A Safety Audit of Seven Signalized Intersections in Ghana Based on Crash Data, Video Observations, and Surveys

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***Abstract*—Signalized intersections require regular safety and performance audits because of their high user demands. Most of the crashes on urban roads are attributed to the condition of signalized intersections. Some typical audit variables comprise vehicle crashes, road markings, signal control, pedestrian-vehicle movements, the composition of the flows, and violations of traffic regulations. This is critical in some sub-Saharan African countries, including Ghana, where transportation is at least 95% road-based and thereby putting excess demand on road infrastructure. Nonetheless, extant literature from sub-Saharan Africa has given little attention to auditing the basic infrastructure and studies focusing on specific road intersections. This paper fills this gap by auditing seven signalized intersections in three major cities in Ghana. A combination of road accident data compiled from 2010 to 2018, video observations during peak hours, and 1,489 questionnaires were employed. The results showed that the safety problems at the studied signalized intersections include conflicting mixed-flow traffic, in-lane hawking, unsignalized crosswalks, illicit parking of minibuses in intersection exit lanes, pedestrian and motorcyclist violations, road encroachment, and depleted road markings, among others. Several problems with the basic infrastructure, traffic violations, and proposed motorcycle taxi regulations were identified. Notably, the morning peak hours in Bolgatanga are 9-11a.m. There are proposed priority investments for each of the intersections. Our findings are beneficial to traffic engineers in Ghana, other sub-Saharan African countries, and their international development partners. Further studies on service design optimization and visible road markings are required.**

Keywords—signalized intersections, traffic safety audit, traffic violation, pedestrian behavior, road infrastructure, Ghana

I. INTRODUCTION

Traffic safety is one of the global hot topics in transportation research in light of the growing concern about road crashes. There are about 1.25 million road crash-related fatalities globally each year, resulting in an average daily death of about 3,287 people [1]. Researchers and traffic managers have been finding practical measures to reduce road crashes and optimize road capacity [2,3]. Realistically, solutions must reflect specific contexts because of heterogeneities in infrastructural development, users, and sometimes traffic regulations.

For low and middle-income countries, the road infrastructure remains underdeveloped and sometimes in low supply. The most effective approach to manage the existing systems is regular audit [4]. This approach can help maximize the capacity and safety of the basic infrastructure and users respectively.

In urban traffic management, intersections are the most critical bottlenecks and conflict zones. The essence of traffic control at an intersection is to reduce these conflicts and bottlenecks [5]. However, if this is not appropriately engineered and regularly audited, the demerits could outweigh its purpose. The number of crashes recorded in an intersection depicts its level of safety [6]. Similarly, human behavior causes about 90% of road crashes [7]. In principle, knowing the number of crashes at signalized intersections, the traffic violations, and the state of the signalized intersection helps to ascertain its safety performance.

Several researchers have investigated the causes of crashes at signalized intersections and proposed a plethora of preventive mechanisms. In Ghana, past researchers found poor traffic safety in urban areas and several intersection bottlenecks [8]. It is appropriate to find out whether signalized intersections are effectively performing their basic function or not. Through observations, different mixed traffic flows exist across the country. The Northern part of Ghana is predominantly motorcycle and auto-rickshaw traffic. The Southern part is mainly cars, motorcycles, and minibus/buses. Even within the capital city (Accra), there are different traffic conditions in different suburbs. These complex heterogeneities make traffic management difficult.

However, one basic challenge for researchers is data availability and reliability [9-11]. Some researchers analyzed crash data gathered by traffic police to understand the performance of the infrastructure. This method gives an understanding of the safety condition and shows the possible causes. However, it does not present real-time events and traffic behaviors that happen on the blind side of traffic police.

To mitigate this, traffic engineers have globally adopted the use of video surveillance to observe traffic. This approach remotely identifies conflicts, uncommon traffic behaviors, and traffic violations. Perkins and Harris [12] was the first researcher to introduce the concept of traffic conflicts to serve as an alternative to accident data. The objective is to identify incidents that have a high likelihood of causing crashes. Researchers have identified that this approach is efficient in identifying traffic conflicts and possible crash precursors [13-16]. Some traffic violations are difficult to identify unless with video surveillance. Therefore, it is appropriate to study the safety performance of signalized intersections using video data. However, in Ghana, most of the signalized intersections lack surveillance cameras. Researchers would therefore be useful in bringing out the unknown through their video observations.

