (May, 2012)

Table 2 shows the actual average traffic count of PUJs in various streets around the CBD of Cagayan de Oro obtained during peak hours (7-9 AM and 4-6PM) during the month of June 2013. Based on actual observation of the real traffic condition of Cagayan de Oro's traffic network and the data obtained from RTA, congestion mostly occurs in C.M. Recto Avenue, Yacapin Extension, Vamenta Boulevard, J.R. Borja Street, Capt. Vicente Roa Street, Ysalina Bridge, Don A. Velez Street, Marcos Bridge, Sergio Osmeña

Table 2. Actual average traffic count of some streets in Cagayan de Oro during peak hours.

Name of Street	Average PUJ Volume Count per Hour
C.M. Recto Avenue	594
Capt. Vicente Roa Street	941
Corrales Street	818
Corrales Extension	478
Don A. Velez Street	648
Don Julio Pacana Street	714
Gaabucayan Street	556
Gaerlan Street	902
Gen. Capistrano Street	788
J.R. Borja Extension	856
J.R. Borja Street	722
Castro Street	712
Yacapin Extension	674
Marcos Bridge	609
Osmena Extension	898
R.N. Pelaez Boulevard	726
Sergio Osmena Street	604
Vamenta Boulevard	771
Ysalina Bridge	853

Street, Gaabucayan Street and Castro Street. Yacapin Extension and Capt. Vicente Roa Extension are narrow roads yet most of the PUJs are required to pass through these streets since it provides access to Cogon Public Market. Most PUJs are also required to pass through Castro Street, which provides access to Carmen market. Moreover, most eastbound PUJs and some westbound PUJs are required to pass along the streets passing through the Market City in Agora.

2.2 Mathematical Model for Optimizing Link Capacities

Mathematical models are constructed by taking into consideration the number of PUJ units that travel the westbound, eastbound and northbound routes of Cagayan de Oro, the link capacities of the streets surrounding the CBD of Cagayan de Oro, the actual (average) traffic count on each street and other restriction factors of the streets under consideration (e.g., one-way streets).

In order to determine the new routes for the traffic network around the CBD of Cagayan de Oro, critical links were identified. A link is considered "*critical*" if more than 5 PUJ liners pass along this link and its total link flow exceeds the maximum link capacity. Based on the actual observation conducted and from the information obtained from the RTA, the critical links in the road network around the CBD of Cagayan de Oro were identified. The attributes of these critical links, based on the data provided by the RTA, are shown in Table 3. The link capacity of each link is computed by taking into consideration the occupancy value of each PUJ and the assumed flow rate of vehicles in the network during peak hours.

Table 3. Attributes of the critical links

Street Name	Length (m)	Width (m)	Link Capacity per Hour (u_{ij})
C.M. Recto Ave.	600	4	460
Yacapin Extension	720	3	550
Marcos Bridge	135	4	100
Ysalina Bridge	98	4	70
Castro Street	75	3	50
Vamenta Boulevard	290	4	220
Sergio Osmeña Street	100	4	70
J.R. Borja Street	693	4	530
Gaabucayan Street	300	4	230
Don A.Velez Street	600	4	460
Capt. Vicente Roa	750	4	570
Corrales Street	180	4	130

Based on the attributes of the traffic network around the CBD of Cagayan de Oro, a maximum flow problem (MFP) was then formulated to identify how much traffic flow should be allowed on specific streets given the link capacities of these streets. This formulation is as follows:

$$\text{maximize } f = \sum_{i\in J}\left(\sum_j x_{ij} - \sum_j x_{ji}\right)$$
$$\text{subject to}$$
$$\sum_j x_{ji} - \sum_j x_{ij} = \begin{cases} f & \text{if } i \in I \\ 0 & \text{if } i \in L \setminus (I \cup J) \\ -f & \text{if } i \in J \end{cases} \qquad (2)$$
$$0 \le x_{ij}, x_{ji} \le u_{ij}$$

