Corozal Metric for Intersection Improvement and Implementation: A Tool to Improve Vulnerable Road User Safety in a Developing Country

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Abstract

As the town of Corozal, Belize has developed along the Philip Goldson Highway, the increase in traffic has led to increased issues with the safety of drivers and vulnerable road users (VRUs). In September 2021, the town experienced its first VRU fatality, which led to the town council searching for a solution. This research, therefore, first made use of limited crash data provided by the town council to develop a heat map using a Geographic Information System (GIS). Next, based on the critical intersections from the heat map, pneumatic tube counters were transferred from The University of Texas at Tyler to Corozal to be placed at the critical intersections in Corozal for three weeks in February and March 2022 to collect traffic pattern data such as volume, speed, and vehicle classification. Then, two simulation models were developed using Synchro and VISSIM for microscopic and macroscopic modeling, respectively. Overall, this research is centered around a scoring matrix, CMI3: Corozal Metric for Intersection Improvement and Implementation, which has been developed based on the collected data and simulation models, and in close collaboration with the town council. The CMI3 tool considers cost, operational performance, and safety to prioritize possible intersection improvements and recommendations, which includes traffic signal installation, positioning of a traffic officer at an intersection, improved pavement striping and traffic signage, and no action. In this research, the CMI3 tool is applied to six intersections in Corozal, and recommendations are provided to improve VRU and driver safety in the developing country.

Keywords: Developing country, traffic law enforcement, vulnerable road users, scoring matrix

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INTRODUCTION

Belize had been an independent country since 1981, as it was formerly known as British Honduras, a colony of Great Britain. The country retains many traditions of its colonizing country; there is a parliamentarian government, schools follow the British traditions, and the roads use roundabouts and speed bumps for much of its traffic control. The country is small, taking up just under 9,000 square miles, and since it is a developing country, the infrastructure is in need of further development and enhancement. A major infrastructure concern is the traffic congestion in selected parts of the country, particularly in border towns, because of heavy vehicular and pedestrian traffic around markets and travel through country borders. This is the case at certain locations in Corozal, a northern town along the Mexican border, as a majority of the traffic is comprised of vulnerable road users (VRUs).

VRUs are those who are unprotected by an outside shield, as they sustain a greater risk of injury to a collision with a vehicle and are therefore highly in need of protection against such collisions (*1*). This includes pedestrians, bicycles, and motorcycles. In the country of Belize, there are much more VRUs per capita than in the United States (*2*). In the town of Corozal, Belize, the first VRU pedestrian fatality occurred in September 2021. The members of the Town Council determined an immediate need to address traffic safety in the town after the first fatality occurred.

The University of Texas at Tyler (UT Tyler) has several Memorandums of Understanding (MOUs) with institutions in Belize including the Belize Ministry of Education, junior colleges, and four-year universities. UT Tyler faculty have long-standing partnerships with Belizean educators as the result of nearly 15 years of service provided by the UT Tyler education faculty. Through this relationship, one of the Corozal Town Council members approached the UT Tyler faculty with the traffic safety concern. The UT Tyler faculty requested the research team to assess the traffic situation and to provide recommendations on improvement.

Initially, the research team requested crash data in Corozal. The Town Council developed a report with socioeconomic data including population and household data, as well as the number of registered vehicles within the Town Council database, as well as the town-wide speed limit of 15 mph. Based on experience, the Town Council provided four intersections as areas of urgent concern as well as crash data at intersections, which included the one VRU (pedestrian) fatality. After the crash data was received, the research team traveled to Corozal, Belize in November 2021 in order to visualize the intersections first-hand. At the completion of the initial assessment, a plan was developed to:

1) develop a heat map of traffic hot spots in Corozal;
2) use pneumatic traffic counters to collect volume, speed, and density data in Corozal;
3) use the traffic data and microsimulation traffic software to model the roads in Corozal; and
4) develop a tool that can be used by the Town Council in order to assess future intersections and make recommendations in the future.

The tool should be developed in such a way that is can be easily used by the Town Council to analyze and assess future intersections.

This article is organized as follows. After this introduction, issues related to VRU safety in

Belize are reviewed. The crash data provided by the Corozal Town Council and methodology is then described. The next section describes the development of the scoring matrix, which is a tool that can be used by the Corozal Town Council to improve VRU safety. This paper concludes by highlighting the findings, limitations, and future research.

REVIEW OF THE PROBLEM AND RELATED WORKS

More than 1.2 million people die each year on the world's roads. Approximately 50 million people suffer a nonfatal injury per year. The up-to-date road safety surveys published by the Latin America and the Caribbean *(2)* indicate that the region's road fatality rate is about 17 fatalities per 100,000 population. This is considered a very high number compared to the average of fatalities per 100,000 population in high-income, developed countries, which is about 10. It is also expected that in the next few years these figures will jump to 24 fatalities per 100,000 population. If the abovementioned near future expectations become a reality, Latin America and the Caribbean region will be considered to have the highest roadway fatalities rate in the world!

Among the countries in this region that is plagued with roadway-related fatalities is Belize. With 21.3 road fatalities per 100,000 population in 2012, Belize is significantly above the average for Latin America and the Caribbean. Figure 1 presents the road fatalities per 100,000 population in Latin America and the Caribbean.