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Furthermore, a complementary approach to observations and secondary data analyses is the use of other empirical approaches such as structured questionnaires and interviews to solicit opinion data from road users on specific traffic problems and phenomena as previously used by [17].

The above approaches have their merits and demerits. However, combining all three approaches mitigates that challenge. For this study, all three approaches have been adopted with specific objectives. In this study, seven signalized intersections in Accra, Kumasi, and Bolgatanga were observed with video surveyors. In addition, crash data were analyzed. Further, questionnaires were administered to road users and traffic police.

This paper seeks to answer the following questions. Firstly, what are the possible causes of crashes at these signalized intersections? Secondly, what are the basic design and infrastructural needs identified in these signalized intersections, and what are the priority investments or actions required to improve the conditions? Thirdly, how can motorcycle taxis, which are the most dangerous road participant types be controlled or regulated to reduce conflicts at intersections?

The ensuing part of this paper has four sections. Section II explains the methodology. The results follow in Section III. The discussion and recommendations are in Section IV. Section V has the conclusion and areas for future research.

II. DATA COLLECTION AND ANALYSIS

This section provides details about the methodology of this research. There are 3 approaches namely: crash data collection and analysis, video data collection and analysis, and survey data collection and analysis. The details for each of these methods are in the ensuing sub-sections.

A. Crash Data Collection and Analysis

The crash data were acquired from the national accident database of Ghana, which is managed by the Building and Road Research Institute of Ghana (BRRI). It is an aggregate of Police crash reports from 2010 to 2018. At the beginning of each year, the staff of the BRRI under the auspices of the National Road Safety Commission (NRSC) visit all police stations to retrieve and transcribe data on all reported crashes for the previous year. This report contains information obtained from surviving traffic crash victims, witnesses, detailed crash sketches, hospital post-mortem reports in the event of fatal crashes, and detailed reports from crash investigators and vehicle examiners [18].

The data were collected and a descriptive analysis was computed. The purpose was to identify the crash patterns among different transport modes and different intersection types at the national level. The transport modes comprised car, heavy goods vehicle (HGV), tractor, bus, minibus, motorcycle, pickup vehicle, bicycle, and others (comprising auto-rickshaw, tricycle, etc.).

B. Video Data Collection and Analysis

Field surveyors did video surveillance at seven signalized intersections in three regional capitals between October and November 2020. The mix of 2020 data with previous crash data (2010 to 2018) was justified because not many changes took place between 2018 and 2020. The intersections were selected from Accra, Kumasi, and Bolgatanga (See Table I). They comprised Madina Zongo Junction, Ashaiman First Light Intersection, Nima Junction, Aboabo Post Office Traffic Light, Amakom Junction, Angloga Junction, and the Abilba Barza Road Intersection. These seven intersections have some variations regarding the number of through-going approach lanes. The Madina Zongo Traffic Light has the highest number of lanes (5 lanes) with the Abilba Barza Road Intersection having a single lane.

The videos covered the morning and afternoon peak hours in the three cities lasting three hours, 6 to 9 a.m. and 3 to 6 p.m. respectively. The field surveyors realized that the morning peak hours in Bolgatanga varied slightly from other cities. The morning peak hours in this city start at 9 a.m. and end at 11 a.m. This is because the commercial activities in the Central Business District (CBD) start around this time of the day. Therefore, morning videos in this city covered 9 to 11 am instead.

The videos lasted a minimum of five hours for each intersection. The reason for this time duration was for the authors to get the best of the usually unnoticed traffic events and violations likely to cause crashes at these intersections. Each intersection was observed on one market day. The worst-case scenario of traffic congestion and intersection bottlenecks occurs on market days.

Next, photos of notable events and scenes from the videos that met the objectives of this study were extracted. They comprised some traffic violations, intersection inefficiencies, infrastructural lapses, pedestrian behaviors, and wrongful vehicle-parking behaviors. Then, the findings were presented in photos and tables with discussions linking them to the extant literature to offer solutions. This is an approach adapted from social science and public health research such as [19-21]. The map shown in Fig. 1 indicates the location of our candidate intersections on the map of Ghana. The relevant sections have been circled in red color.

These intersections were selected based on specific premises. First, Accra and Kumasi are the largest cities in Ghana both in terms of space and population sizes. Bolgatanga represents the Northern part of Ghana, which also has unique heterogeneous traffic. The candidate intersections have heterogeneous traffic and pedestrian crossing behaviors in these cities. They are also close to market centers where traffic is usually congested. Distinctively, the Abilba Barza Road Intersection was selected because it forms part of an important highway that links Ghana to landlocked neighbors such as Burkina Faso and Niger.

