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Original article

Evaluation and Redesign of Major Intersections in Monrovia for Efficient Traffic Flow: Case Study of Vomoma Intersection

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Abstract

The migration of rural Liberians to Monrovia in pursuit of employment opportunities, higher education, basic government, and commercial services has led to an annual population growth rate of 3.42%. This has led to an increase in the number of vehicles in the city causing huge traffic congestion on roads in the city, intersections experience frequent congestion, with vehicles queuing up and experiencing delays due to the stop-and-start flow of traffic. This research focuses on the traffic congestion situation at the Vomoma intersection as a case study for a broader evaluation of the traffic congestion at major intersections in Monrovia. The research assessed the existing congestion level and proposed a redesigned three-leg intersection in accordance with AASHTO 2018 guidelines for intersection design. The proposed design presents several features to eliminate traffic congestion and improve traffic flow. This includes the addition of an auxiliary lane, which serves a dual purpose by separating turning vehicles and facilitating smoother traffic movement. Channelization measures, such as the use of a median are introduced to streamline traffic, and an integrated zebra crossing to enhance pedestrian safety, particularly for individuals with special needs (disability).

Keywords: ***Traffic congestion, Intersection, AASHTO 2018, Geometric design.***

1. Introduction

1.1. Traffic congestion

Traffic jams are a common problem worldwide due to the higher number of people living in urban areas, more cars on the road, and the growth of services like ridesharing and delivery. It is among the most common transportation issues globally, particularly in large cities. Congestion can occur when there is a sudden increase in traffic due to the large number of vehicles on the road, which causes delays in the flow of traffic (Afrin & Yodo, 2020).

Road traffic accidents continue to be a significant issue worldwide, with a growing number of fatalities and injuries. The continuing pattern suggests that this problem will likely continue well into the future, cause by poor global traffic management. The lack of comprehensive understanding regarding the scale of this problem, coupled with the associated risks of fatality and injury, severely constrains our capacity to implement targeted and effective interventions. Additionally, the widespread issue of under-reporting road traffic deaths in many parts of the world has led to a decrease in the perceived importance of addressing road safety, causing it to be considered a less urgent priority as compared to many other public issues. Therefore, it is essential to acknowledge the underestimated nature of the issue in order to increase understanding of the dangers and emphasize the importance of global road safety efforts (Therapy et al., 2018).

Worldwide, urban areas are facing a significant traffic problem that could potentially hinder their ability to efficiently regulate and oversee the flow of vehicles. The situation has become more complex in developing countries due to a combination of factors that have contributed to the problem (Jain et al., 2012):

- **Unplanned cities:** Typically, roads are narrow and inadequately built. As cities expand without proper planning, there is a lack of consideration for increasing the capacity of roads, thus leading to numerous traffic congestion on roads. Additionally, the rapid increase in the number of vehicles in many developing nations has led to the ineffectiveness of traditional traffic control strategies.
- **Poor discipline:** Significant issues arise from the insufficient training of drivers in adhering to proper lane discipline, particularly evident at major intersections. This deficiency exacerbates the congestion already prevalent at these crucial points. In addition, drivers often ignore red lights and obstruct intersections, leading to an increase in traffic congestion. The lack of enforcement of traffic laws further complicates the situation as it does not provide

drivers with enough motivation to stay within the rules and regulations imposed on them.

- **Alternate traffic routes:** The number of vehicles in large cities with rapidly growing economies has increase substantially. Many of these urban areas lack efficient public transportation options, forcing locals to depend on their own cars for transportation. This problem is made worse by a common societal prejudice that views owning a private vehicle as a sign of wealth, while public transportation is unfairly linked to lower income groups.
- **Outdated management practices:** Disorderly driving behavior is a common outcome of unmanned traffic intersections. In spite of being controlled by a police officer or traffic light, intersections have a tendency to prioritize the flow of traffic in the direction with the most congestion. These practices allowed for mismanagement on congested roads and accelerated traffic flow due to the absence of effective traffic management strategies.
- **Limited financial resources:** Establishing a scalable traffic management infrastructure demands substantial investment to accommodate rising traffic volumes. This infrastructure includes real-time traffic data measurement, analysis, congestion detection improvement, immediate congestion resolution, and forecasting future congestion scenarios. In many developing countries where corruption and bureaucracy hinder progress, multiple obstacles impede the allocation of funds for such expansive initiatives. While increasing road capacity is advantageous, it alone does not serve as the sole remedy for traffic problems. The implementation of intelligent flow-control techniques within the existing infrastructure presents an opportunity to improve the operational capacity of current road systems.

1.2. Environmental Impact of Traffic Congestion

Traffic congestion is now the main and urgent transportation issue that major cities in developing countries face daily. The significant increase in the number of vehicles on the road in cities like Monrovia over the past ten years has worsened the issue, leading to a more than 50 % decrease in average speeds on roadways. Traffic congestion has other consequences beyond the obvious ones of increased travel time and energy consumption: it also leads to pollution, reduces productivity and has societal consequences. When traffic is heavy, cars are on the road for longer periods of time, either stopped or moving very slowly. This can result in more frequent instances of speeding up and slowing down, which could cause higher levels of emissions. (Bharadwaj et al., 2017).