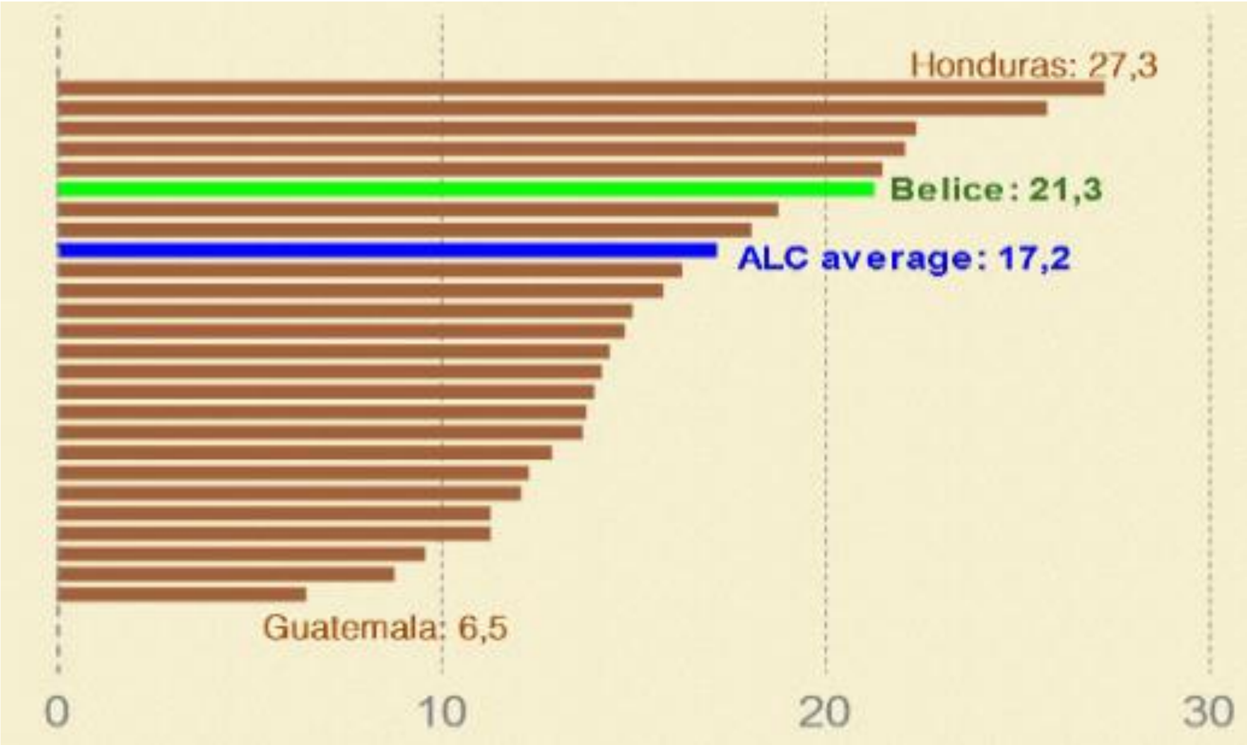

FIGURE 1 Road fatalities per 100,000 population in Latin America and the Caribbean in 2012 (*2*).

The evolution of the number of fatalities does not show a clear trend; fatalities increase and decrease without a discernible return. In 2012, road fatalities were up to 17% over the previous year. VRUs were 36.2% of all road fatalities. The motorization rate (number of motorized vehicles per 1,000 inhabitants) has experienced continuous growth since 2000, with an interruption from 2008 to 2012, as can be seen in Figure 2.

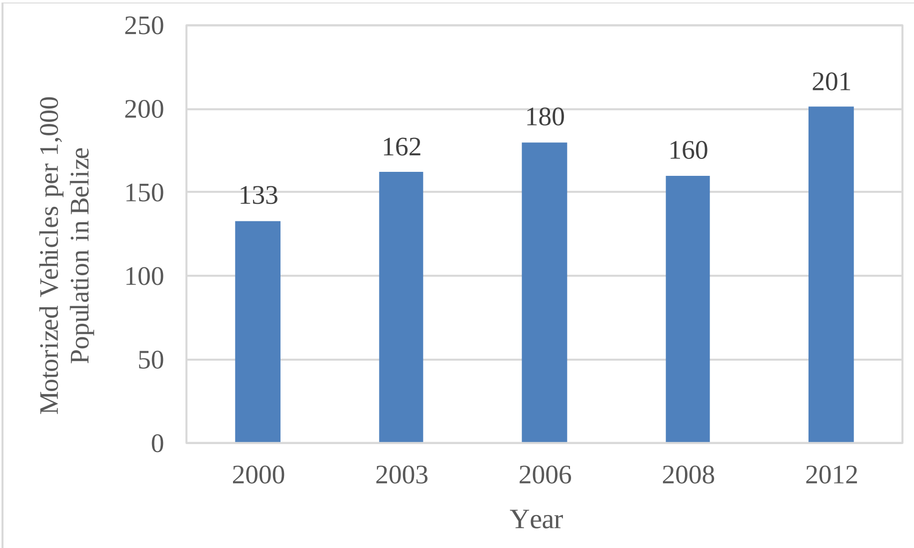

FIGURE 2 Motorized vehicles per 1,000 population in Belize (*2*).

The increase in motorization has resulted in an increase in risk exposure, which requires the implementation of new road safety measures. In order to address the dangerous growth in road fatalities in Belize, the Inter-American Development Bank (IDB) spearheaded an initiative named The IDB's Road Safety Strategy. This was considered one of the first initiatives in the region. With such a program, the Bank aimed to lead a process of change that assisted in promoting road safety actions in Latin America and the Caribbean with the goal of permanently reducing the region's high rate of traffic crashes. The IDB's Road Safety Strategy was built on five main pillars:

1) road safety management: this was coordinated by the ministry of finance and economic development and ministry of works and was financed by public budget and private funds;
2) safer roads and mobility: this included carrying out road safety inspections and audits on projects with multilateral funding;
3) safer vehicles including the initiation of annual vehicle inspection program;
4) safer road users: this included legislating and enforcing speed limits, alcohol consumptions, helmets on motorcycles and mopeds, as well as seat belts. In addition, increase road safety education at all schools' curriculums and the initiation of enforcing theoretical and practical driving exams; and
5) response after accidents: this includes the development of a nation-wide emergency telephone 911 system, increase accident-related injuries training for doctors and nurses, as well as enforcing vehicle insurance by law.

