Assessment on Road Capacity and Levels of Service at Highway Segment of Maharlika Highway in San Jose City, Nueva Ecija as Basis for Sustainable Traffic Improvement for Road Segment of Developing Cities

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Abstract: In urban areas, traffic congestion is a global issue. Traffic congestion in San Jose City, Nueva Ecija affects commuters, drivers, pedestrians, and community residents. The ramifications of congestion surpass inconvenience, impacting productivity, well-being, and environmental welfare. The strategy to mitigate congestion is to determine the road capacity and level-of-service of Maharlika Highway in San Jose City, Nueva Ecija using different parameters such as geometric characteristics, PHF, flow rate, and free-flow speed, as part of the approach for sustainable traffic improvement of road segments of developing cities. The level-of-service of Maharlika Highway in San Jose City, Nueva Ecija was computed under level-of-service D, and level-of-service F, characterized by a forced stop-and-go movement at an intersection that shows congestion and irregular traffic flow. To address the problem, a sustainable traffic management framework integrating policy measures, technological advancements, and shifts in behavior to cultivate optimized urban mobility frameworks was proposed in this study.

Keywords: Road Segments, Road Capacity, Level of Service, Developing Cities, Sustainable Traffic Management

1. INTRODUCTION

Urbanization, the increase of concentration in cities especially in developing cities, is rampant in the world as opportunities are high in urban areas. According to the CIA, the rate of urbanization in the Philippines annually is 2.04% meaning that the urban population increases by 2.04% per year. The rapid rate of urbanization in developing countries has increased the demand for transportation systems that can accommodate the increasing population concentration in urban areas. Increment in the number of motorized, private, and public transportation users is also putting the transportation systems in critical condition. Hence, a flexible and feasible transportation system is necessary. Highly urbanized and developing cities are prone to traffic congestion in the national road network.

Highway Road networks are one of the busiest roads in a country. With the continuous increase of population in the city, the highway road segments are affected by the increase of users. Furthermore, the increase in population results in an increase in vehicle users including private and public vehicles. With these, traffic congestion becomes rampant in urban areas which also leads to increased travel time for commuters and private vehicle owners. According to B.B. Ayantoyinbo et. al. (2015), traffic congestion and workers' productivity are inversely proportional to each other indicating that an increase in the rate of traffic congestion will result in low productivity.

Improvement of road segments of highway road networks can be a viable approach in promoting comfort, convenience, safety, and efficiency of road segments as well as decreasing traffic congestion. A sustainable traffic improvement shall be implemented for highway road segments to increase the road capacity and levels of service of a road segment. In line with these, road capacity and level of service are also variables in determining the efficiency of the road segment. The road capacity of a road segment refers to the ability of the road to accommodate several vehicles while the level of service refers to the quality of service that the end-users experience in terms of speed, convenience, comfort, and security of transportation facilities. Evaluation of road capacity and level of service are the two parameters used to determine the condition of traffic flow to improve the current traffic management on the highways. According to the Highway Capacity Manual (HCM), the level of service in multi-lane highways is categorized from A to F in which the best condition of traffic is classified as LOS A and the worst condition of traffic is classified as LOS F.

The study's objective is to develop a framework for sustainable traffic management derived from the evaluated data on the level of service, road capacity, and current traffic management of highway segments. Additionally, the study aims to compare the gathered data with the provisions and standards for developing cities. Road capacity will be measured by computing the number of vehicles per hour per lane in a given time. Using the gathered data the road capacity will be computed and will be used in classifying the level of service of the highway segment of Maharlika Highway.