Intersections are frequently identified as significant points for elevated vehicular emissions within the road network, primarily attributed to the frequent acceleration and deceleration events of vehicles. The prolonged duration of congestion correlates with a heightened consumption of fuel, leading to increased vehicular emissions, and pollutants such as carbon monoxide (CO), carbon dioxide (CO2), hydrocarbons (HCs), and nitrogen oxides (NOx). The levels of emissions and fuel consumption are inversely linked to a reduction in congestion. It is crucial to note that addressing and ameliorating traffic congestion can have a positive impact on mitigating overall emissions (Mahmudah & Anjasmoro, n.d.).

The connection between emissions and various factors such as traffic flow, vehicle characteristics, and road intersection design is intricate. These elements consist of the type of vehicle, its size, age, engine health, condition of emission control products, engine features, maintenance routines, and weight. The size of the engine is crucial in determining just how emission control devices function, and older vehicles with poor maintenance are major factors in the rise of emissions in various vehicle types. The type of fuel used in a vehicle has a direct impact on the emissions released from the vehicle's exhaust. The extent of emissions released at intersections is influenced by a combination of factors, showcasing the challenges in managing and decreasing vehicle emissions (Pandian et al., 2009). Enhancing the flow of traffic and alleviating congestion can reduce the overall emissions produced by vehicles at intersections, promoting a transportation system that is both environmentally sustainable and efficient.

1.3. Monrovia Traffic Congestion

Monrovia, the capital and largest city in Liberia is situated on Bushrod Island, bordering the Mesurado River. According to the 2022 census, the city's population is estimated at 1,678,020. This marks a significant increase from the 1950 population of 35,150, indicating an annual growth rate of 3.42%. This demographic rise is attributed to the influx of individuals from other regions seeking employment opportunities and access to higher education. Monrovia serves as the central hub for major government offices, both local and international organizations, university campuses, and a thriving commercial sector. Consequently, the city experiences a continuous influx and outflow of individuals engaged in various activities, including work, education, and commerce (Plan et al., n.d.). The primary mode of transportation in Monrovia is by road, the existing infrastructure struggles to provide adequate options for the movement of people and goods.

Figure 1. Map of Monrovia (Async_usersync, n.d.)

1.4. Root Causes of Monrovia's Traffic Congestion

The mounting challenge of traffic congestion in Monrovia is a direct result of the rapid growth in vehicle ownership and utilization. The current road infrastructure is inadequate to cope with the increasing number of vehicles on the city's streets. The severity of traffic congestion is particularly at major intersections along Tubman Boulevard, such as Vamoma, Old Road Junction, and Nigeria House Junction, etc., where the existing road capacity falls short of facilitating smooth traffic flow.

Several factors contribute to this traffic congestion, primary among these are the insufficient public education provided to drivers, lack of effective traffic management, inefficient traffic signal coordination, poorly designed intersections, and lack of proper parking facilities. Additionally, the lack of clear and visible traffic signs and road markings exacerbates the problem, moreover, hindering the efficient movement of vehicles.

- **Poorly designed intersections**

The existing intersections along Tubman Boulevard, Monrovia's busiest road, were not designed to effectively manage the current high volume of traffic. These intersections lack the necessary capacity, leading to prolonged wait times, queues, and disruptions in traffic flow. Consequently, bottlenecks, delays, and mounting frustration among drivers and pedestrians have become prevalent issues. The heightened risk of accidents is another significant consequence, stemming from confusing layouts and inefficient traffic signal timing that create stop-and-go patterns. Compromised pedestrian and cyclist safety further exacerbates these hazards. Beyond Tubman Boulevard, the impact ripples to surrounding city roads, resulting in increased congestion. Furthermore, the associated rise in fuel consumption and emissions raises environmental concerns.

- **Delay in maneuvering time**

The delay in maneuver time significantly hampers traffic flow, leading to congestion, reduced output, and extended queues at intersections along Tubman Boulevard. The delay fosters frustration among drivers, prompting riskier behaviors and disrupting signal coordination, causing a ripple effect of congestion.

- **Poor signalization of intersections**

In Monrovia, inadequate signalization at intersections is significantly impacting traffic flow and road safety. Drivers find it challenging to navigate these intersections, leading to prolonged wait times for vehicles. The inconsistency or lack of clarity in signals disrupts the smooth flow of traffic, prompting drivers to make unprecedented movements. These disruptions often result in bottlenecks and delays, increasing the risk of accidents, particularly at high-traffic intersections. Pedestrians navigating these intersections face increased hazards due to the compromised safety measures.

2.0. Methodology

2.1. Survey Data

The road survey data was obtained by extracting data from the version of Google Earth Pro. To pinpoint the Vamoma intersection, GPS coordinates were input, and the intersection was automatically located. Utilizing the Zoom and Pan tools, the exact location was manually navigated for a detailed examination of the intersection points. The Placemarks and Label button, represented by a pin icon, was used to identify and mark each leg of the intersection. Survey points were gathered at 20-meter intervals, with a 3.5-meter width per carriageway, covering a 100-meter stretch on Tubman Boulevard and 50-meter on the Airfield Road leg of the intersection.

Google Earth Pro provided data, including point coordinates and elevations, which were saved in KMZ file format. The survey data from Google Earth Pro was then transferred to Global Mapper for the conversion of the KMZ data to a CSV file, displaying easting (x), northing (y), and elevation (z) coordinates.