Based on the proposed IDB's Road Safety Strategy, suggested short, medium, and long-term courses of action were recommended:

- Short term actions: (a) improve systems for collecting crash data and preparing annual reports, (b) promote the development of integral road safety plans and improve urban road safety making VRUs safer.

- Medium term actions: (a) ensure the availability of road safety professionals including doctors and nurses, (b) foster the identification and resolution of accident hotspots and the enforcement of road safety inspections and audits, (c) regulate the use of seatbelts in the rear and the use of children restraint system, (d) support the introduction of road safety standards.
- Long term actions: (a) promote research and development.

In the research world, similar work has been done in other developing countries. Crash data and traffic volume data have been used in another developing country, Qatar, to identify high speed areas of concern *(3)*. A similar scoring system has been developed by Souliman et al. *(4,5)* to determine the best locations to install a bike lane in a moderate-sized town.

From the above detailed literature review, it can be seen that road safety in Latin America and the Caribbean nations in general, and in Belize in particular, is a major issue that needs to be addressed and investigated. The IDB's Road Safety Strategy clearly set forth the required actions items that need to be addressed including promoting research and development. We, therefore, intend in this paper to showcase our research efforts by trying to develop a tool to improve VRU safety in the developing country of Belize, specifically in the town of Corozal.

DATA SETS

Initially, limited crash data was provided by the Corozal Town Council. The report contained the date and location of each crash, the types of vehicles involved, and the degree of injuries sustained by those involved in the crash. The timeframe for the crash data was between July 2021 – October 2021. The raw crash data provided by the Corozal Town Council is tabulated in Table 1.

Table 1 Raw Crash Data from Corozal Town Council

Date of Crash	Location of Crash	Type of Vehicles Involved	Degree of Injuries Sustained
July 5 2021	Mile 84, Phillip Goldson Highway	Motorcycle, hit and run	Victim injured
July 7 2021	Santa Rita Road & 10th Avenue	Passenger & Cyclist	Motorcycle driver injured
July 9 2021	7th Avenue & 3rd Street South	SUV & passenger car head-on collision	Vehicles damaged
July 11 2021	5th Avenue & 3rd Street South	SUV & passenger car side collision	Vehicles damaged
July 19, 2021	6th Avenue & 1st Street North	SUV & cyclist	Cyclist suffered severe head injuries
August 21, 2021	4th Avenue & 1st Street South	SUV & mini-van collision	Vehicles damaged
September 11, 2021	7th Avenue & 4th Street South	Multiple passenger car collision	1 pedestrian fatality
September 20, 2021	7th Avenue & 4th Street North	SUV & motorcycle	Motorcycle driver injured

October 26, 2021	Mile 85, Phillip Goldson Highway	SUV & motorcycle	Motorcycle driver injured

During the span of July – October 2021, there were nine traffic crashes reported by the Town Council. The report also provided four areas of urgent concern identified by the Town Council, with information about these intersections, such as paving conditions, number of lanes, pedestrian crossing locations, and surrounding buildings of interest. The areas of urgent concern, as provided by the Corozal Town Council, are summarized in Table 2.

Table 2 Areas of Concern from Corozal Town Council

Area (Intersection) of Concern	Description
7th Avenue and 3rd Street South	Concrete paving 4-Lane highway split by median Pedestrian sidewalk on both sides No pedestrian crossing at intersection Pedestrian cross ramp located 300 yards on one side
4th Avenue and 1st Street South	Tar Paving 2-loan road Downtown area No pedestrian crossing Flanked by Central Park & Adventist Church
7th Avenue and 1st Street North	Concrete paving 4-Lane highway split by median No pedestrian crossing Flanked by Bus Terminal
Santa Rita Road and 10th Avenue	Concrete Paving 4-Lane highway split by median No pedestrian crossing Flanked by Supermarkets

METHODOLOGY

During the initial site visit assessment in November 2021, the Corozal Town Council requested that the research team assess six intersections due to the limited time constraint of the field visit. These intersections were selected based on the crash data and areas of urgent concern, as presented in Table 1 and Table 2, respectively:

1. 1st Street South and 5th Avenue
2. Philip Goldson Highway and 6th Street South
3. Philip Goldson Highway and 3rd Street South
4. Philip Goldson Highway and 9th Avenue
5. 4th Avenue and 3rd Street North
6. 3rd Street South, 4th Avenue, and 3rd Avenue

At the completion of the initial site visit, the crash data from the report and the six assessed intersections were used to develop a heat map using a Geographic Information System (GIS) (6).

The map, presented in Figure 3, included crash locations, noted areas of concern, as well as the intersections visited during the initial site visit assessment.