C. Survey Data Collection and Analysis

Although several traffic regulations exist in Ghana, motorcycle taxis remain unregulated. We included this survey in the study because motorcycle taxi ridership is a developing trend, which has affected traffic flows for the past decade. It constitutes one of the main challenges of traffic police in Ghana. Motorcycles contribute to several crashes at signalized intersections. Oteng-Ababio and Agyemang [22] studied this problem in Ghana and found that the best solution would be an all-inclusive regulatory framework formed out of consultations of all stakeholders. This analysis is therefore has a direct impact on signalized intersections because of their growing demand. The study will be incomplete without this survey.

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TABLE I. DETAILS OF CANDIDATE INTERSECTIONS AND EXPERIMENTATION DAYS

City	Region	Observed Intersections	Intersection Type	No. of lanes	Date of Observation
Accra	Greater Accra	Nima Junction	T Junction	3	29/10/2020
		Madina Zongo Traffic Light	Crossroad	5	28/10/2020
		Ashaiman First Light	Crossroad	3	07/11/2020
Kumasi	Ashanti	Angloga Junction	Crossroad	2	29/10/2020
		Aboabo Post Office Traffic Light	Crossroad	2	30/10/2020
		Amakom Traffic Light	crossroad	2	30/10/2020
Bolgatanga	Upper East	Abilba Barza Road Intersection	T Junction	1	07/11/2020

