Estimating the Transport Urban Carrying Capacity of a City

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Abstract: The Urban Carrying Capacity (UCC) studies were undertaken in specific cities and municipalities in Asia to include China, Hong Kong, India, and Indonesia. Lately, from 2012 to 2017 several studies were done in selected cities in China that are suffering from high population density and exhaustion of infrastructure and transport services. There were no studies conducted in the Philippines based on the exhaustive review of published journals and articles. The city of Baguio was selected for the conduct of sample UCC benchmarks. Compared with other cities, the vehicle density for Baguio City appears to be above satisfactory. However, vehicle density in the city reaches its highest peak and exceeds the carrying capacity of roads during weekends, holidays, and peak months because of the large number of tourist arrivals in addition to urban migration in the city. Recommended solutions are varied but the two most outstanding ones include improved traffic management and strict implementation of the Traffic Impact Assessment study of establishments.

Keywords: Transport Urban Carrying Capacity, Level of Service, Capacity

1. BACKGROUND OF THE STUDY

Baguio City is currently experiencing rapid urbanization, a high in-migration rate, a construction boom on multi-story dwellings and commercial buildings, a high influx of tourists, and a growing student population. These dynamic phenomena will most likely intensify in the future, particularly in the next 25 years, unless growth centers in neighboring provinces' cities and towns are developed. Hence, it is highly anticipated that the city would suffer more from crowding and congestion, Unabated, these effects of the fast pace of urbanization would eventually redound to the deterioration of the environment and natural resources (forest, water, and land), overloading of infrastructure and urban facilities making them dysfunctional, and lowering the quality of life of residents, reducing the level of satisfaction among tourists, and less conducive learning environment for students.

The acceleration of economic activities and population concentration in Metro Manila and other cities in the Philippines has caused severe social problems such as traffic congestion, traffic accidents, and deterioration of the living environment according to a study by JICA and DOTC on MUCEP (MMUTIS Update and Enhancement Project) in 2015. The focus of these social problems that beset a city is traffic congestion. Traffic congestion relates to an excess of vehicles on a portion of the roadway at a particular time resulting in speeds that are slower-sometimes much slower than normal or "free flow" speeds (FHWA, 2018). The common practice in the Philippines in the alleviation of traffic congestion was increasing the capacity of roads. Major road capacity solutions include road widening and the construction of flyovers. These solutions are particularly applied to roads with sufficient RRW (road right of way) particularly in Metro Manila and other key cities. In the case of Baguio City, Road Right of Way (RRW) is a serious problem since the majority of establishments encroached on the boundaries of standard carriage width of highways and urban roads. A road-widening project for a two-lane; two-way road in Baguio was the usual solution when it reached its vehicle carrying capacity in terms of LOS (Level of Service). A widening of the two-lane road results in an additional lane totaling three lanes only because of the RRW violations. Figure 1 shows a three-lane; two-way highway which is a major error in highway design because of the even traffic flow during peak hours. The middle lane is being utilized in both directions resulting in traffic congestion and probable road crash collisions. This sends an alarming signal that the transport urban carrying capacity of the city has probably exceeded.