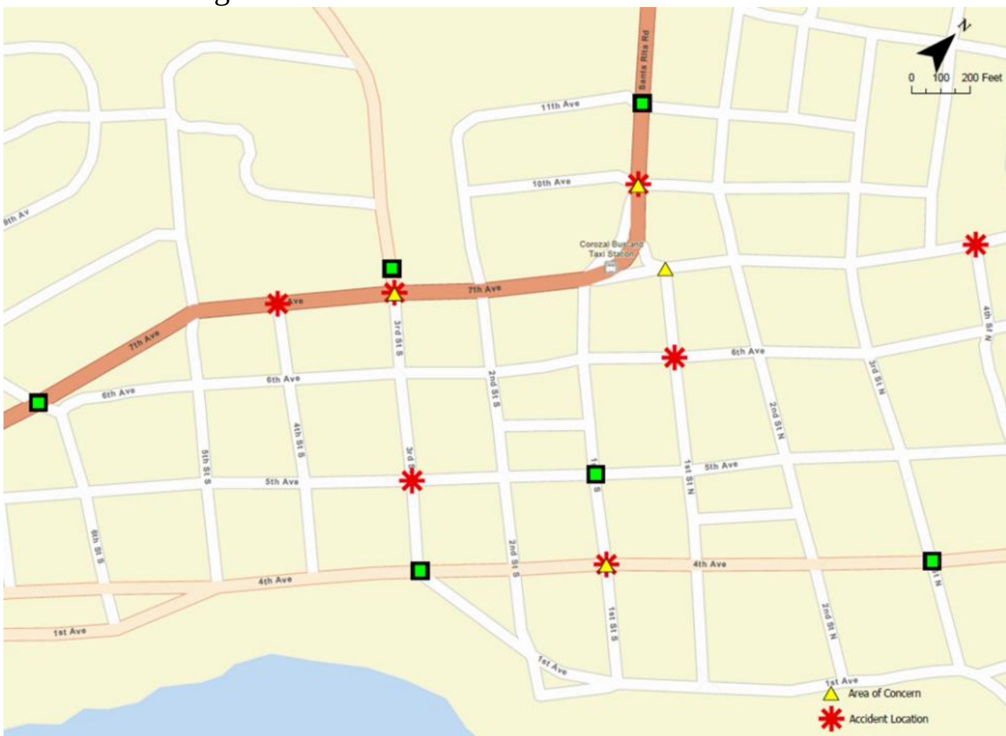

FIGURE 3 Corozal Assessment Map.

The next step was to collect traffic data in Corozal. Based on the results from Figure 1, it was determined that the six intersections from the initial assessment would be used to collect traffic data. In February 2022, the UT Tyler research team delivered six pneumatic traffic counters to Corozal for use by the Corozal Town Council. Virtual meetings were held between the UT Tyler research team and Corozal Town Council on how to properly set-up and use the traffic counter equipment. Each traffic counter was placed at all of the approaches to each of the six intersections for a period of one week throughout February and March of 2022. A summary of the data collection schedule is presented in Table 3.

Table 3 Data Collection Schedule

Intersection	Date Traffic Counters Were Placed	Date Traffic Counters Were Collected
1	February 23, 2022	March 2, 2022
2	February 16, 2022	February 23, 2022
3	February 23, 2022	March 2, 2022
4	February 16, 2022	February 23, 2022

5	March 2, 2022	March 9, 2022
6	March 2, 2022	March 9, 2022

The pneumatic traffic collectors were placed at the approaches to each intersection in order to collect ADT, speed, and heavy vehicle percentage data. The descriptive statistics for the six intersections are presented in Table 4.

Table 4 Descriptive Statistics of Data Collected

Traffic Exposure						
Intersection	**1**	**2**	**3**	**4**	**5**	**6**
Units	*ADT*	*ADT*	*ADT*	*ADT*	*ADT*	*ADT*
Mean	10,502	16,835	12,714	1,132	12,303	7,008
Peak Day	Friday	Friday	Friday	Friday	Friday	Friday
Morning Peak Hour	8:30 – 9:30 AM	9:30 – 10:30 AM	11:00 AM – 12:00 PM	9:30 – 10:30 AM	11:00 AM – 12:00 PM	11:00 AM – 12:00 PM
Afternoon Peak Hour	3:30 – 4:30 PM	3:30 – 4:30 PM	5:30 – 6:30 PM	4:00 – 5:00 PM	12:45 – 1:45 PM	12:00 – 1:00 PM
Speed						
Intersection	**1**	**2**	**3**	**4**	**5**	**6**
Units	*mph*	*mph*	*mph*	*mph*	*mph*	*mph*
Min.	2.7	4.0	4.0	4.2	4.0	4.0
Max.	99.9	99.7	99.5	93.8	97.4	98.2
Mean	11.4	21.3	17.7	14.7	14.9	14.9
85^{th} Percentile Speed	14.7	26.5	22.3	18.2	19.9	19.9
Heavy Vehicle Percentage						
Intersection	**1**	**2**	**3**	**4**	**5**	**6**
Units	%	%	%	%	%	%
Min.	11.2	4.8	4.2	6.5	4.0	3.9
Max.	11.4	8.1	7.7	6.5	7.0	9.9
Mean	11.3	5.4	5.7	6.5	6.3	7.5

The traffic exposure was calculated by the summation of the ADT volumes for all vehicles (i.e., cars and trucks) entering an intersection from all approaches. This was done so that, in the future, the Town Council may quickly use pneumatic traffic counter results when using the scoring matrix tool, which will be discussed in a subsequent section. The traffic exposure results from Table 4 show that all of the intersections experienced high traffic exposure volumes with the exception of Intersections 4 and 6. Intersections 2 and 3 are both located along the main Philip Goldson Highway, and Intersection 1 is located on the square, a heavy traffic area in Corozal. Intersection 4 had a much lower volume due to data collection issues where only one of the tube counters collected data for approximately 2 days out of the week. Despite the tube counters being relocated for the six different intersections over a span of three weeks (see Table 3), the peak day of the week was Friday for all six intersections studied. Furthermore, the morning and peak hours were not constant throughout the study period. The morning peak hours ranged from as early as 8:30 am to as late as 12:00 pm. The afternoon peak hours also ranged from as early as 12:00 pm to as late as 6:30 pm depending on the intersection.

Table 4 also shows that the average and 85th percentile speeds were faster on the highway than at other intersections in town (i.e., Intersections 2, 3, and 4). Across all intersections monitored, the average 85th percentile speed stayed around 20 to 25 miles per hour, which is a moderately safe speed for the town of Corozal when considering the heavy VRU traffic. The maximum values of 99 mph for each intersection were likely caused by errors in the tube counter equipment (e.g., spacing of the tubes).

Based on the heavy vehicle percentage presented in Table 4, the heavy vehicle percentage is mostly constant across the monitored intersections, with the exception of Intersection 1, which has much higher heavy vehicle traffic. This could be because Intersection 1 is located directly adjacent to the town center, which includes the Corozal Town Hall and Corozal Central Park.