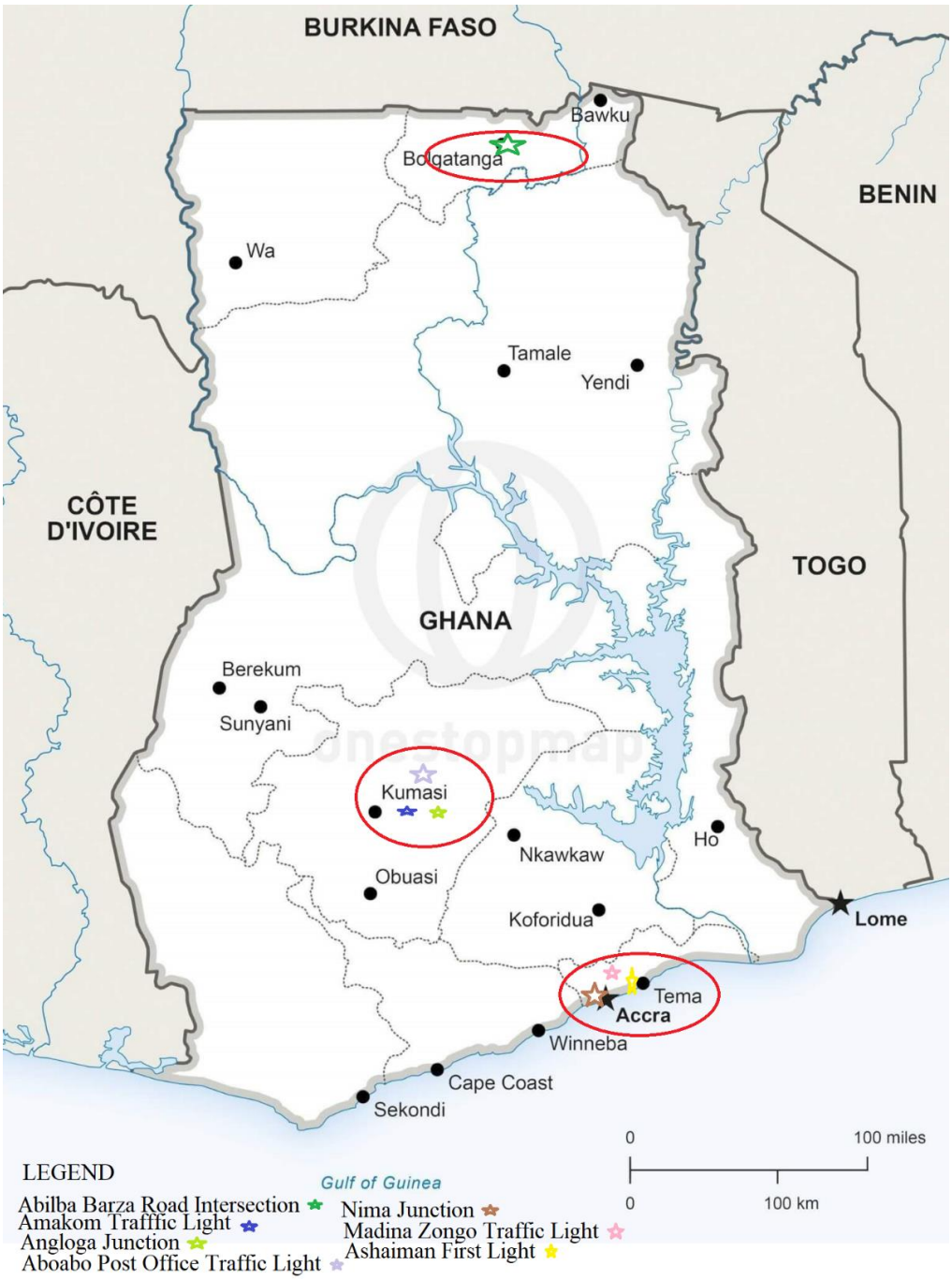

Fig. 1. Political map of Ghana showing the candidate signalized intersections

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Next, a survey involving 1,489 respondents was conducted in September 2020. It was analyzed to make traffic control recommendations regarding motorcycle control. The sampling was purposive for only people who have at least used the motorcycle taxi once either as riders or passengers in their lifetime. The survey data constituted the opinion of users of motorcycle taxis on the expectations for new regulation. The respondents answered an open-ended question that sought one recommendation on what a new regulation for motorcycle taxis should entail. Trained surveyors administered the questionnaire. They administered the questionnaires to drivers, motorcyclists, traffic police, pedestrians, and vehicle passengers along some major road intersections in Ghana. Finally, we analyzed all the findings to identify investments needed in Ghana to make signalized intersections more effective and safer.

III. RESULTS

A. Results of Crash Severity at Intersections

Table II shows the number of crashes among different modes of transport at crossroad and T-junction intersections from 2010 to 2018. Notably, cars had the highest number of crashes at crossroads (7,111) followed by minibuses (2,999). Regarding T-junctions, cars had the highest (14,709) followed by motorcycles (4,495). Table III shows that crashes were prevalent at T Junctions (31,694) and crossroads (15,366).

Besides, the authors identified that in the Southern part of Ghana, cars, HGVs, buses, minibuses, motorcycles, and pickup vehicles are the main transport modes. Some slums have an emergence of auto-rickshaws. In the Northern part, the main modes identified were car, motorcycle, and auto-rickshaws. The accident severity data shows that regarding fatalities at crossroads, cars, motorcycles, and minibuses were the most affected modes of transport in descending order. At T Junctions, fatalities involved motorcycle, car, and HGV in descending order.

Regarding injuries at crossroads, the severities were mainly associated with cars, minibuses, and motorcycles. At T/junctions, cars, motorcycles, and minibuses had the most injury severities. Cars, minibuses, and pickups had more damages in road accidents than other modes. This statistic shows that traffic managers should pay more attention to cars, motorcycles, minibuses, pickups, and HGVs.

B. Results of Video Observation at the Signalized Intersections

This sub-section presents the observations made at all intersections as captured from the various video footage. These are presented in Figs 2 to 8. The red circled portions are points of focus. Further Table VI summarizes the key observations at each of the intersections. Table VII presents the heterogeneous traffic identified at these intersections. The discussions appear in Section IV together with proposed priority investments in Table VIII.

Generally, some findings were identified at all the intersections. The results show a depletion or absence of stop lines and pedestrian crossings in the majority of the intersections we observed. These are basic components of road design that are missing. Other general observations include inadequate signage, and demand exceeding road supply due to conventional signal timings. The mixed traffic flow and non-priority signaling are also common for all intersections.

First, the video data show overspeeding into dilemma zones and conflicts at some intersection left-turns and U-turns (Fig. 2a). The road width is insufficient, requiring optimization of the saturation flows in some intersections (e.g., Fig. 2c). This observation relates to the Ashaiman First Light intersection.

The encroachment of intersections by traders, typically around markets, is another situation that needs urgent attention, especially as the road width per se is already insufficient (Fig. 2c). A non-function or absence of pedestrian signals was found.

The Ashaiman First Light and Madina Zongo Junction have the minibus-parking phenomenon at signalized intersections, which prevents smooth traffic flow and causes traffic conflicts (Figs 2c and 4a).