where each x_{ij} is the decision variable designating the flow passing through each link (*i*,*j*) from source node $i \in I$ to node $j \in J$ and L is the set of all links in the network being considered. The MFP (1) aims to send as much flow as possible between two special nodes, a source node *i* and a sink node *j*, without exceeding the capacity of any link in the network. Hence, the objective function *z* in (1) is the total number of PUJs allowed to pass into the sink nodes without exceeding the link capacity u_{ij}. Note that in this formulation, only the links identified as critical links as shown in Table 3 have limited link capacities. It should be noted that not only PUJs can pass through these critical links. However, this study only considers PUJs as the main users of the critical links since there are various alternate links available for the other modes of transportation. The traffic network surrounding the CBD of Cagayan de Oro is shown in Figure 1. Each of the links in this network was considered in the MFP formulation (1).

3. Results and Discussion

By solving the MFP (1), the maximum number of PUJs that must be allowed to pass through the links around the CBD of Cagayan de Oro were determined. In particular, the solutions of MFP (1) provide the total number of PUJs that must be allowed to pass through the critical links around the CBD of Cagayan de Oro. Table 4 shows the maximum number of PUJs allowed to pass through the critical links around the CBD of Cagayan de Oro as compared to the current number of PUJs passing through the critical links.

It can be seen from Table 4 that based on the current routing scheme being implemented by the RTA, there are critical links in which the total number of PUJs passing through these links exceed the maximum capacities of these

Figure 1. The traffic network surrounding the CBD of Cagayan de Oro

links (e.g., Corrales street and S. Osmeña Street). However, after solving MFP (1), link capacities of the critical links have been strictly observed and hence, the total number of PUJs allowed to pass through each link in the network around the CBD do not exceed the allowable link capacities. Taking into consideration the maximum number of PUJs allowed in the critical links, proposed routes are suggested and are shown in Figures 2-8.

It should be noted that these proposed new routes only considered the link capacities of the links in the network surrounding the CBD of Cagayan de Oro.

Table 4. The proposed maximum number of PUJs that must be allowed to travel in the critical links as compared to the existing routing scheme.

Critical Link	Link Capacity	Current (Average) Number of PUJs passing through critical link i per Hour		Proposed (Average) Number of PUJs allowed to pass through critical link i per Hour	
		No. of PUJ liners	No. of PUJ units	No. of PUJ liners	No. of PUJ units
C.M. Recto Ave.	460	12	594	4	358
Yacapin Extension	550	12	674	5	354
Marcos Bridge	100	8	309	8	89
Ysalina Bridge	70	8	153	8	64
Castro Street	50	5	212	5	46
Vamenta Boulevard	220	7	371	7	186
Sergio Osmeña Street	70	11	94	7	64
J.R. Borja Street	530	13	722	5	454
Gaabucayan Street	230	4	356	3	188
Don A.Velez Street	460	8	648	7	358
Capt. Vicente Roa	570	9	441	3	562
Corrales Street	130	6	418	5	112

The MFP formulation (1) does not consider the effect of the proposed rerouting to the riding public. Some of the proposed new routes may cause inconvenience to the PUJ commuters but these new routes are expected to ease the currently congested critical links in the network.