2. METHODOLOGY

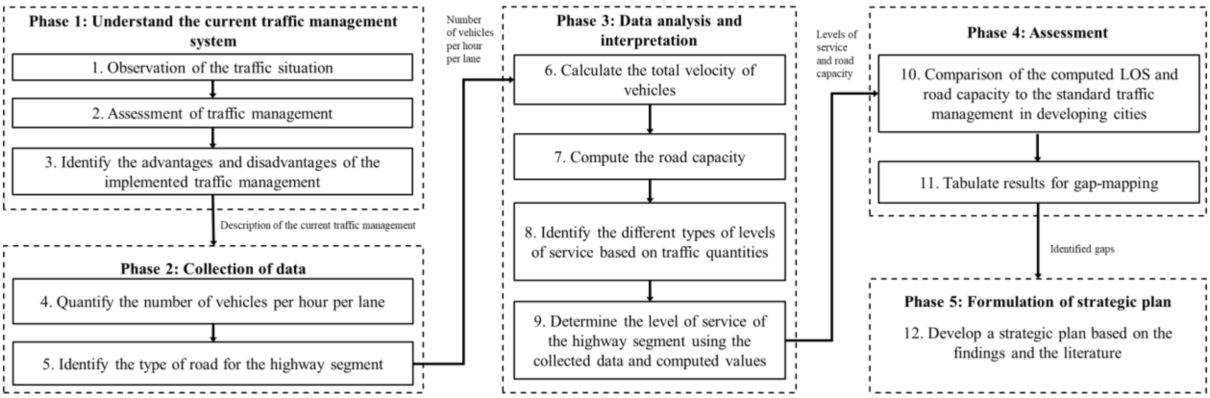

Figure 1. Conceptual Framework

2.1 Assessment of the current traffic management system

The main goal of the first phase of the research is to describe the current traffic management system including availability of the traffic control devices, implemented rules, and current traffic situation of a highway segment of Maharlika Highway in San Jose City, Nueva Ecija at a specified time. Through on-site observation, the researchers distinguished the traffic flow in the area and the number of vehicles in the highway segment to obtain the advantages and disadvantages of the currently implemented system.

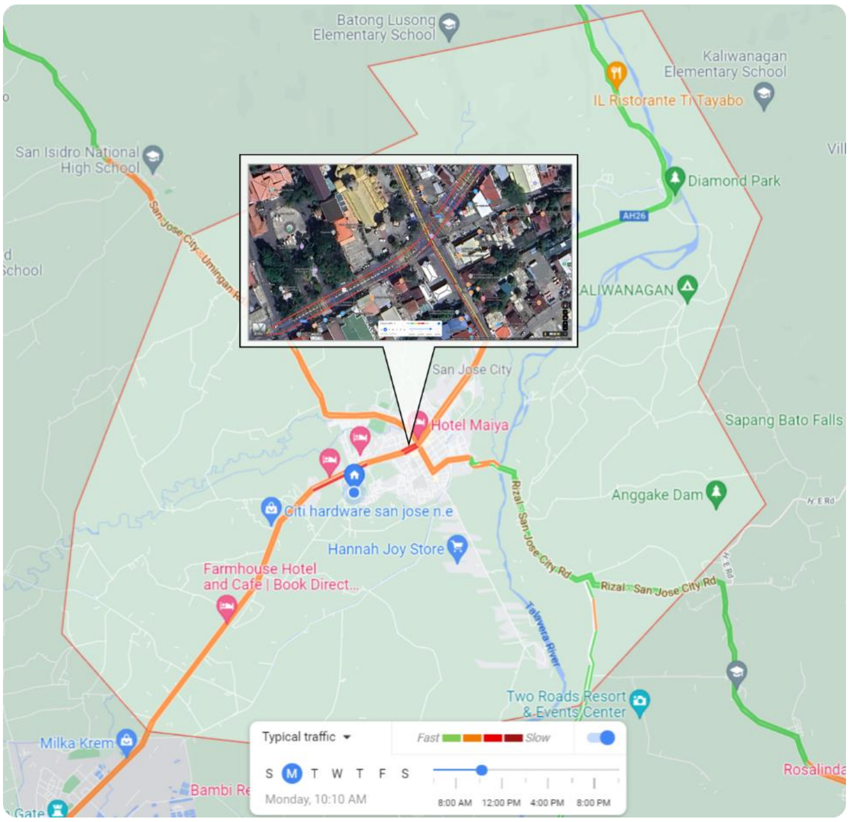

Figure 2. Location of road segment in the road network of San Jose City, Nueva Ecija

Figure 3. Typical Traffic (Monday, 5:00PM) at the road segment; red lines indicating slowest traffic situation, and red blocks indicating critical zones

2.2 Collection of Data

The second phase of the research involves the quantification of vehicles per hour per lane was done by counting the number of vehicles using the road for each lane. The researchers observed the number of vehicles that passed in the lane for a whole hour. In this phase, the researchers identified the type of the road segment using the road network classification from the Philippine National Road Network of the DPWH and the Highway Capacity Manual 7th edition.