TABLE II. CRASH SEVERITY AT CROSSROADS AND T JUNCTIONS (2010 TO 2018)

Intersection type	**Severity**	**Transport mode**									**Total**
		Car	***HGV***	***Tractor***	***Bus***	***Minibus***	***Motorcycle***	***Pickup***	***Bicycle***	***Others***	
Crossroads	Fatal	209	98	6	41	167	184	51	30	2	788
	Injury	2,498	421	47	307	1,239	1,100	638	118	14	6,382
	Damage only	4,404	256	78	531	1,593	170	1,147	8	9	8,196
	Total	7,111	775	131	879	2,999	1,454	1,836	156	25	15,366
T/Junction	Fatal	657	318	20	148	307	739	141	109	22	2,461
	Injury	5,844	942	106	856	1,729	3,417	987	368	70	14,319
	Damage only	8,208	1,293	103	1,230	1,983	339	1,572	82	104	14,914
	Total	14,709	2,553	229	2,234	4,019	4,495	2,700	559	196	31,694

TABLE III. CRASH STATISTICS AT INTERSECTIONS (2010 TO 2018)

Intersection type	**Fatal**	**Injury**	**Damage Only**	**Total**
Crossroads	788	6,382	8,196	15,366
T/Junction	2,461	14,319	14,914	31,694
Staggered Crossroads	151	887	899	1,937
Y/Junction	27	227	241	495
Roundabout	115	855	1,367	2,337
Total	3,542	22,670	25,617	51,829

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The Nima Junction mainly had motorcycle violations (Fig. 3). It is not surprising that an on-the-spot motorcycle accident happened during our survey of this intersection. Several motorcyclists moved despite the onset of the red light.

It is not only a traffic violation but also a high risk for a motorcyclist to be on phone in busy traffic. Figs 3e and 6b show some observations of this phenomenon. In relation, some pedestrians prefer to cross the roadway instead of using footbridges (Fig. 4d). The presence of food hawkers in the roadway at the onset of the red signal is also a common phenomenon at signalized intersections in Ghana (e.g., Fig. 4b).

Driver violations were identified in the Angloga Junction as shown in Fig. 5. Drivers should not stop at the pedestrian crossing. When this happens, it reduces the saturation flow of pedestrians. Fig. 6 shows the depleted ground markings at the Amakom Junction.

It was observed that at the Aboabo Post Office Traffic Light, there were non-functional traffic lights, even during peak hours, which created several conflicts among the mixed traffic commodities (see Fig. 7a). This observation however lasted for only the first one hour of the morning peak hour period. The rest of the day had functional traffic lights. Some studies identified poor transportation planning, management, and equipment maintenance in Ghana [23].

The Abilba Barza road intersection being a major route for vehicles going beyond Ghana to Burkina Faso has a mixed flow. The flow is motorcycle-dominated. From Fig. 8, it is evident that it also lacks visible road markings.

(a) crumble at the U-turn (the small road width) (b) vehicle-pedestrian mixed-flow

(c) Minibus parking at the intersection, mixed flow conflicts, road encroachment, no stop line

Fig. 2. Problems identified at the Ashaiman First Light Intersection

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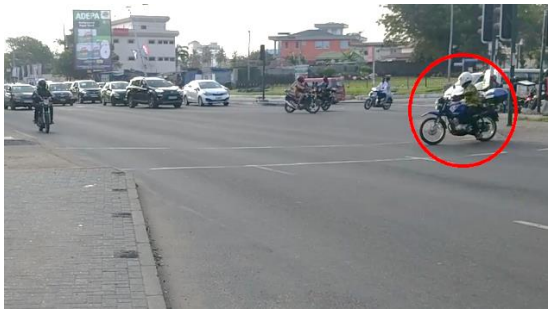
(a) Motorbike moving at the onset of the red signal

(b) Real-time over-speeding accident



(c) Motorcycle veers off opposite lane through crosswalk (heading for a possible crash)

(d) Minibus-motorcycle-bicycle conflict due to traffic violation

(e) Motorcyclist on phone in busy traffic

Fig. 3. Violations identified at Nima Junction

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(a) Minibus parking at intersections obstructs the smooth flow and causes crashes

(b) Several food hawkers in traffic (c) Pedestrians not using the footbridge

(d) Depleted stop lines

Fig. 4. Problems Identified at Madina Zongo Junction

Vehicle stopping in the crosswalk

Fig. 5. Violations identified at Angloga Junction

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(a) Depleted Ground markings (b) Rider on phone in traffic