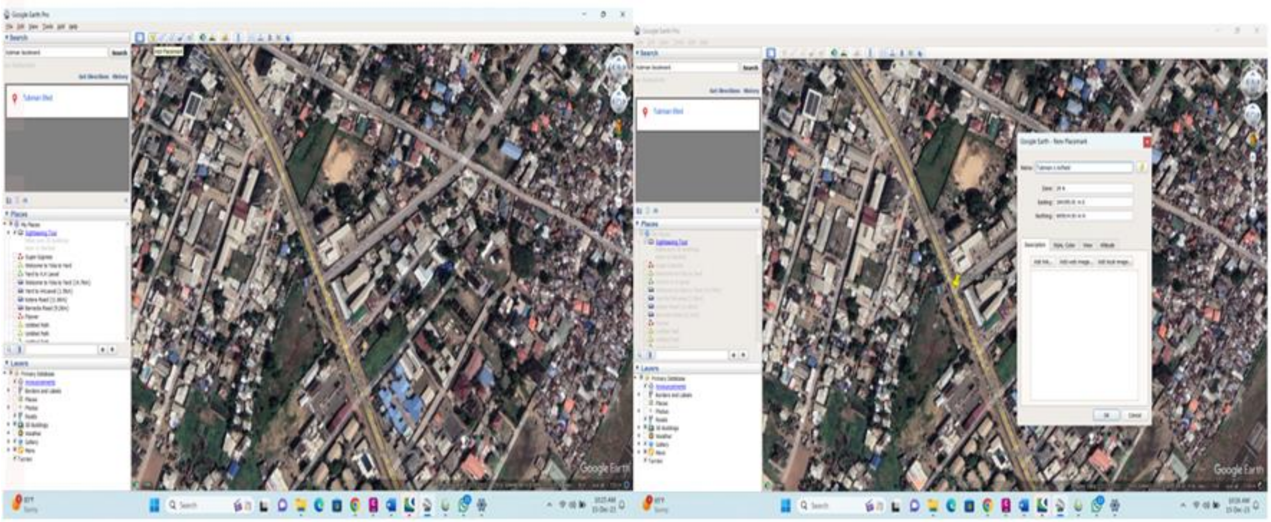

Figure 2. View Google Earth Pro Point Marking

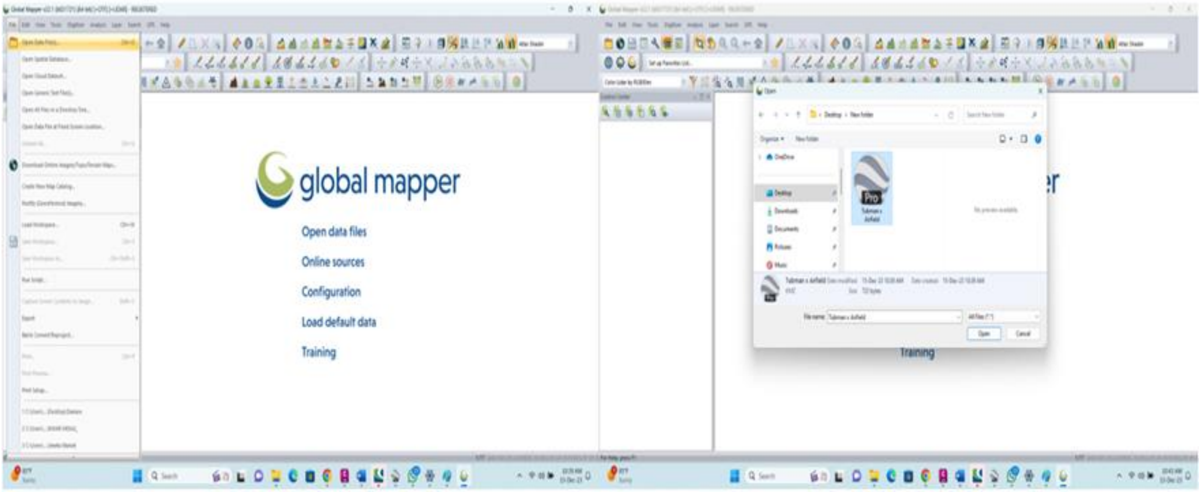

Figure 3: Overview of Inputting Data in Global Mapper

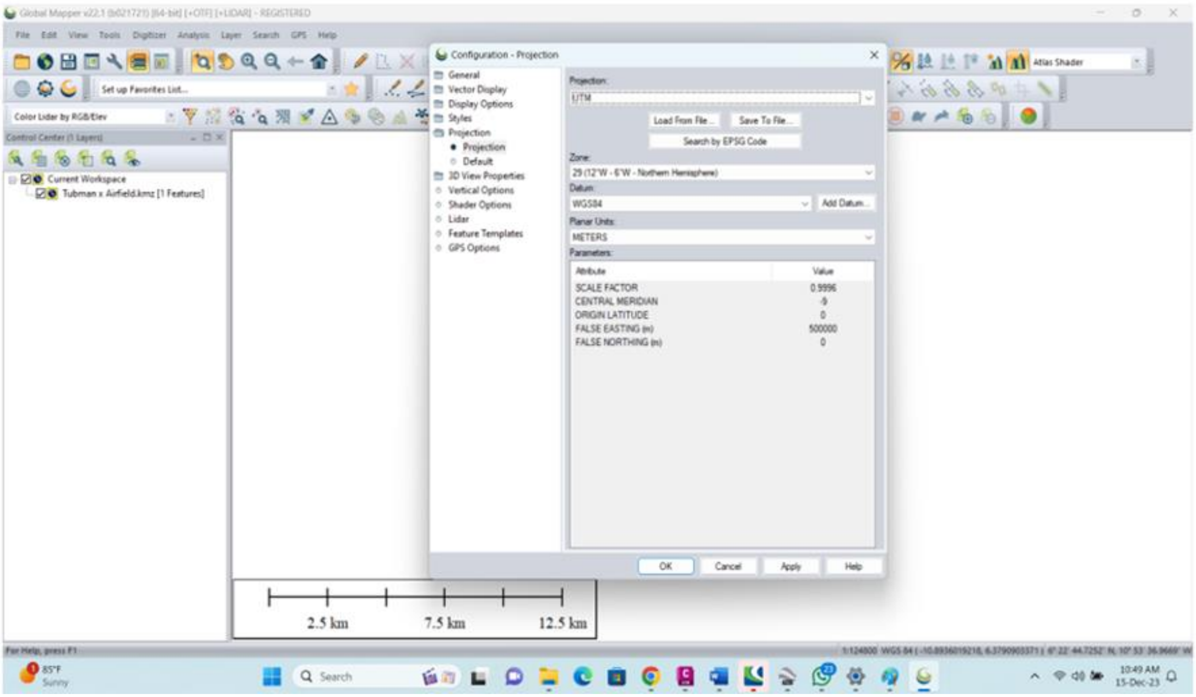

Figure 4. Overview of Inputting Data in Global Mapper

2.2. Geometric Design per AASHTO Green Book Standards using AutoCAD Civil 3D

The survey data in CSV format, with easting (x), northing (y), and elevation (z) were inputted into Civil 3D, this made it easier to show the existing condition of the intersection and the proposed design of the intersection. An image of the intersection from Google Earth was uploaded into Auto Civil 3D. Using polylines, the current carriageway configuration of the three-legged intersection was drawn.

a. Existing Road Corridor b. Proposed Road Corridor

Figure 5: Google Earth Image in Civil 3D with Existing and Proposed Road Corridor

The three-legged channelized intersection is designed following standards outlined in the AASHTO Green Book. Every aspect of the geometric design, including sight distances, turning radius, and placement of crosswalks is implemented to enhance the traffic flow and bolster the safety of the intersection for road users, especially pedestrians safety.