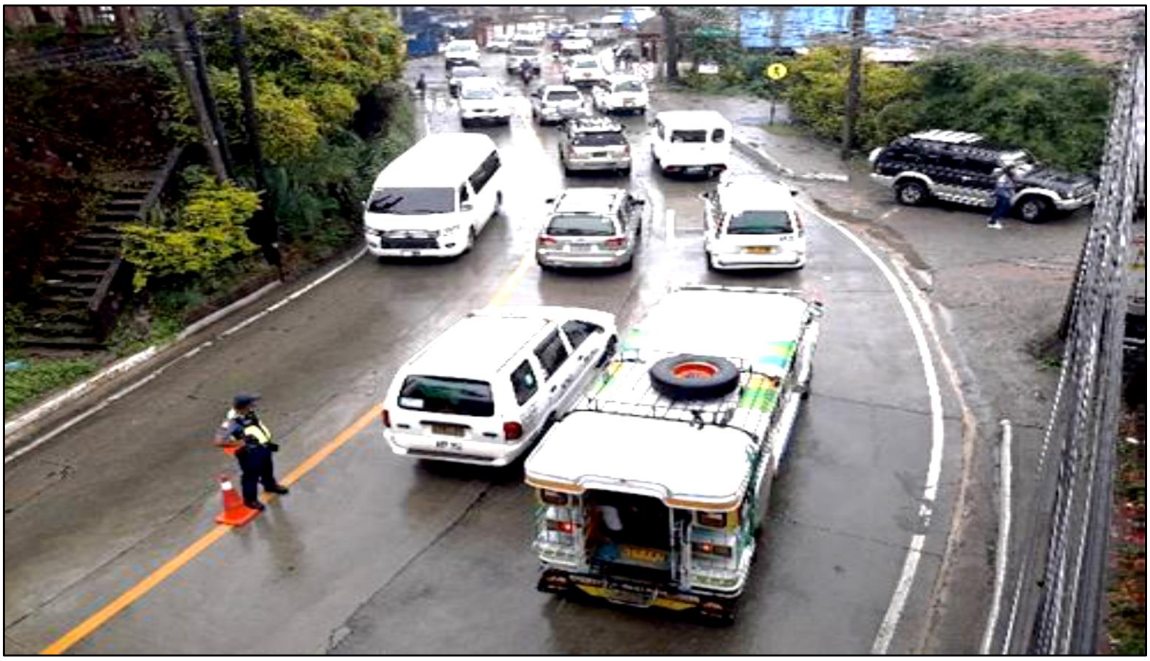

Figure 1. Three-lane; two way along Marcos Highway (Ben Palispis highway)

2. OBJECTIVES OF THE STUDY

The study aims to establish the Transport Urban Carrying Capacity (TUCC) of Baguio City to serve as a baseline for its strategic development planning.

Specific Objectives:

- Formulate a framework and set of measurable indicators for assessing the TUCC of the City of Baguio;
- Validate the proposed methods, indicators, standards, and benchmark values and the results of the TUCC calculations and;
- Identify appropriate policies and directions for the sustainable development of Baguio City considering its limits to growth.

3. REVIEW OF RELATED LITERATURE

The Urban Carrying Capacity (UCC) is defined as the level of human activities, population growth, land use, and physical development, which can be sustained by the urban environment without causing serious degradation and irreversible damage [10]. The UCC of a developing city was not given much emphasis as a basis for policy implementation to anticipate future urban problems such as traffic congestion. The focal point of this study is the analysis and evaluation of the transport demand concerning the carrying capacity of roads. Studies related to UCC are shown in Figure 3 in a form of a text graph to show the sequential development in the analysis and solution of transport demand to road capacity which led to this study. In the Philippine context, the Government of Japan has provided technical assistance to the Philippines' Department of Transportation and Communications (DOTC) and other related agencies through the Japan International Cooperation Agency (JICA) in leading a capacity development project entitled "The Project for Capacity Development on Transportation Planning and Database Management in the Republic of the Philippines [9]." The study supports the DOTC to prepare a public transportation plan for Metro Manila for strategic corridors by reinforcing their capacity in transportation database management and public transportation network planning. Thus, the results of this study are aimed at encouraging motorists to shift from using their private vehicles to public transport.

A study by Miharja and Sjafruddin in 2017 discusses the concept of urban land use development control which relates to transport carrying capacity in Indonesia [8]. Traffic congestion alleviation was to tackle both demand and supply problems. The enhancement of the public transport system and potential road network capacity altogether was the proposed solution on the supply side. From the demand side, the analysis would be through the control of a maximum floor area and public transport provision. Their allowed maximum floor area for development would be at the level of generating traffic at a reasonable volume. A study by Wei, et al. established benchmarks for the urban carrying capacity of Beijing and signaled the benchmark values as a basis for comparison to other cities. This will also signal other cities to establish Transport Urban Carrying Capacity (TUCC) benchmarks to determine the threshold of these values and establish standard TUCC benchmarks [13]. For the carrying capacity of roads, Lam & Shi presented a method for capacity analysis in urban roads using Hong Kong Annual Traffic Census (ATC) data. The method eliminates the complex methods and excessive adjustment factors which are complications in studying and determining the capacity threshold. Both of these studies will be the basis of the output of the study [7].

Key indicators selected for the Transport sector are intended to measure the existing capacity of roads in the city to absorb the growing number of vehicles spawned by the increase in resident, daytime, and projected populations. Inversely, the road requirements of projected populations were also estimated based on per capita standards to determine whether there is enough space where new roads could be built. The key indicators employed to measure the TUCC sector include the following: 1) Vehicle density per km^2 (veh/km^2); 2) Vehicle density per km (veh/km); and 3) Vehicle density per 1000 population (veh/1000 population). These three (3) related indicators measure the vehicle density in the existing road area and road length vis-a-vis projected plus daytime populations in Baguio City and compare it with the vehicle density in other cities. Vehicle density is the number of vehicles occupying a length of roadway.