After examining the traffic counter data, the next step was to develop a microsimulation and macrosimulation model to determine the operational performance of each intersection as well as the performance of the town of Corozal as a whole. The microsimulation models of each intersection were done in Synchro *(7)*, while the macrosimulation model of the entire network was done in VISSIM *(8)*. Using the peak day and peak hour volumes presented in Table 4, each intersection was imported into Synchro in order to determine the existing level of service (LOS). The LOS results for each intersection are presented in Table 5. Furthermore, an example of Intersection 3, as modeled in Synchro, is presented in Figure 4.

Table 5 Level of service Results

Intersection	Level of service
1	A
2	F
3	C
4	A
5	F
6	F

Despite the high traffic exposure ADT volumes for Intersections 1 and 3, the intersections are performing well from an operation and delay standpoint. Intersection 2 had a very high delay, which contributed to the poor LOS score of an "F." Intersection 4 performed well operationally, as there was minimal data collected due to data collection issues. Intersections 5 and 6 performed poorly as well, despite the low traffic exposure ADT volumes.

FIGURE 4 Example of Intersection 3 Modeled in Synchro (*7*).

The VISSIM model was used as a *macroscopic* simulation model to assess overall traffic patterns within of the entire town of Corozal. It should be noted that this macroscopic model cannot be used for intensive analysis due to the limited data at only six intersections within the town. The VISSIM model can, however, be used to see how a change to an intersection (e.g., installing a signal or converting an intersection to a roundabout) affects the town of Corozal as a network. Furthermore, the macroscopic model may be used for visualization purposes for the public, in order to show improvements since the first VRU fatality occurred. Figure 5 presents an overview of the macroscopic VISSIM model.

FIGURE 5 Town of Corozal in VISSIM (*8*).

The last step as part of the initial assessment was to conduct a signal warrant analysis for each of the six intersections where data was collected. A summary of the signal warrant results for each intersection are presented in Table 6.

Table 6 Summary of Signal Warrant Results

Intersection	1	2	3	4	5	6
Warrant 1						
Warrant 2						
Warrant 3						
Warrant 4			✓			
Warrant 5						
Warrant 6						
Warrant 7						
Warrant 8						
Warrant 9						

Out of the six studied intersections, only one met the requirements specified for a signal warrant: Intersection 3 met the signal warrant for pedestrian volume (i.e., Warrant 4). Out of the remaining intersections, two did not have enough traffic on the minor street to warrant a signal, and the other three did not have enough traffic on the major street to warrant a signal.

SCORING MATRIX TOOL

Development

Following the initial data collection, assessment, and modeling, it was determined that a tool should be provided to the Corozal Town Council so that the Town Council can assess any intersection and determine the mitigating next steps for improvement. The developed scoring matrix tool, CMI3: Corozal Metric for Intersection Improvement and Implementation, was developed in order to score each intersection with respect to safety, operational performance, and cost concerns. Each of the three categories was given a “credit” for importance. This was done to give different weight to each category. The weights were assumed to be on a Likert Scale of 1 – 5. It was our opinion that a credit value of 5 was deemed the most important and a credit value of 1 was deemed not important at all. This was done intentionally, as our future research plans include surveying the Corozal Town Council and citizens on their perceptions about safety, operational performance, and cost; and we will be using a 1 – 5 Likert Scale as part of the survey instrument. At the conclusion of the survey in the future, the CMI3 tool will be more optimized specifically for the town of Corozal based on feedback from the citizens and end users.

Safety received a credit value of 5, as it was deemed most important, followed by operational performance with a credit value of 4, and cost with an assigned credit value of 3. Within safety, there were four chosen subcategories for each intersection:

- if a crash had been recorded at the intersection;
- if a fatality had been recorded at the intersection;
- if there were noticeable complaints from citizens regarding the intersection; and
- if the intersection was a noted area of concern by the Town Council.

In the safety category, more points were given to intersections that experienced a fatality, followed by a non-fatal crash, and lastly intersections that are an area of concern or have experienced noticeable complaints. The noticeable complaints subcategory could be recorded by the Town Council or simply by “word of mouth” amongst the community. One of the major benefits of this subcategory is that the data is easily obtainable for the Town Council, i.e., no equipment or software needs to be purchased.

The second category scored was operational performance. Within operational performance, there were seven chosen subcategories scored for each intersection:

- Intersection exposure was the first subcategory, which uses the ADT for the entire intersection. The thresholds were determined based on the results presented in Table 4;
- The 85th percentile speed was the second subcategory, which uses the 85th percentile speed for the intersection. The thresholds were determined based on the results presented in Table 4;
- The number of lanes in each approach was the third subcategory;
- The fourth subcategory was related to the MUTCD signal warrants. A score was assigned based on whether one of the nine signal warrants was met;
- The heavy vehicle percentage was the fifth subcategory, which uses the heavy vehicle percentage for the intersection. The thresholds were determined based on the results presented in Table 4;

- The pedestrian volume was the sixth subcategory, which simply follows a discrete $\{low, medium, high\}$ function. Because the pneumatic tube counters did not count any pedestrians, at this point of this preliminary research, the pedestrian subcategory would have to be a visual observation and estimation; and
- The intersection level of service (LOS) was the seventh and final subcategory, which simply uses the overall LOS of the intersection from LOS A to LOS F.

In the operational performance category, more points were given to intersections that experience high traffic exposure volumes, excessive speed, and high truck percentages, all of which can be easily obtained from the pneumatic tube counters. In addition, more points were given to an intersection that had more lanes, required a signal, had a high VRU volume, and a low LOS. One of the major benefits of this subcategory is that the thresholds for the volume, speed, and heavy truck percentages are calibrated specifically for the town of Corozal. The volume, speed, and heavy truck percentages can also be easily obtained using pneumatic tube counters; however, the Town Council would be required to have the tube counter equipment as well as someone who can set-up and interpret the data. In addition, other downfalls for this subcategory are that the Town Council will have to be familiar with the MUTCD for signal warrants and require licenses of a traffic simulation software for LOS analyses. Lastly, the tube counters do not collect pedestrian data.