Utilizing the international standard set by the AASHTO Green Book, the design parameters cover every essential aspect necessary to optimize the functionality of the roadway. From ensuring adequate serviceability to fulfilling the diverse needs of road users the adherence to these standards guarantees a superior intersection that prioritizes both efficiency and safety, therefore, setting a new standard for future urban planning and traffic engineering design.

- **Turning Radii**

As per the guidelines outlined in the AASHTO 2018 publication, section 9.6.1.4, which specifically addresses intersections prone to frequent turns by large trucks and buses, such as the Vomoma intersection, it is recommended that turning radii of 40 ft (12m) be utilized. In strict accordance with these recommendations, a turning radius of 12 meters was adopted for the Vomoma intersection design.

- **Sight Distance**

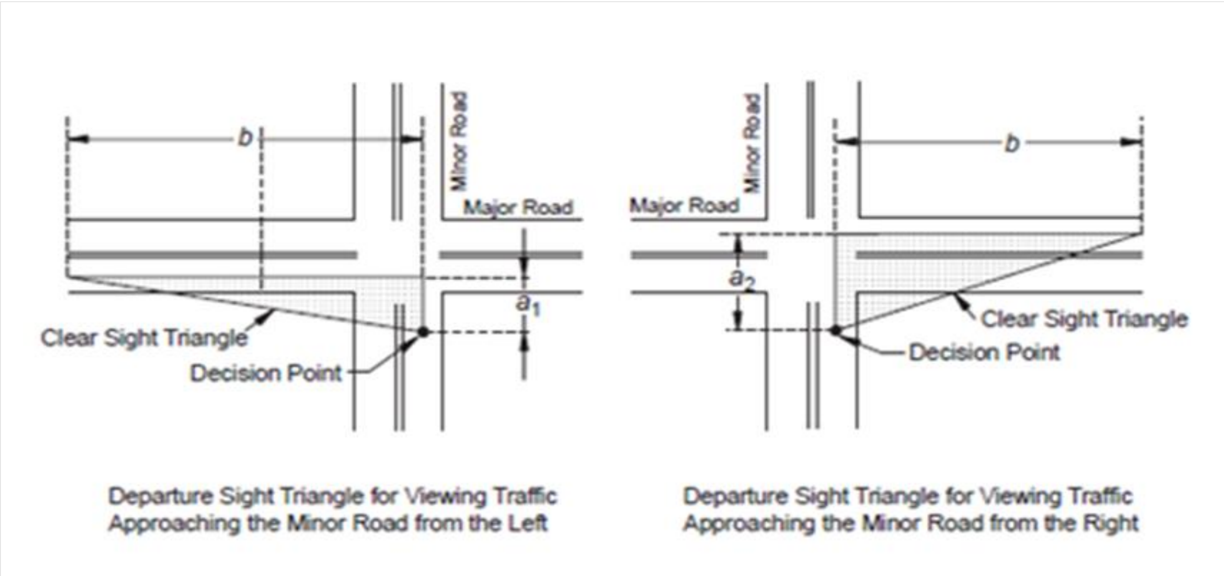

Figure 6: Departure Sight Triangles (Stop-Controlled) (AASHTO, 2018)

The clear sight distance for the intersection design was derived from the parameters shown in Figure. Based on the position of the stop signs, the parameters are as follows: (AASHTO, 2018)

Distance a1= 11m
Distance a2 = 4m
Distance b = 75m – according to Table for a design speed of 80km/hr.