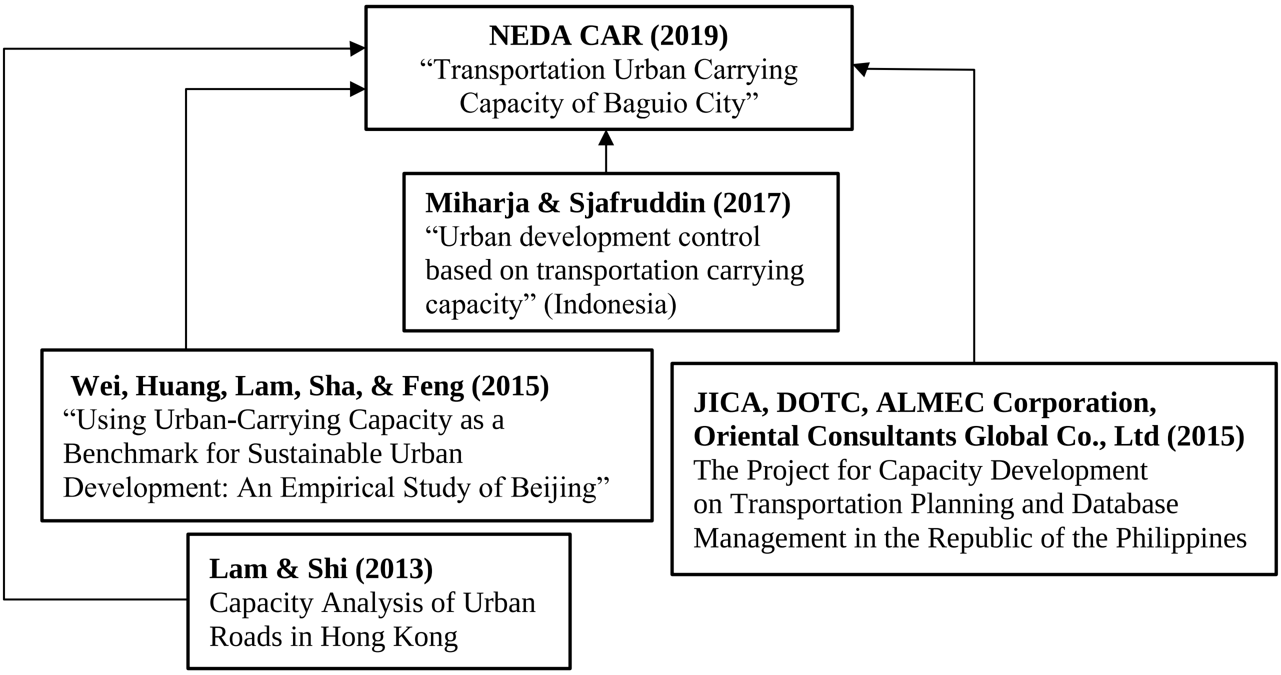

Figure 3. The framework of related studies

A comparison of vehicle density in key cities in the Philippines and Asia is shown in Table 1. Metro Manila's vehicle density is at 3,677 per square kilometer which is way above Singapore and Tokyo which is also consistent with the density in vehicles per kilometer. There were no data available for density in vehicles per 1000 population for Tokyo and Singapore.

Table 1. Vehicle density in key cities

	Key cities		
Vehicle Density	Tokyo	Singapore	Manila
Vehicle per square km (veh/km^2) (Source: Santiago, 2016)	**967**	**1360**	**3677**
Vehicle per km (veh/km) (Source: GIZ,2018)	**202**	**230**	**1895**
Vehicle per 1000 population (veh/1000 pop) (Source: MUCEP,2016)	Not available	Not available	**94**

The solution to traffic congestion which is often overlooked by transport experts is the reduction of the volume of vehicles to balance the reduced capacity of existing roads. Several volume reduction solutions such as the number coding system, truck ban, lane segregation scheme, phasing out of old vehicles, increasing parking fees, and even increasing the tax for brand new cars were implemented by the national government. To evaluate the effectiveness of these solutions, the transport carrying capacity of roads is initially analyzed by comparing the benchmark indicators of other cities with Baguio City. The indicators and benchmarks are also shown in Table 2.