The final category assessed for each intersection was cost. This category looked to incorporate the cost of improvements recommended for each intersection. Pavement conditions were assessed, as improving the pavement in an intersection was considered to be a significant cost for Corozal. Lastly, the cost of any signal improvements was also incorporated. One of the major benefits of this subcategory is that the pavement condition can simply be visually observed. The major downfall of this subcategory is that the cost estimate values for a signal improvement have not been studied intensively for this first version of the CMI3 tool. Once points have been assigned for each subcategory and multiplied by the respective credit for that subcategory, the sum of all scores will provide an overall score for an intersection.

Implementation

Once the CMI3 tool was developed, it was then applied to the six intersections where the traffic data was collected. Figure 6 presents the mockup of CMI3 as well as the assigned scores for each of the six selected intersections of study.

Decision Factors	Measures	Points	Credit	Intersection 1	Intersection 2	Intersection 3	Intersection 4	Intersection 5	Intersection 6
	Crashes								
	No Crash Recorded	0		0	0		0	0	0
	Crash Recorded	2				10			
	Fatalities								
	No Fatalities Recorded	0		0	0	0	0	0	0
	Fatalities Recorded	3							
Safety	**Complaints**		5						
	No Noticeable Complaints	0		0	0		0	0	0
	Noticeable Complaints	1				5			
	Area of Concern								
	Not Area of Concern	0		0	0		0	0	0
	Area of Concern	1				5			
	Intersection Exposure (ADT)								
	Low (< 5,000)	1					4		
	Medium (≥ 5,000, ≤ 10,000)	2							8
	High (> 10,000)	3		12	12	12		12	
	Speed (85%)								
	< 15 mph	1		4					
	≥ 15 mph, ≤ 20 mph	2					8		8
	> 20 mph	3			12	12		12	
	Number of Lanes (Each Way)								
	1 Lane	1		4				4	4
	2 Lanes	2			8	8	8		
	Signal Warranted								
	No Signal Warranted	0		0	0		0	0	0
	Signal Warranted	2				8			
Operational Performance	**Truck Percentage**		4						
	< 5%	1							
	≥ 5%, ≤ 10%	2			8	8	8	8	8
	> 10%	3		12					
	Pedestrian Volume								
	Low	1							
	Medium	2			8				8
	High	3		12		12	12	12	
	Level of Service								
	A	0		0			0		
	B	1							
	C	2				8			
	D	3							
	E	3							
	F	4			16			16	16
	Pavement Conditions								
	Good	0		0	0	0	0		
	Moderate	1						3	
	Poor	2							6
	No Pavement	3							
Cost	**Signal Improvements**		3						
	< $50,000	0		0	0		0	0	0
	≥ $50,000, ≤ $100,000	1							
	> $100,000, ≤ $200,000	2							
	> $200,000	3				9			
Total Points				**44**	**64**	**97**	**40**	**67**	**58**

FIGURE 6 CMI3 Mockup and Evaluation Results for Six Intersections.

Based on the results presented in Figure 6, Intersection 3 was well above the other five intersections when scored with the CMI3 tool. This difference in scores shows the need for dramatic improvements at Intersection 3 to improve both the safety and functionality of the intersection. Intersection 1 received a low score, as it did not receive any points in the safety category. Intersection 4 received the lowest score, as expected, due to the errors in the data collection process for this intersection. The remaining intersections, Intersections 2, 5, and 6, all received moderate scores.

Out of the six intersections evaluated, the total scores ranged from 40 – 97 points. Based on the overall points received by each intersection, a decision tree was developed to assign threshold values and determine the best course of action for an intersection in Corozal.

It is our opinion that a high scoring intersection should have a signal installed; however, this should be done sparingly, as there are currently no signalized intersections in Corozal. In fact, there are only a few signalized intersections in the entire country of Belize (*2*). Therefore, most residents of Corozal have never experienced a traffic signal.

Intersections with a relatively high total score should warrant an improvement; however, not to the extent of a traffic signal. Therefore, the recommendation for intersections with a relatively high score is to place a traffic officer to monitor the intersection. Based on the initial assessment when the research team visited Corozal in November 2021, Corozal has 16 traffic officers, which can be strategically placed based on the scores from CMI3.

Intersections with a relatively lower total score should still receive some improvements. Since intersections in this point range are not necessarily unsafe to VRUs nor should they be the top priority, it is recommended that the intersection receive new signage and striping. Based on the initial assessment when the research team visited Corozal in November 2021, there is very little signage and pavement markings, especially in Corozal. Therefore, intersections within this range should receive new signage and pavement markings; however, due to the high costs for a developing country like Belize, this should be done sparingly.

Intersections with a very low total score should receive no further action. Since the intersection received very few points, it is either not a safety concern, has good operational performance, and/or the cost of improving the intersection does not outweigh the benefits.

The decision tree associated with the CMI3 tool is presented in Figure 7. Essentially, once an intersection has been assigned a score, the threshold of 55 points was determined to separate intersections that require a signal or traffic officer and the intersections that only require signage, pavement markings or no further action. Whether the intersection has more or less than the 55-point threshold, the next criteria is whether or not a signal was warranted when evaluating using CMI3.