Table 1. Length of Sight Triangle Leg-Case A, No Traffic Control Table 9.4. (AASHTO, 2018)

U.S. Customary		**Metric**	
Design Speed (mph)	**Length of Leg (ft)**	**Design Speed (km/h)**	**Length of Leg (m)**
15	70	20	20
20	90	30	25
25	115	40	35
30	140	50	45
35	165	60	55
40	195	70	65
45	220	80	75
50	245	90	90
55	285	100	105
60	325	110	120
65	365	120	135
70	405	130	150
75	445		
80	485		
Note: For approach grades greater than 3 percent, multiply the sight distance values in this table by the appropriate adjustment factor from Table 2.			

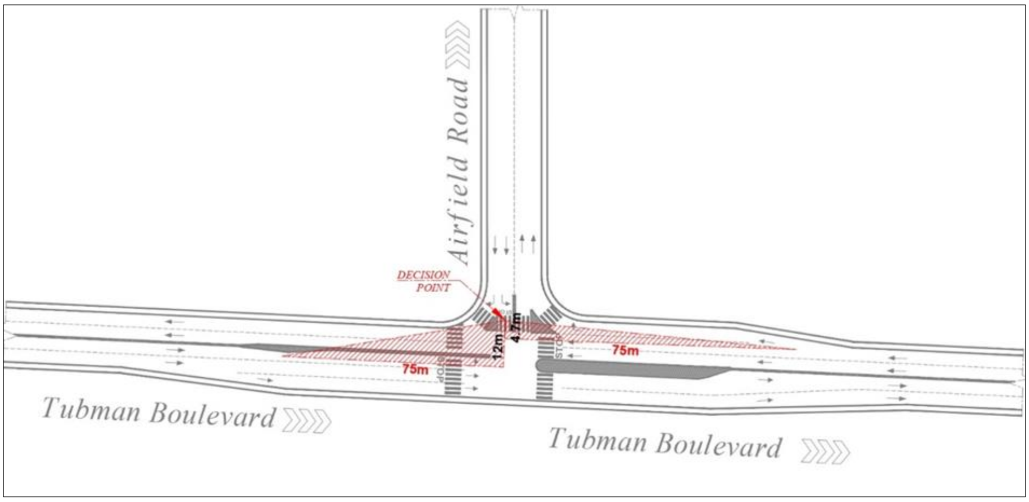

Figure 7. Layout of the Intersection Showing Sight Distance Triangle

- **Lanes**

To enhance the flow of traffic and improve maneuvering efficiency, storage, and auxiliary lanes have been strategically incorporated, as outlined in the provided Table 2. The storage lane, also referred to as the queue lane, serves as an area designated for vehicles awaiting left turns. Following the guidelines outlined in Table 9-23 of the AASHTO, which accounts for a maximum of 25% of vehicles being trucks, the recommended storage length is 12.5 meters per vehicle. Accordingly, the proposed storage length has been designed to accommodate up to 4 trucks or 10 passenger vehicles (with an allocation of 5 meters per car). Ensuring a sufficient storage length of 50 meters to accommodate these vehicles at any given time.

Table 2. Queue Storage Length Adjustments for Trucks (48) Table 9-23 (AASHTO, 2018)

Percent Trucks	U.S Customary	Metric
	Assumed Storage Length (ft) per Vehicle in Queue	**Assumed Storage Length (m) per Vehicle in Queue**
< 2	25	7.6
5	28	8.5
10	32	9.8
15	35	10.7
20	38	11.6
25	41	12.5

3.0 Proposed Improved Three-Leg Intersection Design for Vomoma Intersection

The redesign of the Vomoma Intersection following the international benchmarks outlined in the AASHTO Green Book 2018 Edition, provides solutions to the existing traffic flow challenges at the intersection. The proposed alternative design goes beyond the primary goals of improving traffic flow and ensuring road safety. The design focuses on maximizing the intersection's capacity to deliver the required level of service. It is a crucial solution based on the fact that the Vomoma intersection stands at the busiest intersection along Tubman Boulevard. By prioritizing efficiency, safety, and serviceability, the intersection design aims to meet the needs of road users while effectively managing the high volumes of traffic.