Table 2. Transport Urban Carrying Capacity benchmarks

Evaluative Sectors and Indicators	Standards/Benchmarks*	Source
Urban road	2.4 km per 1000 population	HLURB, 2017
	> 1.0 km per 100 hectares	MUCEP, 2016

The 30th highest peak hour volume is the most reasonable hourly volume that provides the best result in designing the number of lanes of a highway. Depending on the type of highways, the value of K may range from 7 to 15 percent. K factor is the proportion of daily traffic occurring during peak hours, expressed as a decimal. In the case of Baguio City, the K value is 0.09 categorized as an Urbanized area. The AADT is computed in terms of PCU (Passenger Car Units) to convert a mixed type of traffic into asingle unit, which is the car [12].

Given the AADT, the design hourly volume is computed as follows:

$$\mathbf{DHV = AADT \times K} \quad (1)$$

The Highway Capacity Manual (HCM), using letters A through F, with A being the best and F being the worst describes the conditions. Table 3 provides a guide on the basic capacity for various road types.

Table 3. Basic capacities for highways and urban streets

Level of Service	Volume-Capacity	Road Type	Carriage Width, (meters)	Basic hourly capacity in pcu in both directions
		Highway	<= 4.0	600
A	**Less than 0.20**		4.1 – 5.0	1200
B	**0.21 – 0.50**		5.1 – 5.5	1800
C	**0.51 – 0.70**		5.6 – 6.1	1900
D	**0.71 – 0.85**		6.2 – 6.5	2000
E	**0.86 – 1.00**		6.6 –7.3	2400
F	**Greater than 1**		2 x 7.0	7200 (expressway)
		Urban	~6.0	1,200
			6.1 – 6.5	1,600
			6.6 – 7.3	1,800
			2 x 7.0	6,700
Basic capacity for multilane highway				
No. of lanes per direction		2	3	4
Hourly capacity, pcu/lane		1800	1750	1700

Source: (Sigua, R (2008), Fundamentals of Traffic Engineering.

Where: [16]

LOS A: represents the zone of free flow. Here the traffic volume will be less, traffic will be experiencing free flow also. The drivers will be having the complete freedom to choose their desired speed. Even at maximum density, for this LOS the average spacing between vehicles is 167 m. Lane changes within the traffic stream, as well as merging and diverging movements, are made relatively easy.

LOS B: represents a zone of reasonably free flow. Free flow speeds are still maintained at this level of service. The driver's freedom to choose their desired speed is only slightly restricted. The lowest average spacing between vehicles is about 100 m. The effects of small incidents and point breakdowns are still easily contained.

LOS C: the presence of other vehicles begins to restrict the maneuverability within the traffic stream. Average speeds remain at or near the free-flow speed level, but a significant increase in driver vigilance is required at this level. The minimum average spacing between the vehicles is in the range of 67 m. Queues may be expected to form behind any significant blockage

LOS D: the average speeds begin to decline with increasing flows. Freedom to maneuver within the traffic stream is noticeably restricted. At this level, density deteriorates more quickly with the flow. The spacing between the vehicles is about 50 m. As the traffic stream has little space to absorb disruptions, minor incidents can lead to queuing of vehicles.

LOS E: define operation at capacity. At this level, the stream reaches its maximum density limit. There will be no usable gaps in the stream and even slight disruptions will cause a breakdown, with queues forming rapidly behind the disruption. Maneuvering within the traffic stream becomes extremely difficult.

LOS F: describes conditions in a queue that has formed behind a point of breakdown or disruption. As vehicles shuffle through the queue, there may be periods when they move quickly, and others when they are stopped completely. Thus this level of service is used to describe the point of breakdown as well, even though operations downstream of such a breakdown may appear good. It represents the region of forced flow and having low speed.

The highway capacity manual is a basis in the analysis of the performance of non-signalized intersections to find appropriate measures to minimize congestion and reduce the occurrence of traffic accidents. The method calculates the maximum flow in any given minor road traffic stream. It is then compared with the existing traffic flow to estimate the reserve capacity. The probable delay and level of service are determined based on this reserve capacity. The difference between the existing flow and capacity is termed reserve capacity. The magnitude of delay and level of service is directly related to this reserve capacity as shown in Table 4.