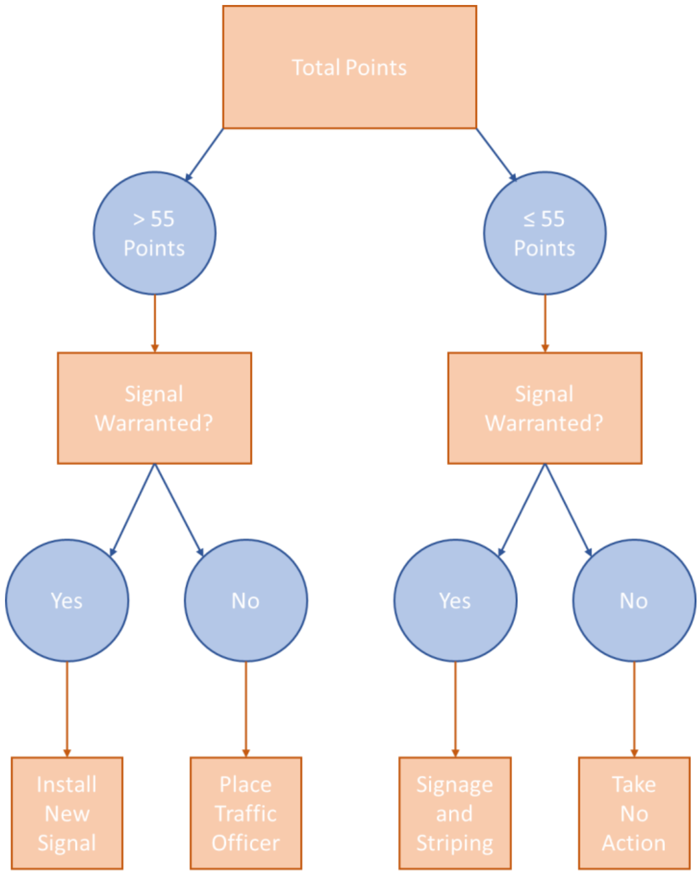

FIGURE 7 CMI3 Decision Tree

RESULTS AND DISCUSSIONS

If a signal was warranted for an intersection that received a score higher that 55 points, CMI3's recommendation is to install a new traffic signal at the intersection. This was determined to be the recommendation for Intersection 3, between 3rd Street South and Philip Goldson Highway. The installation of a traffic signal is considered to be a significant decision, as this not only involves the cost of installing the signal, but the education of drivers should also be considered, as traffic signals in Belize are not common.

The second recommendation is to place a traffic officer if an intersection received more than 55 points and a signal was not warranted. This is the recommendation by CMI3 for the following intersections in the study:

- Intersection 2: 6th Street South and Philip Goldson Highway;
- Intersection 5: 3rd Street North and 4th Avenue; and
- Intersection 6: 3rd Street South, 4th Avenue, and 3rd Avenue.

The third recommendation and lowest level of improvement was to increase safety signage and striping at the intersection. This recommendation was selected if an intersection warranted a signal, but the intersection received less than 55 points in the scoring process. After applying the CMI3 tool to the six intersections as part of this initial study, it was determined that no intersections met the requirements for signage and striping improvements.

The final recommendation, which is for intersections with less than 55 points and no signal warrant, no action should be taken. These intersections were determined to be operating at an acceptable level and/or are safe to VRUs, thus improvements would therefore not be needed. This was the recommendation by CMI3 for the following intersections in the study:

- Intersection 1: 1st Street South and 5th Avenue; and
- Intersection 4: 9th Avenue and Philip Goldson Highway.

CONCLUSIONS AND RECOMMENDATIONS

Major Findings and Recommendations

Traffic and VRU safety were observed and assessed in the developing country of Belize, specifically the town of Corozal. In coordination with the Town Council, six selected intersections were observed, measured, and scored using the CMI3 tool that was developed as part of this research. Based on the recommendations provided by CMI3, necessary improvements to increase safety at each of the six observed intersections were made. Based on the scores from CMI3, a decision tree separated the scores into categories so as to provide a recommendation to the Town Council. Of the six intersections studied, the following recommendations were determined:

- Installation of a new traffic signal: Intersection 3
- Placement of a traffic officer, Intersections 2, 5, and 6
- Improvement of existing signage and striping: no chosen intersections
- No action required: Intersections 1 and 4

In addition, a macroscopic VISSIM model was created, which considers the entire town of Corozal as a network. It should be noted that this macroscopic model cannot be used for intensive analysis due to the limited data at only six intersections within the town at the time of this study. The VISSIM model can, however, be used to see how a change to an intersection (using the CMI3 tool) affects the town of Corozal as a network. In the meantime, the macroscopic model may be used for visualization purposes for the public.

Future Research

One of the main limitations of this research is that data was only collected in one-week periods for only six intersections in the entire town of Corozal. The developed CMI3 tool and accompanying decision tree have been applied to the six intersections analyzed; however, other intersections in Corozal have not been tested using CMI3 and the accompanying decision tree. The research team plans to test CMI3 on other intersections in Corozal and to adjust the credits for each category by conducting a survey of the Town Council and residents as part of future research.

In addition, it is required that the end-users of CMI3 have background knowledge on intersection LOS analysis and signal warrants, which requires pneumatic tube counters, a traffic software such as Synchro *(7)* or VISSIM *(8)*, and the MUTCD *(9)*. For this study, Synchro *(7)* was used for the intersection LOS analysis. Therefore, as part of our future research, we plan to apply for grant funding in order to:

1) Purchase traffic signal equipment based on the results from this preliminary study of six intersections, primarily a traffic signal at Intersection 3;
2) Continue to improve the CMI3 tool by surveying the Town Council and citizens, apply the CMI3 tool to other intersections in Corozal, and develop a graphical user interface

(GUI) plug-and-play tool for ease-of-use for the end users in Corozal (see Figure 8 for a mockup of the GUI tool). In addition, training for the Town Council on how to implement and use the CMI3 tool and accompanying decision tree on other intersections will be required; and

3) Purchase the necessary equipment so that the Town Council may use the CMI3 tool effectively in the future: traffic pneumatic tube counters, traffic software, and MUTCD.