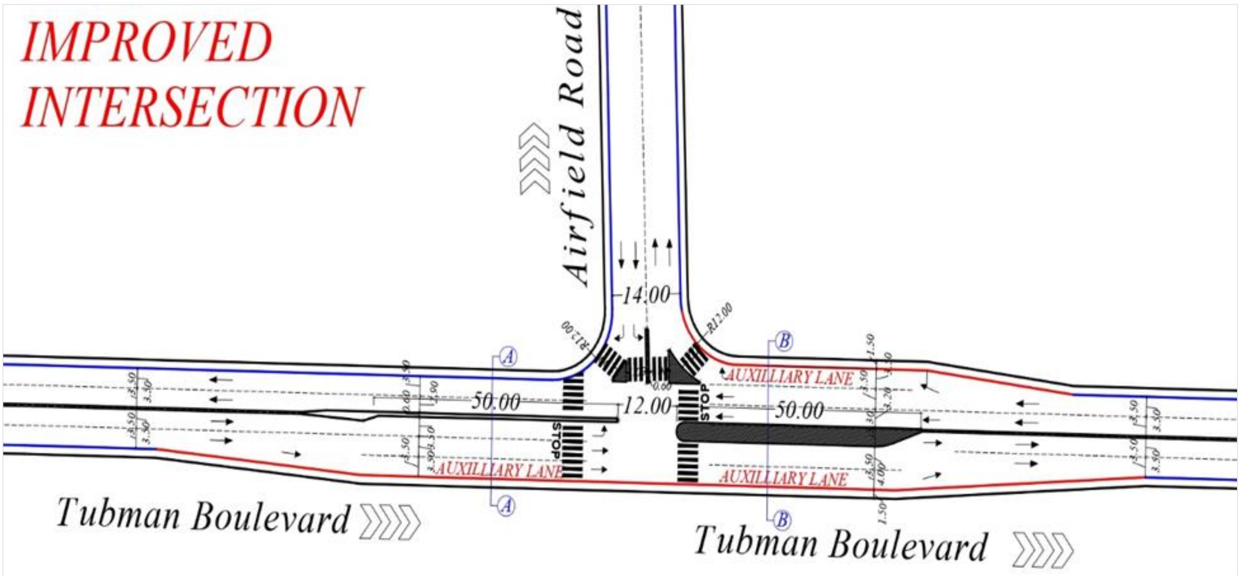

Figure 8. Proposed Improved Intersection Layout

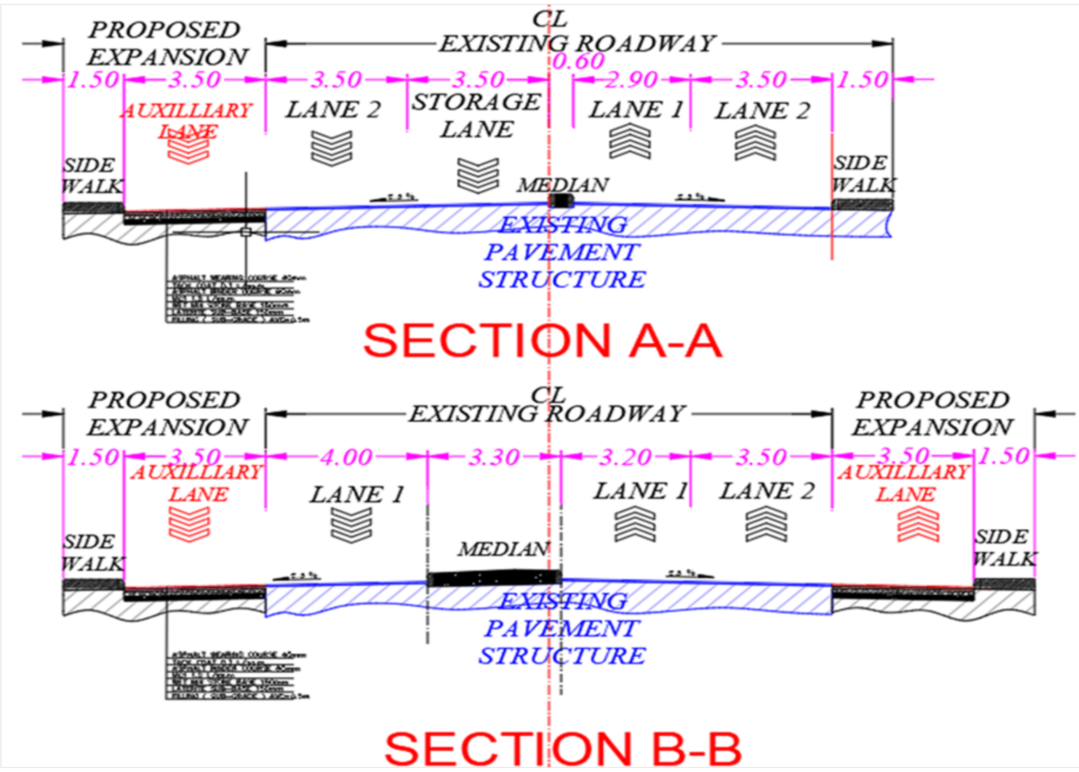

Figure 9: Proposed Improved Intersection Cross Sections

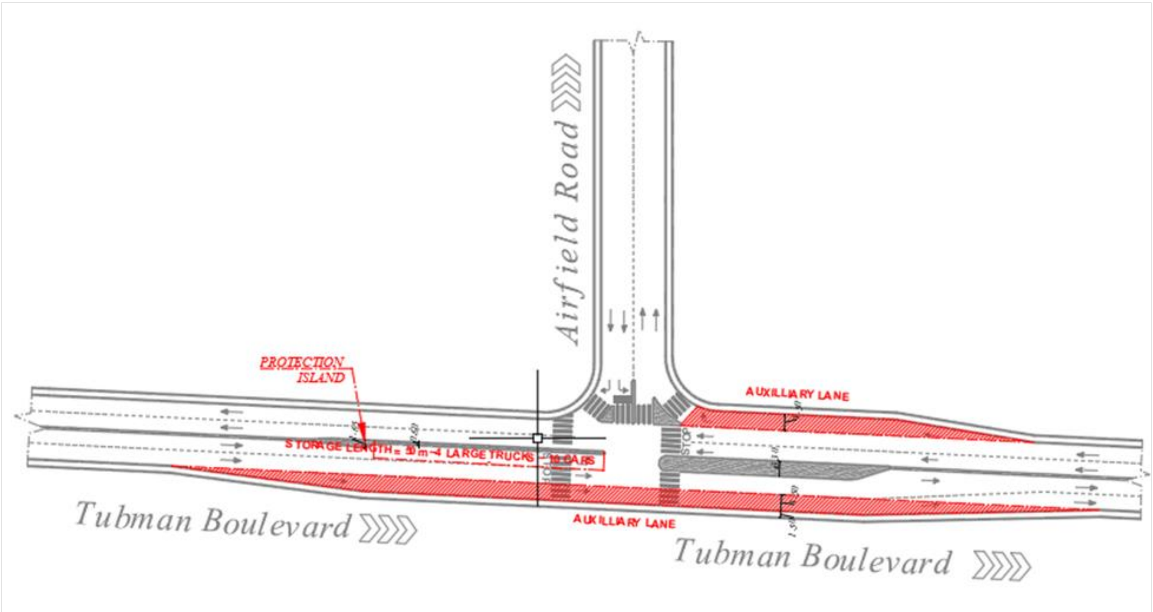

Figure 10. Proposed Auxiliary Lane Highlighted in Red

Figure 9 shows a significant improvement in the intersection design, presenting the integration of an auxiliary lane 3.5 meters wide. The auxiliary lane plays an important role in optimizing traffic flow and safety. Specifically, it acts as a dedicated right-turn lane for vehicles driving from Paynesville, thus enabling a smoother transition onto Airfield Road. Also, the introduction of another auxiliary lane addresses the needs of vehicles traveling from Sinkor toward Paynesville. This lane facilitates efficient right-of-way usage, allowing vehicles to utilize both the middle lane and the auxiliary lane. These auxiliary lanes eliminate the scenario of turning vehicles and those proceeding straight are forced to share the same lane.

The key benefit of this design is the elimination of potential congestion and safety hazards associated with mixed-directional traffic in a single lane. By providing designated lanes and intuitive guidance through strategically placed road safety signs, drivers are informed to select the appropriate lane based on their intended direction. This proactive approach not only enhances traffic efficiency but also significantly reduces the likelihood of accidents and delays at the intersection.