Table 4. Volume-Capacity ratio and LOS for intersections

Reserve capacity (PCU/hr)	Description	Level of Service
> 600	Free Flow, no traffic delay	A
251 - 600	Stable flow, very short traffic delay	B
176 -250	Stable flow, short traffic delay	C
126 – 175	Approaching unstable flow, average traffic delay	C to D
76 – 125	Long traffic delay	D
0-75	Unstable flow, very long traffic delay	E
< 0	Forced flow, congestion	F

Source: Sigua, R (2008), Fundamentals of Traffic Engineering.

Present TUCC values for Baguio City were compared with the established benchmark in Table 2 and the results were eventually used to forecast the values for transportation demand management solutions to minimize traffic congestion. The framework of the Transport Urban Carrying Capacity is shown in Figure 4.

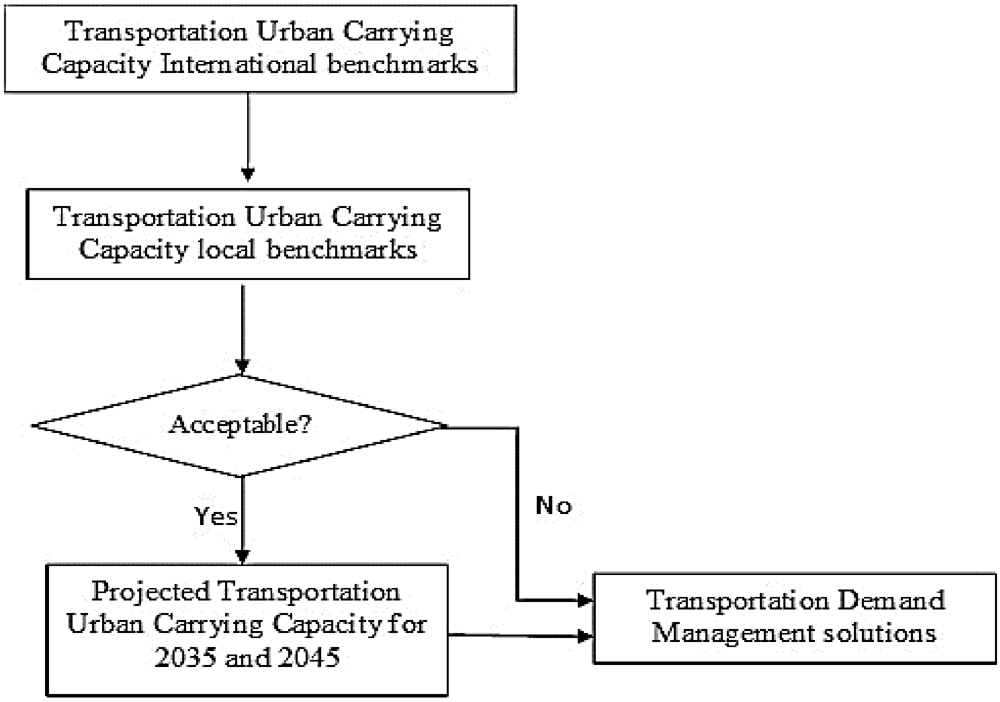

Figure 4. Transport Urban Carrying Capacity benchmark framework

4. DATA & RESULTS

This section shows the first part of the analysis by comparing the vehicle density benchmarks to Baguio City as shown in Table 5 and TUCC benchmarks for Baguio City and Manila as shown in Table 6. The second part in Table 7 examines the capacity of strategic roads and intersections in the Central Business District and key entry points to Baguio City.

Table 5. Vehicle density

	Key cities			
Vehicle Density	Tokyo	Singapore	Manila	Baguio City
Vehicle per square km (veh/km^2) (Source: Santiago, 2016)	967	1360	3677	**425**
Vehicle per km (veh/km) (Source: GIZ,2018)	202	230	1895	**171**
Vehicle per 1000 population (veh/1000 pop) (Source: MUCEP,2016)	Not available	Not available	94	**37**

Urban road capacity was established by HLURB (The Housing and Land Use Regulatory Board) at 2.4 km per 1000 population and 1.0 km per square km. In a study by MUCEP, Baguio has 1.0 km per 1000 population and 5 km per square kilometers. Although a road length of 1.0 km per 1000 population is much lower than the standard value, this may be an indication that residents prefer public transport which was validated by the public transportation ridership rate at key entry points to Baguio City and in the Central Business District at 70% and 60% respectively. The majority of the cities in the Philippines have road densities higher than the 1.0 km per square kilometer threshold that corresponds to the sufficiency of roads. A higher density indicates a comprehensive road network system. Baguio City has 5 kilometers per square kilometer which is quite high while Manila has the highest road density at 20 kilometers per square kilometer.