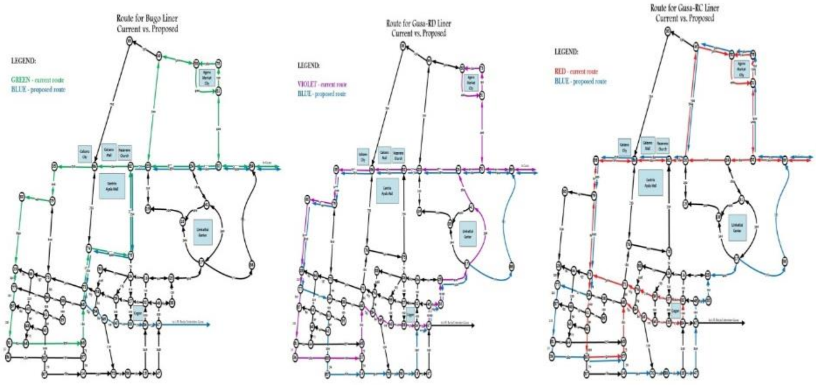

Figure 2. Proposed routes for Bugo, Gusa RD and Gusa RC

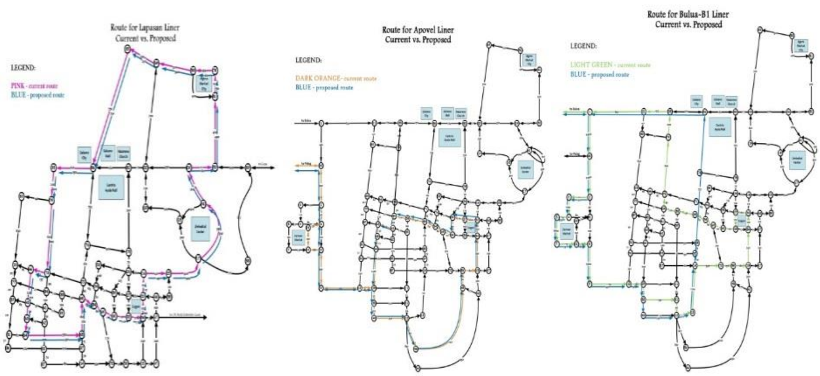

Figure 3. Proposed routes for Lapasan, Apovel and Bulua B1

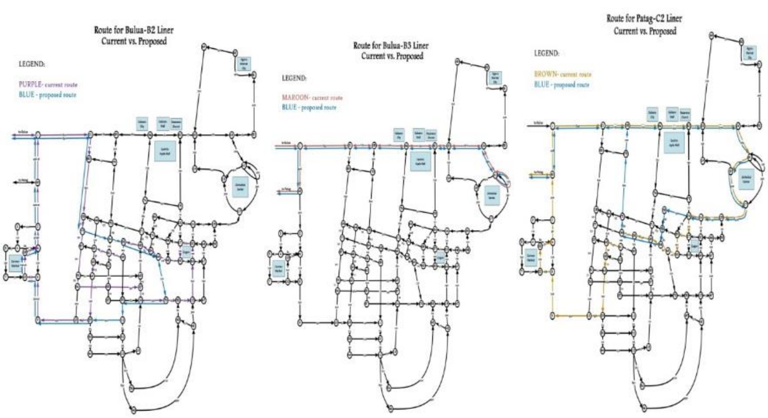

Figure 4. Proposed routes for Bulua B2, Bulua B3 and Patag C2

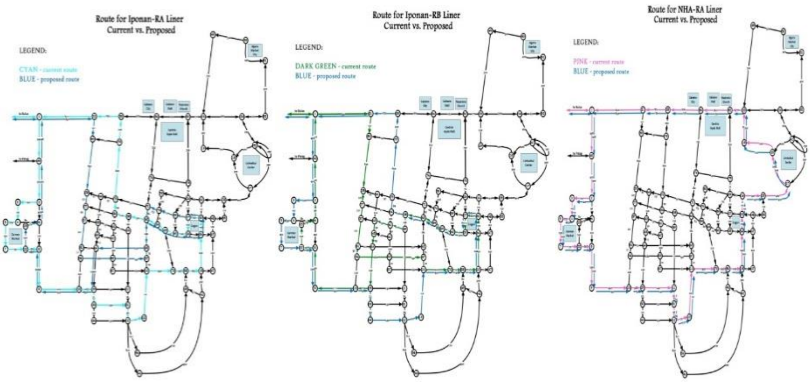

Figure 5. Proposed routes for Iponan RA, Iponan RB and NHA RA

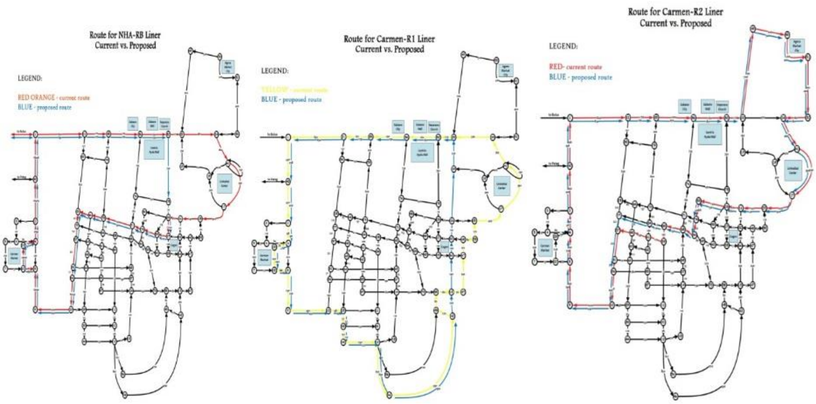

Figure 6. Proposed routes for NHA RB, Carmen R1 and Carmen R2

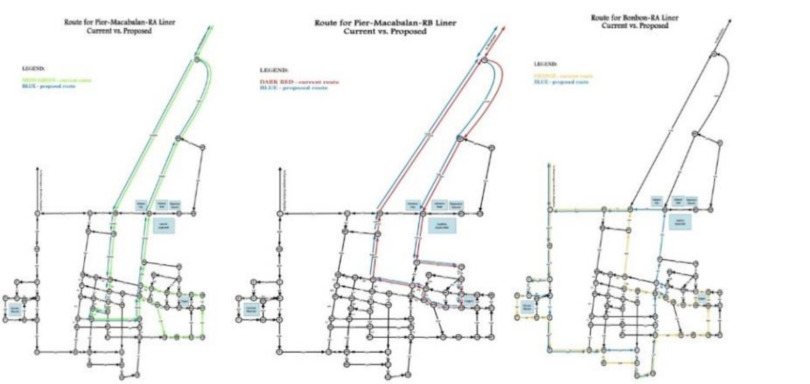

Figure 7. Proposed routes for Pier Macabalan RA, Pier Macabalan RB and Bonbon RA

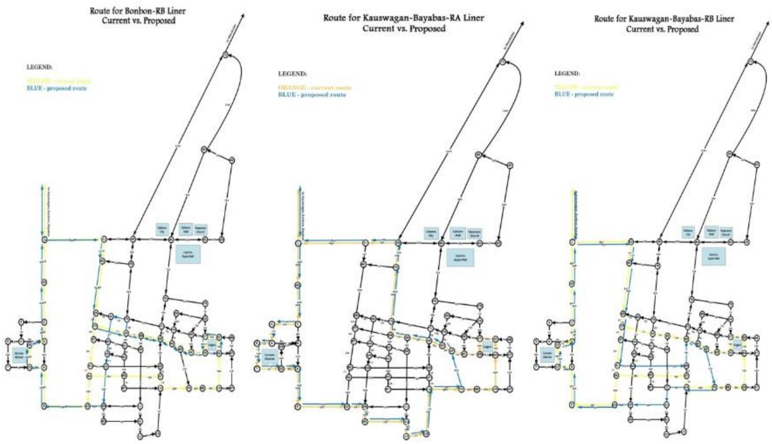

Figure 8. Proposed routes for Bonbon RB, Bayabas RA and Bayabas RB

4. Conclusion and Recommendation

In this study, a model for optimizing link capacities in the traffic network surrounding the CBD of Cagayan de Oro City was formulated and solved using maximal flow problem formulation. Solutions to this MFP provide the total number of PUJs that should be allowed to pass through each link in the network. By allowing only a specified number of PUJs to pass through these critical links, traffic congestion around the CDB of Cagayan de Oro may be minimized.

This study only focused on the public utility jeepneys plying through the streets around the CBD of Cagayan de Oro. For future studies, it may be interesting to include other vehicles to provide a more realistic approach to alleviating congestion

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