Furthermore, the proposed design includes a central median to effectively manage opposing traffic flow, addressing one of the key issues contributing to traffic congestion at the intersection. The median is 1.65 meters in width and 0.3 meters in height, serving as a protective barrier, which mandates vehicles to remain within designated lanes or queues minimizing the risk of chaotic maneuvers. This strategic positioning not only facilitates a smoother merger of traffic lines but also prevents abrupt forward movements that contribute to traffic congestion. The proposed median offers a practical solution to alleviate congestion and enhance traffic management, promoting safer and more efficient vehicular movement at the intersection.

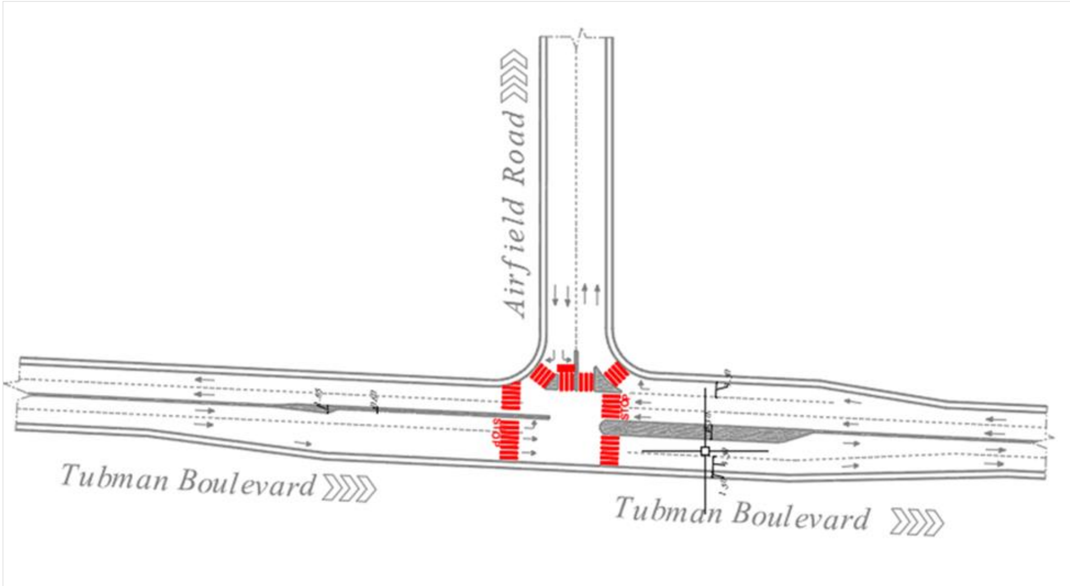

Figure 11. Proposed Zebra Crossings Highlighted in Red

The existing intersection is faced with inadequate traffic light signalization and pedestrian infrastructure, often leading to manual intervention from police officers assigned at the intersection. As shown in Figure 11, the proposed improved intersection design considers crucial safety measures by introducing a zebra crossing. The zebra crossing serves as an important element of road safety infrastructure, promoting continuous interaction between pedestrians and vehicles. This ensures a safer environment for all road users, mitigating the risk of accidents and promoting mutual respect between pedestrians and drivers. This designated crossing point marked with black and white stripes and lined by zigzag markings, serves as a clear visual cue to drivers, signaling the presence of pedestrians or potential pedestrians crossings.