2.3 Data Analysis Procedure

From the previous steps and data collection using mobile phone cameras, the velocity of vehicles was calculated by recording the time spent by the vehicles to pass from point 1 to point 2 which were determined by the researchers. The total velocity of vehicles was calculated by calculating the summation of the velocity of each vehicle that passed the road segment for the whole hour, as shown in the equation below.

Total Velocity:

$$V_{total} = \Sigma(d/t) \tag{1}$$

where:

V_{total} = Total Velocity
d = distance between two designated points
t = time from point 1 to point 2

Multilane Highway Free Flow Speed:

$$FFS = BFFS - f_{LW} - f_{TLC} - f_M - f_A \tag{2}$$

where:

FFS = Free flow speed (mph)
$BFFS$ = base free-flow speed (mph);
f_{LW} = adjustment for lane width (mph), 0.0 for lane widths ≥12 feet, 1.9 for lane widths less than 12 feet but ≥11 feet, and 6.6 for lane widths less than 11 feet but ≥10 feet;
f_{TLC} = adjustment for total lateral clearance (mph), from Table 1;
f_M = adjustment for median type (mph) = 1.6 for undivided highways and 0.0 for divided highways and highways with a two-way left-turn lane; and
f_A = adjustment for access point density (mph), from Table 2.

Multilane Highway Free Flow Speed:

$$BFFS = SPEED\ LIMIT + 7\ mi/h\ (for\ speed\ limit\ less\ than\ 50\ mi/h) \tag{3}$$

Table 1. Total Lateral Clearance Adjustment Factor f_{TLC} Values (mph) from Highway Capacity Manual

Four-Lane Highways		Six-Lane Highways	
TLC (ft)	Reduction in FFS, f_{TLC} (mi/h)	TLC (ft)	Reduction in FFS, f_{TLC} (mi/h)
10	0.4	10	0.4
8	0.9	8	0.9
6	1.3	6	1.3
4	1.8	4	1.7
2	3.6	2	2.8
0	5.4	0	3.9

Table 2. Adjustment for Access Point Density on Multilane Highway Segments from Highway Capacity Manual

Access Point Density (Access points/mi)	Reduction in FFS F_A(mi/h)
0	0.0
10	2.5
20	5.0
30	7.5
≥40	10.0

Note: Interpolation to the nearest 0.1 is recommended

Upon the collection of data on the type of road, total number of vehicles per hour per lane, total velocity of a vehicle, and the measure of time delay and turnover, the data was used to compute the road capacity to determine the volume-capacity ratio.

The levels of service of highway segments are determined in referral to the HCM 7th edition criteria for level of service. And using the gathered data in total velocity of vehicles, road capacity, and number of vehicles per hour per lane, the LOS of the highway segment was identified using the HCM 7th edition LOS Criteria.

Road Capacity:

$$C\ (\text{multilane highway segment}) = 1{,}900 + 20 \times (FFS_{adj} - 45) \tag{4}$$

where:

FFS = Free Flow Speed
$BFFS$ = Base Free Flow Speed
C = Capacity
FFS_{adj} = adjusted Free Flow Speed

Adjustment of Demand Value:

$$v_p = V/(PHF \times N \times FHV) \tag{5}$$

where:

v_p= demand flow rate under equivalent base conditions (pc/h/ln)
V = demand volume under prevailing conditions (veh/h)
PHF = peak hour factor (decimal), 0.95 is the suggested value
FHV = adjustment factor for presence of heavy vehicle (decimal)
N = Number of lanes in analysis direction (ln)

Adjustment for heavy Vehicles:

$$FHV=1/(1+PT \times (ET-1)) \tag{6}$$

where:

FHV = heavy vehicle adjustment factor (decimal)
PT = proportion of SUTs and TTs in traffic stream (decimal)
ET = passenger equivalent of one heavy vehicle in the traffic stream (PCEs), from Table 3.

Table 3. PCEs for General Terrain Segments from Highway Capacity Manual

Passenger Car Equivalent	Terrain type	
	Level	Terrain
ET	2.0	3.0

Estimating Density:

$D = vp/S$ (7)

where:

D = density (pc/mi/ln)
vp = demand flow rate (pc/h.ln)
S = mean speed of traffic stream under base conditions (mi/h), S=FFS

Table 4. Levels of Service from Highway Capacity Manual

LOS	Speed Range (mph)	Flow Range (veh./per/lane)	Density Range (Veh./mile)
A	Over 60	Under 700	Under 12
B	57-60	700-1100	20-12
C	54-57	1100-1550	20-30
D	46-54	1550-1850	30-42
E	30-46	1850-2000	42-67
F	Under 30	unstable	67

2.4 Assessment

The researchers conducted a direct comparison to existing standards of traffic management for a developing city. The gaps are identified through tabulated data shown in Table 9 discussed in section 4.3.