Fig. 6. Problems identified at Amakom Traffic Light

(a) Non-functional traffic lights causing conflicts (b) Depleted stop line in some lanes

Fig. 7. The situation at Aboabo Traffic Light

Mixed traffic, no stop lines, no pedestrian crossing

Fig. 8. The situation at Abilba Barza road intersection

C. Regulation of Motorcycle taxis

As indicated in the preceding sections, the use of motorcycle taxis remains unregulated. The questionnaire, which was administered, gave some intersection-user feedbacks, which are presented in this section.

Table IV presents the socio-demographic characteristics of the respondents. The general overview is that the respondents included more youth (74.5%), more men (60.8%), and more respondents who have at least been to university (38.4%).

The results in Table V indicate that aside from the demand for separated lanes (bike lanes), registration of the motorcycles, insurance, use of helmets, training for riders, among others dominated the suggestions of our 1,489 respondents across the country. The regularization of motorcycle taxis could therefore consider these findings in doing wider consultations.

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TABLE IV. SUMMARY OF RESPONDENTS' CHARACTERISTICS

Characteristics	Variable	Frequency (n = 1489)	Percentage (%)
Age	18-29	640	43
	30-39	469	31.5
	40-49	236	15.8
	50 plus	144	9.7
Gender	Male	905	60.8
	Female	584	39.2
Academic level	Primary to Junior High School	259	17.4
	Senior High School	373	25.1
	Tertiary Education	409	27.5
	Postgraduate Education	162	10.9
	None	286	19.2

TABLE V. RESPONDENTS' SUGGESTIONS FOR THE REGULATION OF MOTORCYCLE TAXIS

Opinion	Frequency	Percentage (%)
Segregated lanes	309	20.8
Registration and Insurance	300	20.0
Helmet	205	13.8
Training for riders	108	7.3
Standardized pricing	100	6.7
Riders' Union with Uniform	97	6.5
Monitor speed	89	6.0
Payment of Taxes	78	5.2
Limited to 18 years plus	79	5.3
One passenger day-time operation	59	4.0
Designate a number plate	41	2.8
No highway activity	24	1.6

IV. DISCUSSION AND RECOMMENDATIONS

The present study used crash data, video data analysis, and surveys to identify some traffic safety problems, infrastructural gaps, and traffic violations associated with seven signalized intersections in Ghana. The study also solicited road users' opinions on motorcycle taxi regulation in Ghana. The authors sought to identify the problems and propose prioritized investments as well as actions needed to mitigate them.

Regarding the road crashes, the results showed the need to focus more on T Junction and crossroads to unravel evidence-based problems for management and traffic control. Perhaps this is because these two types of intersections have challenges with left-turns and left-turning vehicles (LVs). The literature identifies left-turns as the major cause of crashes at signalized intersections [24-28]. Providing left-turn waiting areas could reduce the conflicts between LVs and through-going vehicles as well as U-turning vehicles [29]. Alternatively, left-turn optimization studies would be useful.

Motorcycle regulation is imperative. Regarding traffic management, decentralizing regulations among the local authorities would help in their registration. For the infrastructure, signalized intersections should have a component for separated flows such as bike lanes and dedicated left-turn movements.

The video surveillance showed several conditions at the candidate intersections summarized in Tables VI and VII below. Interestingly, 9 different vehicle modes of transport were identified in addition to pedestrians. A significant percentage of the candidate intersections have a mixed flow comprising car, bus, minibus, motorcycle, bicycle, HGV, pickup, truck, tricycle, and auto-rickshaw. These vehicles vary in size and speed. How about separating some of the vehicles, which have low speed from the others? Intersection signal control being conventional as it presently is does not suit these flows. At the time these intersections were signalized, the flows were mainly cars, minibuses, and buses. This problem is different from Europe, America, and other advanced economies. The use of intelligent traffic control technologies, a revision of the conventional designs together with signal control, unconventional systems, and new installations are prerequisites to handling these challenges.

One of these unconventional systems is bus priority. Local engineers and international partners can consider this in the future. Some previous studies in Ghana found that commercial transport especially public buses and minibuses get involved in more highway crashes than private vehicles [30-32]. Perhaps this is because there is no priority for these vehicles in the signal cycle.