Table 6. Transport Urban Carrying Capacity

Evaluative Sectors and Indicators	Standards/ Benchmarks*	Manila	Baguio City
Urban road	2.4 km per 1000 population (source: HLRUB)	**0.26**	**1.0**
	> 1.0 km/km^2 (source: MUCEP2016)	**20**	**5**

The key entry points to the Central Business District of Baguio City are depicted in Figure 4 while the four major urban roads within the city are illustrated in Figure 5.

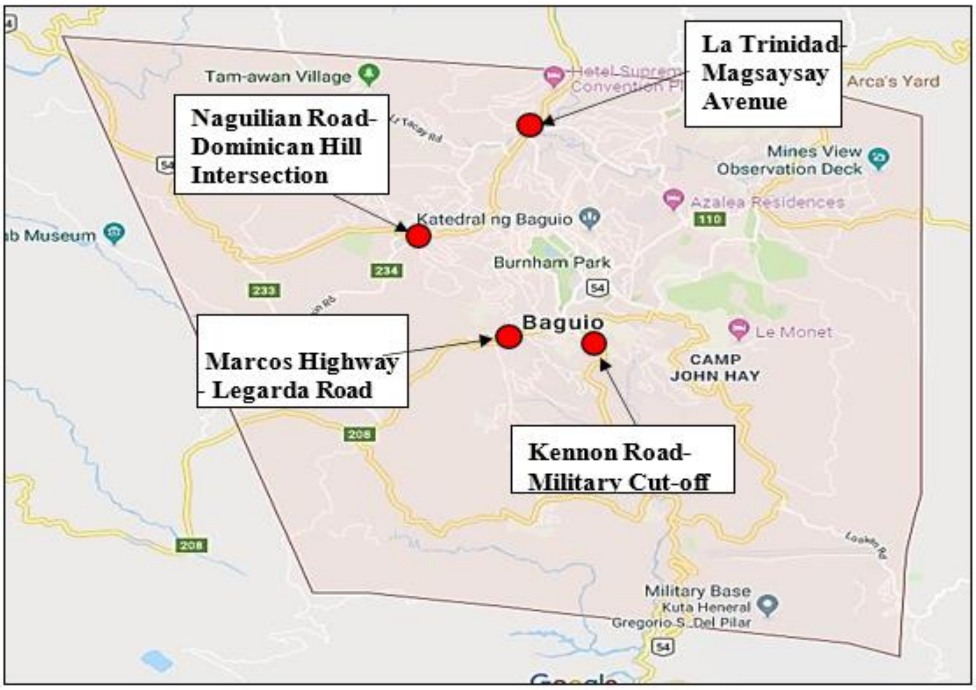

Figure 4. Key entry points to Baguio's Central Business District (Source: Google Map)

A survey was conducted for 8 hours at peak hour increments on February 9, 2015. The reserved capacity and volume over capacity ratio with its corresponding LOS (Level of Service) are shown in Table 7**.** The results show that key entry points have already reached their carrying capacity at the level of service E to F which indicates unstable movement of vehicles to frequent slow movement since 2015.

Table 7. Level of Service Capacity at key entry points (year 2015)

	Movement	Reserved Capacity (PCU/hr)	Level of Service
Naguilian Rd-Dominican Hill	Right Turn to Major Traffic	416	**LOS B**
Intersection	Left Turn off Major Road	310	**LOS B**
	Left Turn into Major Road	-273	**LOS F**
Marcos Highway-Legarda Rd	Right Turn to Major traffic	20.7	**LOS E**
Intersection	Left Turn off Major Road	56.9	**LOS E**
	Left Turn into Major Road	-142.4	**LOS F**
La Trinidad-Magsaysay	Right Turn to Major traffic	410	**LOS B**
Avenue	Left Turn off Major Road	413.5	**LOS B**
Intersection	Left Turn into Major Road	-918.1	**LOS F**
		V/C ratio	**Level of Service**
Kennon Road – BGH approach	Both directions	0.9744	**LOS E**

The carrying capacity at major roads was also analyzed by solving carriage width capacity. The major urban roads in the CBD are shown in Figure 5.