2.5 Formulation of Strategic Plan

From the assessment and with the review of literature, researchers formulate strategic plan to mitigate traffic congestion and other issues concerning the road segment. The strategic plan follows the standard traffic management in developing cities as an effort for sustainable traffic management.

3. RESULTS AND DISCUSSION

Table 5 presents the geometric data essential for evaluating road capacity and determining the level of service of two road segments: "RS_{ideal}" for the Ideal Road Segment for Maharlika Highway and "RS_{actual}" for the surveyed Road Segment of Maharlika Highway in San Jose City, Nueva Ecija. The geometric characteristics include lane width, number of lanes per direction, median type, total lateral clearance, and access point density. Each of these factors plays a crucial role in traffic management and planning for sustainable improvements.

Table 5. Geometric Data for Road Segments

Segment Name	Lane Width (mi/h)	Number of Lane per Direction	Median Type	Total Lateral Clearance (ft)	Access Point Density (mi/h)
RS_{ideal}	12	2	Divided	2	1.5
RS_{actual}	12	2	Divided	2	1.5

Both road segments feature a lane width of 12 feet. This width is standard for highways and is designed to accommodate various types of vehicles, including large trucks and buses. Adequate lane width is crucial for ensuring the safety and efficiency of traffic flow. Wider lanes allow for easier maneuvering and can help reduce the likelihood of collisions, especially in high-traffic areas.

Each segment has two lanes per direction. This configuration supports a moderate to high volume of traffic, facilitating better traffic distribution and reducing congestion during peak hours. Having multiple lanes in each direction is beneficial for maintaining a steady flow of vehicles and minimizing delays caused by lane changes and merging traffic.

Based on the Highway Capacity Manual 7th Edition (HCM), the median type for both segments is divided, indicating the presence of a physical separation between the two directions of traffic. A divided median significantly enhances safety by preventing head-on collisions and can also improve traffic flow by reducing interruptions from cross-traffic movements. This separation is particularly important on busy highways where high-speed travel is common.

Both segments have a total lateral clearance of 2 feet. Lateral clearance is the space between the edge of the travel lane and any roadside obstacles. Adequate lateral clearance is important for vehicle maneuverability and provides a safety buffer in case of emergencies. It allows vehicles to recover safely if they veer off the road and provides space for road maintenance activities without disrupting traffic flow.

The access point density for both road segments is 1.5 access points per mile. This metric indicates the frequency of intersections, driveways, and other entry or exit points along the road. A higher access point density can lead to increased potential for traffic conflicts, affecting safety and traffic flow efficiency. Managing access point density is essential for minimizing disruptions and maintaining smooth traffic flow, particularly in urban areas where frequent access points are common.

In summary, the geometric data provided in Table 5 offers a comprehensive overview of the physical characteristics of the road segments on Maharlika Highway. Understanding these characteristics is vital for planning and implementing traffic management strategies that enhance safety, improve traffic flow, and support sustainable development in San Jose City, Nueva Ecija.

3.1 Peak Hour Factor (PHF) and Speed Limit Determination

Table 6 presents detailed data on the Peak Hour Factor (PHF), flow rate, and heavy vehicle adjustment factor for two road segments on Maharlika Highway in San Jose City, Nueva Ecija. These factors are crucial for determining the speed limit and overall capacity of the road segments, which are essential for sustainable traffic improvement.

The flow rate, measured at 1180 vehicles per hour per lane for both road segments, indicates the volume of traffic during peak hours. This data is fundamental for calculating the PHF, which is a measure of the variability in traffic flow throughout the day. A PHF of 0.95 for both segments suggests that traffic flow remains relatively stable during peak hours, with minimal fluctuations, impacting the overall capacity and speed limit considerations.

The proportion of heavy vehicles, recorded at 78.67% for both segments, is significant as heavy vehicles have different traffic characteristics compared to light vehicles. This proportion is used to calculate the heavy vehicle adjustment factor, which accounts for the impact of heavy vehicles on traffic flow and capacity. A higher proportion of heavy vehicles can reduce the overall capacity of the road segment, affecting speed limit determination.