Usually, when the average delay in the signalized intersection is high, drivers of public transport tend to accelerate on the highway to offset the time spent in the traffic jam. Buses and minibuses constitute the main public road transport. It, therefore, becomes imperative to give priority to these modes in the signal timing at signalized intersections. This would enhance shared mobility and reduce congestion in the cities. Bus priority can reduce bus delays at the intersection by up to 100% [33]. In developing countries, it can improve the level of service of public transportation, reduce operation costs, reduce delays and reduce congestion [34-37].

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TABLE VI. SUMMARY OF OBSERVED PROBLEMS AT THE INTERSECTIONS

Identified Problems	**Signalized Intersections**						
	Nima Junction	***Madina Zongo Traffic Light***	***Ashaiman First Light***	***Angloga Junction***	***Aboabo Traffic Light***	***Amakom Traffic Light***	***Abilba Barza Road***
Conflicting mixed flow	x	x	x	x	x	x	x
Non-prioritized signal	x	x	x	x	x	x	x
Traffic violations	x	x	x	x	x	x	
Unsignalized crosswalk		x	x	x	x	x	x
Minibus parking	x	x	x				
Depleted stop line	x	x	x		x	x	x
Depleted lane markings		x	x		x	x	x
Depleted marked crosswalk	x	x	x		x	x	x
Insufficient road width			x				
Road encroachment by traders			x				
Non-functional traffic light					x		

TABLE VII. HETEROGENEOUS TRAFFIC FLOW AT THE INTERSECTIONS

Intersection	**Transport Modes**								
	Car	***Bus***	***Minibus***	***Motorcycle***	***Bicycle***	***HGV***	***Pickup truck***	***Tricycle***	***Auto-rickshaws***
Nima Junction	x	x	x	x	x	x	x		
Madina Zongo Traffic Light	x	x	x	x	x	x	x		
Ashaiman First Light	x	x	x	x	x	x	x	x	x
Angloga Junction	x	x	x	x	x	x	x		x
Aboabo Traffic Light	x	x	x	x	x	x	x	x	x
Amakom Traffic Light	x	x	x	x	x	x	x	x	x
Abilba Barza Road Intersection	x	x		x	x	x	x	x	x

How about the numerous violations identified? Thi et al. [38] posited that distractions such as mobile phone usage in traffic account for 9% of motorcycle accidents. First, traffic regulations must be strictly implemented. Secondly, road safety education has proven helpful in several countries [39-42]. Perhaps more education and on-the-spot punishments for such offenses could discourage this behavior.

Next, the installation of more surveillance cameras at congested signalized intersections could indirectly control traffic behavior. Humans have been observed to behave better when they see the camera [43-49]. Nonetheless, to make this rigorous, Central traffic control rooms are needed in all the major cities to process and analyze video surveillance data.

Moreover, the deplorable state of road markings at some of the candidate intersections depicts a bigger problem across the country. Road markings must be visible to enhance safety in the road network. In recent times, several researchers have emphasized the importance of visible road markings especially in light of the emergence of autonomous vehicles [50-52]. Others emphasized the need to use sustainable materials for road markings [53]. This would enhance the safety level of the intersections.

Pedestrian behavior has been extensively studied in many countries, but given little attention in Ghana. Why do pedestrians behave in a certain manner? Perhaps this question can lead to more discussions and empirical studies to find engineering solutions. This would be helpful in future designs of road infrastructure performance. It was observed that pedestrians ignored a footbridge next to the Madina Zongo intersection. This would require experimentation and periodic evaluations.

The allocation of off-street parking and loading stations for public transport need engineering attention. The results show how minibuses wrongfully stop in the exit lanes at the Madina Zongo Junction. This bottleneck impedes smooth flow and creates crashes at at-grade intersections. Extant literature on this phenomenon has been largely about prohibition other than modeling engineering solutions. However, we agree with previous studies in Ghana, that identified this same problem and proposed a ban [8,54]. In a recent study in Accra, the creation of off-street car parks for private car parking and public minibuses to pick passengers was proposed [54]. We also propose that off-street parking spaces are provided for the minibuses and private cars that stop along the roads especially at intersections. This would ensure smooth traffic flows.

Another important finding is the street hawking usually at the onset of the red light. This usually occurs at signalized intersections and road sections close to market centers. This is a problem largely found in sub-Saharan Africa. Engineers must find an alternative sales point to end this socio-cultural bottleneck. This problem is a sub-set of the larger street vending problem. Findings show that street vending constitutes as high as 55% of the total number of informal vendors in West African cities [55-58]. However, it is unsafe as it creates pedestrian-vehicle conflicts. Therefore, it requires alternatives.