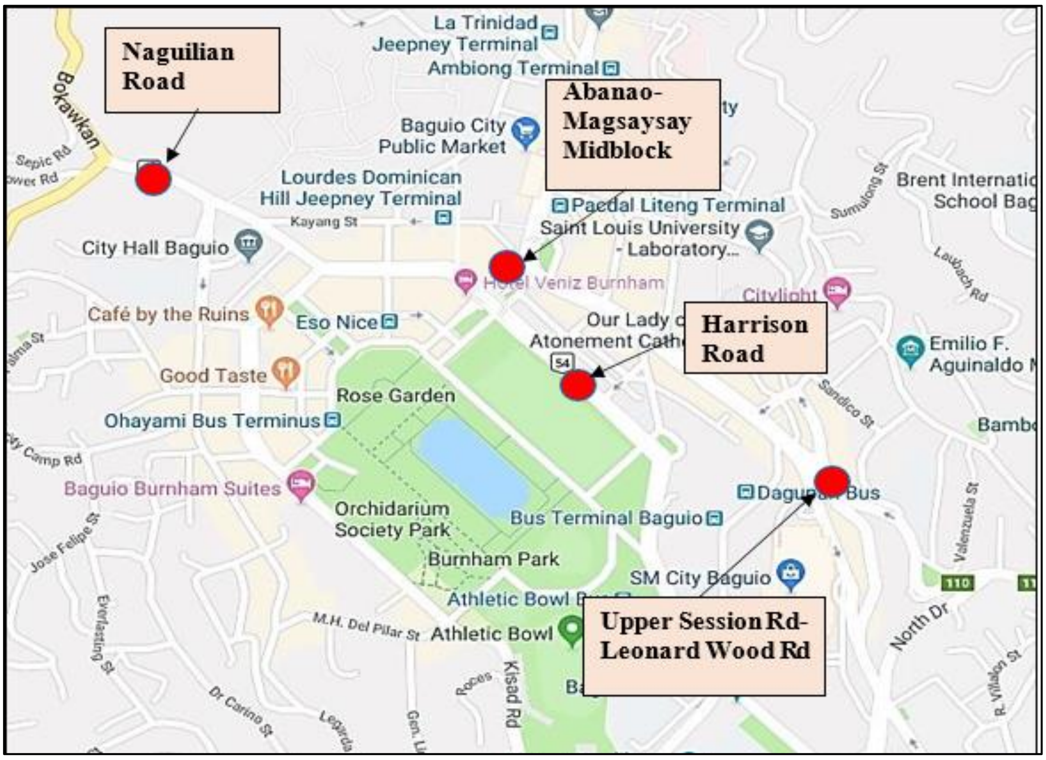

Figure 5. Key urban roads in Baguio City's Central Business District (Source: Google map)

A survey was conducted in 2 days for 16 hours in March of 2018. The volume over capacity ratio and its corresponding LOS (Level of Service) are shown in Table 8. The results of the major roads in the CBD are reaching their carrying capacity at LOS D specifically on the western part of the CBD.

Table 8. Level of Service capacity at major roads in the CBD year 2018

Central Business District		V/C ratio	Level of Service
Harrison Rd (Midblock)	Both directions	0.310448	LOS B
Naguilian Rd (Midblock)	Both directions	0.809167	LOS D
Abanao-Magsaysay (Midblock)	Both directions	0.833333	LOS D
Upper Session Rd-Leonard Wd. Rd Approach	Both directions	0.323433	LOS B

5. CONCLUSION & RECOMMENDATIONS

The Transport Urban Carrying Capacity of Baguio City has already reached its maximum carrying capacity specifically at key entry points to the Central Business District since 2015 as shown in Table 9.

Table 9. Transport Urban Carrying Capacity Issues and Challenges in Baguio City

Sector	Density (2016)	Forecasted Value	Issues and Challenges
Vehicle density (veh/km^2)	425 veh/km^2	**Year 2035** 1,039 veh/km^2 **Year 2045** 1,272 veh/km^2	Baguio's computed vehicle density on an average day is low compared to other highly urbanized cities here and abroad.
Vehicle density (veh/km)	171 veh/km	**Year 2035** 171 veh/km **Year 2045** 210 veh/km	Based on the international reference standards, the vehicle density for Baguio city appears to be low as compared to other key cities. The vehicle density is high and exceeds the carrying capacity of roads during weekends, holidays, and peak months because of the large number of tourist arrivals.
Vehicle density (veh/1000 population)	37 veh per 1000 population	**Year 2045** 63 veh/1000 population	
		Volume-Capacity Ratio & Level of Service	**Issues and Challenges**
		Naguilian Rd (Midblock) V/C= 0.80 **(LOS D)** **Abanao- Magsaysay** (Midblock) V/C = 0.83 **(LOS D)** **Kennon Rd- BGH Approach** V/C= 0.9744 **(LOS E)**	Some driver frustration; moderate delay to high levels of delay 0.90-1.00