The heavy vehicle adjustment factor is 0.91 for RS_{ideal} and 0.94 for RS_{actual}. This adjustment factor is crucial for adjusting the capacity of the road segment to account for the presence of heavy vehicles. A higher adjustment factor indicates a greater impact of heavy vehicles on the capacity of the road segment, which can influence speed limit considerations.

Overall, these factors play a crucial role in determining the speed limit and overall capacity of the road segments on Maharlika Highway in San Jose City, Nueva Ecija. They provide valuable insights into the traffic conditions and help in planning sustainable traffic improvements to enhance traffic flow and safety in developing cities.

Table 6. Flow Rate, PHF and Heavy Vehicle Adjustment Factor

Segment	Flow Rate (pc/h/ln)	PHF	Proportion of Heavy Vehicle	Heavy-Vehicle Adjustment Factor
RS_{ideal}	1180	0.95	78.67	0.91
RS_{actual}	1180	0.95	78.67	0.94

3.2 Level of Service and Capacity Computation for the Segments

Table 7 displays the calculation of Free Flow Speed (FFS) for the segments, highlighting the process of determining FFS based on various parameters. These parameters include Total Lane Capacity (TLC) and adjustment factors such as Lane Width (fLW), Median (fM), and Alignment (fA).

The parameters of the geometric characteristics of the segments are given in Table 7. In the ideal segment, the fTLC is recorded at 3.21, with adjustment factors of fLW = 0, fM = 1.5, and fA = 0. Using the formula FFS = BFFS - fLW - fTLC - fM - fA, the FFS is calculated as 27.15 for this segment. Similarly, for the actual segment, the fTLC and fLW values remain consistent at 3.21 and 0, respectively, while the fM and fA values differ, with fM = 1.5 and fA = 0. Consequently, the FFS for RS_{actual} is also determined as 14.06.

Table 7. Free Flow Speed Computation

Segment Name	*Flw*	*fTLC*	*fM*	*fA*	*FFS*
RS_{ideal}	0	3.21	0	1.5	27.15
RS_{actual}	0	3.21	0	1.5	14.06

Table 8 presents the computation of Level of Service (LOS) and Capacity for the two segments based on the Flow rate (vehicles per hour per lane), Free Flow Speed (FFS), and

Density.

For RS_{ideal}, with a Flow rate of 1180 vehicles per hour per lane and FFS of 27.15, the Density is calculated as 1180 / 27.15 = 43.54 vehicles per kilometer per lane. This Density corresponds to LOS D, which indicates unstable flow conditions and a high likelihood of congestion. The Capacity for this segment is computed as 1543 vehicles per hour per lane.

In comparison, RS_{actual}, with the same Flow rate of 1180 vehicles per hour per lane but a lower FFS of 14.06, the Density is calculated as 1180 / 14.06 = 84.04 vehicles per kilometer per lane. This higher Density corresponds to LOS F, indicating severely congested conditions and low speeds. The Capacity for this segment is computed as 1281 vehicles per hour per lane.

Table 8. Level of Service and Capacity Computation for the Segments

Segment Name	Flow rate (pc/h/ln)	FFS	Density	LOS	Capacity
RS_{ideal}	1180	27.15	31.99	D	1543
RS_{actual}	1180	14.06	49.86	F	1281

These results suggest significant differences in traffic conditions between the two segments, with RS_{ideal} functional at a lower capacity but with more stable flow conditions compared to the RS_{actual}, which is operating at or near capacity and experiencing severe congestion. Such insights are crucial for transportation planning and management efforts to address congestion and improve traffic flow along these road segments.

3.3 Gap Mapping for Traffic Management

Table 9 shows the observed factors that directly affects traffic conditions in the road segment of Maharlika Highway in San Jose City. The approaches presented are adopted from various literature and enhanced existing traffic management strategies.