Additionally, the proposed improved design required a planned traffic light system, positioned to regulate vehicular traffic and prioritize pedestrian crossing. The traffic light not only ensures orderly traffic flow but also provides dedicated intervals for pedestrians to safely traverse the intersection. Introducing these essential features, the proposed improved intersection aims to significantly enhance road safety standards, foster smoother traffic management, and create a more pedestrian-friendly environment.

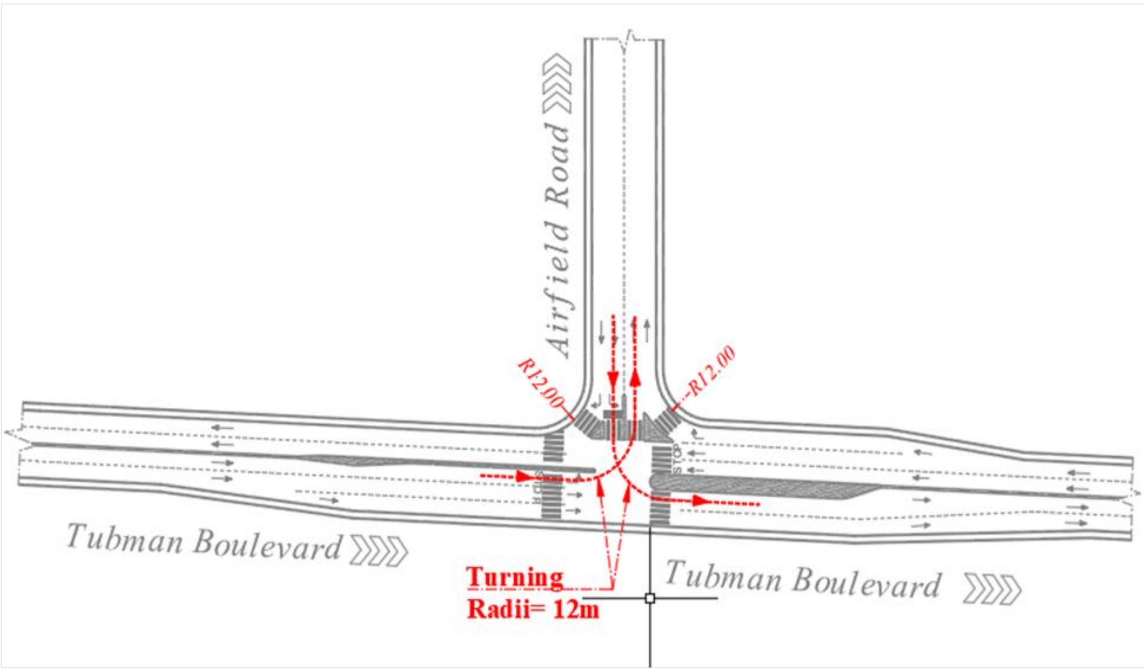

Figure 12. Design Turning Radius of the Proposed Improve Three-leg Intersection

Turning is a crucial part of intersection functionality, the lane widths of the intersection are designed to accommodate different vehicle types and turning frequencies. As shown in Figure 12, the turning radius of the proposed improved three-leg intersection is determined by the minimum turning path required for designated vehicles (Taylor, 2015). A 12-meter turning radius within 1800 degree triangular in the auxiliary lane to ensure ample space for safe and smooth turning of large vehicles, reducing delays in travel time given the high volume of turns at the intersection.

The improved Three-leg considered paving widths and corner radii to accommodate various types of vehicles, especially trucks and buses. The introduction of auxiliary lanes on both sides of the intersection to expand the roadway capacity and provide dedicated storage areas for vehicles making turns. The channelization widens the corner radii and turning lanes from regular travel lanes which optimize safety and traffic flow at the intersection.

4.0. Conclusion and Recommendations

The proposed improved three-leg intersection design is a strategic intervention to ease the persistent traffic congestion at the Vomoma intersection. Given the urgent need to optimize the level of service of the intersection, this design is in adherence to the guidelines set forth by AASHTO for intersection design. The proposed improved intersection design presents several features, including the integration of a zebra crossing to ensure pedestrian safety, the crossing paths are equipped with specialized markings to facilitate safe passage for individuals with special needs (disabilities). Also, the widening of the intersection introduces an auxiliary lane, serving a dual purpose; separating turning vehicles from those traveling straight and providing a designated area for vehicles awaiting clearance to turn.

For future infrastructure improvement research, it is essential to explore the possibility of designing an overhead pass, which addresses long-term infrastructure needs, but several challenges must be addressed. The challenges include the proximity of adjacent properties, limited available space, and allocation of resources (funds) as this is a huge undertaking. These constraints serve as significant barriers to the design and construction of an overhead pass but demand further assessment in future research endeavors.

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