	<u>Naguilian Rd-Dominican</u> (Left turn movement to Naguilian Rd) (-273 pcu/hr) (**LOS F)** **<u>Marcos Highway-Legarda Road</u>** (56.9 pcu/hr) **(LOS E)**	High level of driver frustration; high levels of delay. Convenience in driving through major intersections in the city is low with LOS E and F categories.
	La Trinidad- Magsaysay Ave (Left turn to Bokawkan) (-918.1 pcu/hr) **(LOS F)**	

<u>Note:</u> Level of service (LOS) is a qualitative description of how a facility is performing.

The principle of one-hundred small cuts states that "*just as a woodsman with a small axe can only chop down a large tree with many small blow*" [1]. An urban city can reduce its peak hour congestion only by applying many different remedies simultaneously in a coordinated approach as shown in Table 10.

Table 10. Transport Urban Carrying Capacity recommendations

Sector	Policy Recommendations
<u>MIDBLOCK</u> Level of service (LOS) of roads Volume over Capacity ratio	• Correct 3 lane-2-way highway to 4 lane-2 way to accommodate a 50-50% directional distribution especially at Ben Palispis highway (Marcos Highway) by constructing an elevated two-lane; two-way highway. • Prohibit On-Street Parking at major roads and convert to an extra lane. • Closely manage traffic situations in major arterial roads by deploying an adequate number of traffic enforcers.
<u>INTERSECTION</u> Level of Service (LOS) PCU (Passenger Car Units) per Hour	• Increase right turning radius at major intersection's key entry points particularly Naguilian-Lourdes intersection and Kennon Rd.-Military Cut-off intersection. • Prohibit on-street parking 45 m from the approach of major intersections • Closely manage traffic situations in major arterial roads by deploying an adequate number of traffic enforcers. • City government to prepare a Transport Master Plan in collaboration with DOTr and DPWH.

Adding a lane is not the solution as of this moment although this was a common practice by local government units for the past years. Additional lanes converted to three lanes are not a practice in the geometric design of highways because the middle lane usually brought confusion to drivers on who has the right of way that eventually leading to traffic congestion and probable road crash collisions as shown in Figure 6. Moreover, some widened roads were utilized as parking spaces by some drivers.

Figure 6. Marcos Highway (Ben Palispis Highway) to Baguio CBD (2018)

The solution to improving the capacity of roads is first, the local government must reclaim RRW (Road Right of Way) from establishments that violated the RRW as shown in Figure 7. Second, to increase the right turning radius at key entry points so that vehicles can maneuver a right turn movement easily and improve traffic flow as shown in Figure 8. Note the additional right turn lane in Figure 8.

Figure 7. Naguilian-Lourdes Intersection in August 2018 (Source: Google Maps, 2018)

Figure 8. Naguilian-Lourdes Intersection with an increased right turning radius (2019)

There is no local standard from which to compare the vehicle density situation in Baguio City. Based on international and local reference standards, the vehicle density for Baguio city appears to be low as compared to other highly urbanized key cities. However, it is quite apparent that vehicle density in the city reaches its highest peak and exceeds the carrying capacity of roads during weekends, holidays, and peak months because of the large number of tourist arrivals. Severe lack of parking space and public transport terminals in public places poses another serious problem. Urgent measures needed were recommended as follows:

- Establish a traffic engineering center similar to the Metro Manila Development Authority (MMDA)with qualified traffic engineers to monitor and document traffic congestion and road crash accidents yearly – this will enable a scientific approach to traffic problems besetting the city;

- Strictly implement zoning ordinances for the type of buildings to be constructed to anticipate trip productions and attractions in the future that contributes to additional traffic volume resulting in traffic congestion even during non-peak hours;

- Strictly implement TIA (Traffic Impact Assessment) studies as a requirement for a building permit – traffic Impact studies anticipate future traffic volume and plan necessary operational, geometric, or enforcement solutions.

- Explore the possibility of a multi-modal transport network such as walking, bicycle mode, consolidating PUJ staging areas to PUJ terminals linked to monorail systems, and aerial ropeway cable cars.

- Review and evaluate sidewalk capacity to enhance walkability in the CBD of Baguio.

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