Table 9. Observed Road Segment Condition, factors, and approach

Variable	Observed Segment	Ideal Segment	Target	Present factors	Possible Approach
Level of Service	LOS-F	LOS-D	LOS-D to LOS-B	PUV Loading zones along the segment	Relocation of Loading Zone for PUVs
Road capacity	1281	1543	Minimum of ideal	Roadside Parking	Strengthen implementation of parking rules and allocation of parking areas to optimize road capacity
Free Flow Speed	14.06	27.15	Minimum of ideal	Tricycle operators' queue	Reformation on city tricycle operations
Density	49.86	31.99	Maximum of ideal	All time access for all vehicle type	Coding system for vehicle types and plate number

Figure 4. PUVs loading zone along road segment

Figure 5. Tricycle operators waiting for passengers in front of cathedral along the segment

Figure 6. Roadside parking of vehicles in front of establishments along the road segment

According to Silvano, et al. (2020), the mean free flow speed is strongly influenced by several road characteristics such as land use, parking, and the presence of sidewalks. The presence of roadside parking along the road segment is one of the commonly known factors of the impeded traffic flow, reducing the physical capacity of the road itself. Additionally, the road segment's location is relatively near establishments, schools and churches that result to large attraction of pedestrians crossing, walking along or dropping off at their convenience. Upon reviewing the literature and existing management system, the researchers were able to construct a framework that theorizes the potential of improved traffic condition on the road segment.