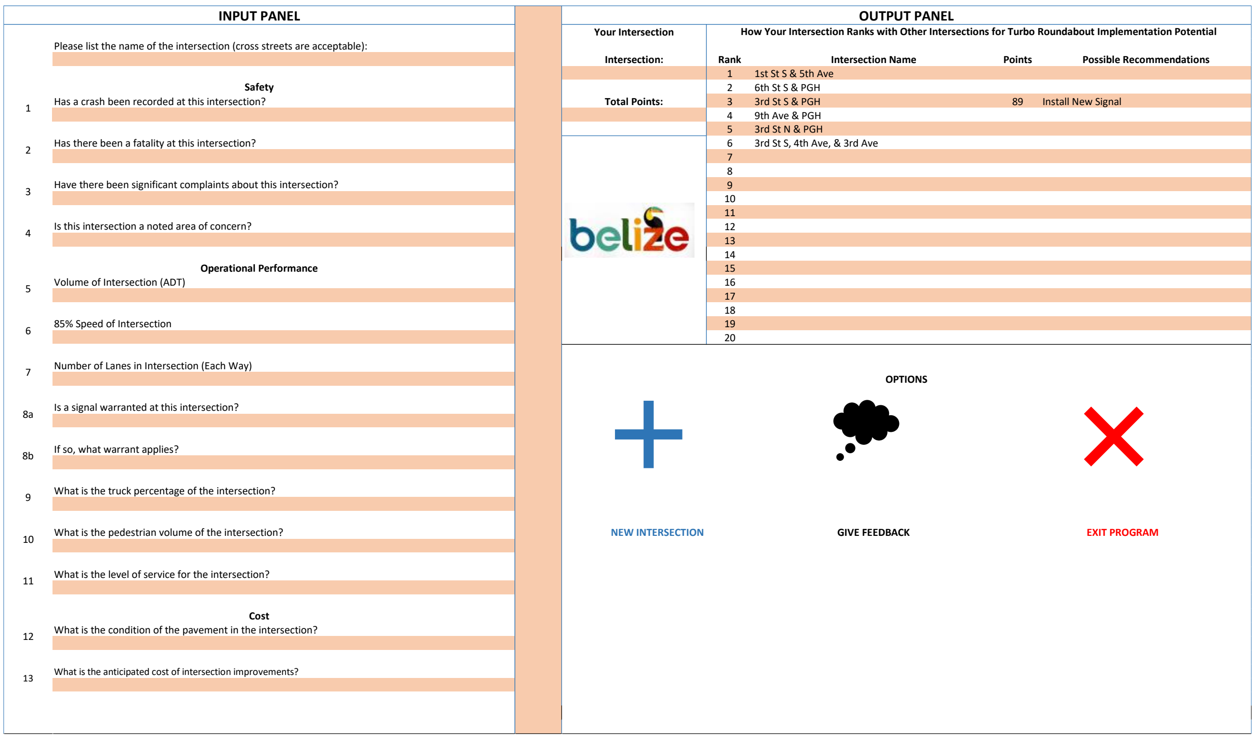

FIGURE 8 CMI3 GUI Plug-and-Play Tool

Furthermore, once CMI3 has been applied to many intersections in Corozal, that information may be georeferenced and converted into a heat map to determine the intersections with the highest scores. Since the costs of installing new signals would be much too high, the optimal location of the 16 traffic officers can be determined similar to an Operations Research facility planning problem (*10*). Essentially, the optimal location of where each traffic officer should be placed could be determined once more data has been collected and more intersections have been assigned recommendations based on the CMI3 tool developed as part of this research.

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AUTHOR CONTRIBUTION STATEMENT

The authors confirm contribution to the paper as follows: study concept and design: L. Proffer, M. Vechione; data processing: L. Proffer; analysis of results: L. Proffer, M. Vechione; model development: L. Proffer; development of scoring matrix and decision tree: L. Proffer, M. Vechione; initial draft of manuscript: L. Proffer; revisions of manuscript: M. Vechione, M. Souliman, Y. Olivares-Ortiz, W. Hickey. All authors reviewed the results and approved the final version of the manuscript.

REFERENCES

1. Shinar, D. Safety and mobility of vulnerable road users: pedestrians, bicyclists, and motorcyclists. *Accident Analysis & Prevention*, *44*(1), pp. 1-2, 2012.
2. McCarvell, G., Augustine, A., Scott, P. A., Johnson, M., and Urzua, J. The Belize Road Safety Initiative (No. 0081), 2015. doi: http://dx.doi.org/10.18235/0000109
3. Shaaban, K., Siam, A, and Badran, A. "Analysis of Traffic Crashes and Violations in a Developing Country," *Transportation Research Procedia*, Vol. 55, pp. 1689 – 1695, 2021.
4. Zavagna, P., and Souliman, M. I. "Engineering Scoring System for Bicycle Lane Mapping Development: Case Study on Tyler, Texas, USA," *Jordan Journal of Civil Engineering*, 12(4), pp. 698 – 706, 2018.
5. Souliman, M. I., and Bastola, N. "Improved Engineered Scoring System for Bicycle Lane Mapping Development," *Material Science & Engineering International Journal*, 6(2), pp. 48 – 55, 2022.
6. ESRI. Getting Started with ArcGIS, *ESRI*, Redlands, CA, 2005.
7. Cubic Trafficware. Synchro Studio 9 with Warrants and TripGen 2014, *Cubic Trafficware*, Sugar Land, TX, 2014.
8. PTV. VISSIM 5.00 User Manual, *PTV*, Karlsruhe, Germany, 2007.
9. FHWA, Manual on Uniform Traffic Control Devices (MUTCD), *Federal Highway Administration*, 2020.
10. Taha, H. A. Operations research: an introduction (Vol. 790). Upper Saddle River, NJ, USA: *Pearson/Prentice Hall*, 2011.