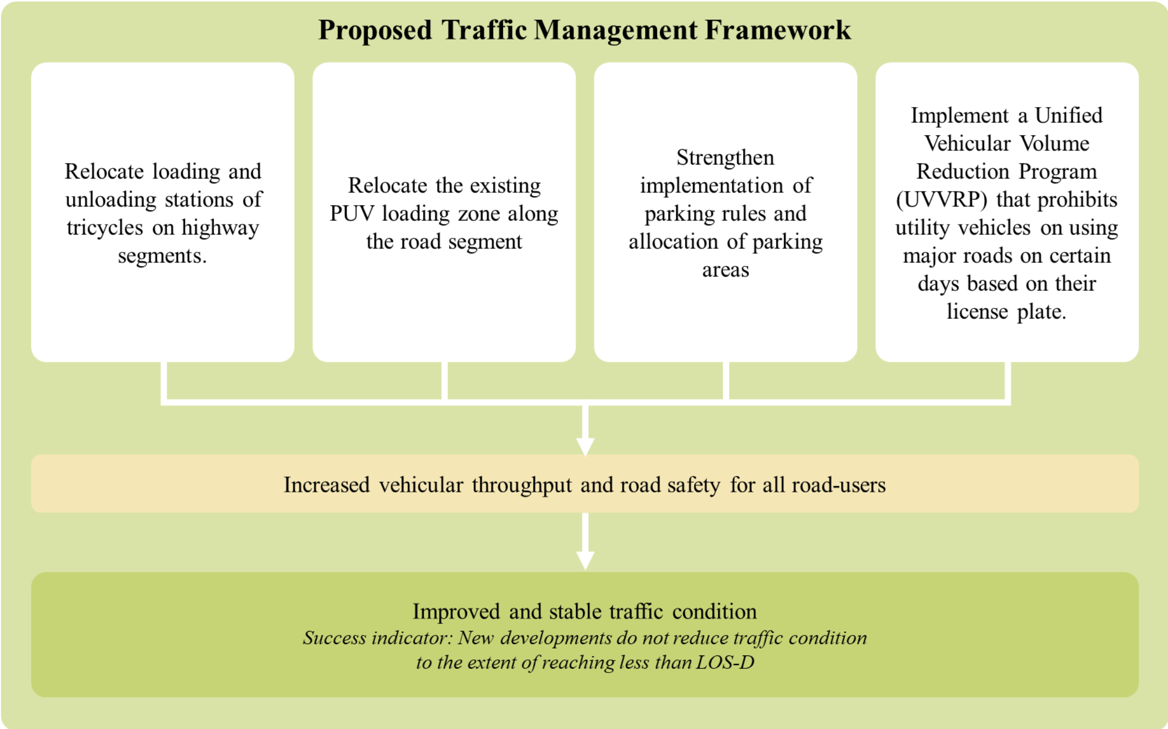

Figure 7. Proposed Traffic Management Framework

4. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

4.1 Summary of Findings

The road segment of Maharlika Highway in San Jose City, Nueva Ecija has an approximate length of 130 meters (m) with a width of 12 ft (approximately 4 meters) which is the minimum requirement by the 2022 7^{th} Edition Highway Capacity Manual (HCM). The segment has a median type of division. The parameters needed in determining the level of service of the road segment are Free Flow Speed (FFS), Basic Free Flow Speed for Multilane Highway (BFFS), Peak Hour Value (PHV), the adjustment factor for the presence of heavy vehicles (FHV), Road Capacity (C), and Density (D). The access point density is 1.5 access points per mile. The flow rate for the segment is 1180 vehicles per hour per lane. The proportion of heavy vehicles is recorded at 78.67% for both ideal and actual segments. In determining the capacity of the segment, adjustments to the Free Flow Speed with Total Lane Capacity (TLC) and adjustment factors such as Lane Width (fLW), Median (fM), and Alignment (fA). Highway Capacity Manual (2022) quoted that there are no fixed speed limits designated on highway segments, however, the BFFS for multilane highways can still be obtained through estimation using the statutory speed limit of the area and the condition given under the manual. For areas with the speed limit of 50 mi/h and higher, 5 mi/h can be added to the statutory speed limit, and plus 7 mi/h for areas with the speed limit of less than 50 mi/h. Therefore, the BFFS of the highway segment of Maharlika Highway in San Jose City can be based from the highway speed limit of 40kph according to section 35 of RA 4136.

In the data sheet for RS_{ideal}, the BFFS is assumed to be the speed limit of 40kph (24.86 mph) with an additional 7 mph for a speed limit of less than 50 mph. The TLC value is 3.21, the fM value is 0, and the fA value is 1.5 resulting in a value of 27.15 for FFS. The calculated capacity of the segment is 1543 vehicles per hour per lane. With 1500 as the demand volume, the VP is computed as 868.42 with adjustments from PHF and N (number of lanes in analysis) with values of 0.95 and 2, respectively. The flow rate is 1180 vehicles per hour per lane with a density of 43.54 vehicles per kilometer per lane which corresponds to LOS D. In the data sheet for RS_{actual}, the FFSs are measured in actual which ranges from 5.08 mph to 22.70 mph. The TLC value is 3.21, the fM value is 0, and the fA value is 1.5 resulting in a value ranging from 9.80 mph to 27.41 mph for BFFS. The calculated capacity of the segment ranges from 1101.7 vehicles per hour per lane to 1454.1 vehicles per hour per lane. The demand value is measured in actual which ranges from 932 vehicles per hour to 1741 vehicles per hour, the VP is computed as 511.05 to 935.79 with adjustments from PHF and N with values of 0.95 and 2, respectively. The flow rate is 1180 vehicles per hour per lane with a density of 49.86 vehicles per kilometer per lane which corresponds to LOS F, less than the LOS based on the HCM.

The identified factors that are known to have direct impact on traffic condition are PUV loading zones along the segment, roadside parking, tricycle operators' queue, all time access for all vehicle types, as well as the land use along the road segment including existing establishments, schools, churches, and public recreational places that attract large number of pedestrians who similarly share road-use with passing vehicles.

4.2 Conclusions

Based on the results obtained, ideally, with the number of vehicles utilizing the segment of Maharlika Highway at San Jose City, Nueva Ecija should have at least LOS-D, and but the actual data resulted to LOS-F characterized by a forced stop-and-go movement at an intersection which shows that there is congestion and irregular traffic flow.

These unstable traffic conditions were mostly caused by the observed scarce traffic controlling devices, unorganized pick-up and dropping-off stations and huge numbers of passengers along the area. For this reason, this study recommends a sustainable traffic management system framework that can help improve the road traffic conditions of the highway segment of Maharlika Highway at San Jose City, Nueva Ecija. This sustainable traffic management system framework includes known concepts from the literature, adopting Intelligent Transportation System, SMART Parking system, socially just and politically balanced approach to land-use specifically on parking and loading/unloading zones.

Additionally, maintenance and installation of additional traffic lights on the intersection could also be one of the expected solutions to help the enforcers to organize the flow of vehicles passing through the given intersection in this study.

4.3 Recommendations

This study is limited to the observation of the highway segment of Maharlika Highway in the City of San Jose, Nueva Ecija. This study is focused on the determination of road capacity and levels of service for the formulation of strategic traffic improvement as reviewed from the literature.

The researchers of this study suggest considering highway segments with higher traffic congestion. Additionally, increase the duration of the study to ensure the reliability of the data and it is encouraged to focus on sustainable traffic improvement research for more comparable studies and to determine the most appropriate sustainable traffic improvement for highway segments. Furthermore, utilize simulation software for a data-driven validation of the sustainability of the proposed strategic traffic improvement framework. Lastly, explore the impacts of signalized and unsignalized intersections to the level of service of a road segment to determine the appropriate measures for improvement for the intersection and road segment.

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