Regarding traffic light management problems, technologies and up-to-date management decisions are imperative [59]. This problem has been in existence for some years. Twenty road intersections were observed in Accra and several incidents of the traffic lights not functioning were reported [60]. This accounts for some of the road crashes. To solve this problem, traffic managers

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can adopt the PAS 55:2008 asset management standard [61]. This standard was developed by a consortium of 50 organizations from 15 different industry sectors in 10 countries. A fault monitoring system for the LED in traffic lights was also designed by [62]. Their system can notify the managers whenever more than 50% of the LED for the traffic light is not functioning.

Table VIII contains the proposed actions and investments needed for increased safety in each of the studied intersections.

TABLE VIII. PROPOSED ACTIONS FOR EACH INTERSECTION

Intersection	Proposed Investments and Actions
Nima Junction	Provide visible stop lines and lane markings, install segregated bike lanes, bus priority signals, monitor motorcycle taxi violations
Madina Zongo Traffic Light	Provide visible stop lines and crosswalks, install segregated bike lanes, bus priority signals, enforce pedestrian use of footbridge, provide off-street parking for minibusses, stop food hawkers from entering the vehicle lanes, install left-turn waiting areas
Ashaiman First Light	Provide visible stop lines and lane markings, install segregated bike lanes, bus priority signals, provide signalized crosswalks, stop road encroachment, optimize u-turn signals, allocate off-street parking for minibuses
Angloga Junction	Signalize crosswalks, improve the surveillance of motorcyclists, bus priority signals
Aboabo Traffic Light	Provide visible stop lines and lane markings, improve the surveillance of motorcyclists, install segregated bike lanes, replace non-functioning traffic lights
Amakom Traffic Light	Provide visible stop lines and lane markings, improve the surveillance of motorcyclists, bus priority signals
Abilba Barza Road Intersection	Provide visible stop lines and lane markings, segregated bike lanes

V. CONCLUSION AND FUTURE RESEARCH

This paper audited some traffic problems at seven signalized intersections in Ghana using video data, crash data, and surveys. Specific traffic problems, violations, and infrastructural inefficiencies were identified.

Some of the traffic safety problems found at the intersections are the use of conventional signaling, mixed flow crossing, mixed flow signaling, depleted pedestrian crossing, unsignalized crosswalks, malfunctioning traffic lights, insufficient road-width, parking of minibuses close to signalized intersections, and depleted road markings. Traffic violations identified include motorcyclists moving at the onset of the red light, motorcyclists on phone in traffic, over-speeding impacting dilemma zones, pedestrians neglecting footbridges, and in-lane hawking at the onset of the red signal.

In summary, the short and medium-term prioritized investments needed to address the problems are as follows:

1) Marking of visible stop lines and crosswalks at all signalized intersections;

2) Signalizing crosswalks at all signalized intersections;

3) Replacement of all non-functioning traffic lights;

4) Installation of segregated lanes for motorcycles and bicycles especially at signalized intersections;

5) Enactment of new regulations for motorcycling mobility;

6) Allotment of off-street parking spaces for commercial minibuses;

7) Enforcement of footbridge regulations;

8) Creation of a Central traffic control room in all major cities;

9) Banning food hawkers from road traffic;

10) Relocation of road encroachers at signalized intersections;

11) Adoption of a national maintenance plan for traffic light management;

12) Prioritize public buses and motorcycles in the signal control;

13) Engineering of new intersection designs to incorporate bike lanes and left-turn waiting areas.

This paper has several contributions. Although previous traffic studies have dealt extensively with signalized intersections, there is little research from sub-Saharan Africa. It is useful to the government of Ghana and its traffic development partners as it shows priority areas for investments regarding the studied intersections. Also, traffic safety analyses related to signalized intersections often focus on vehicle movements other than the infrastructure. However, this study observed several intersections and different problems for better diagnoses of the problems. Furthermore, the mix of statistical data and field observation gives credence to the findings and implementation of the recommendations.

Beyond these, the results present problems to the attention of the research community and traffic managers. At the global level, our results could give valuable guidance to several countries in solving their peculiar traffic safety problems as well as filling their infrastructure and traffic regulation gaps at signalized intersections. To the government, they can identify priority investments to improve traffic management. The traffic violations that were identified need more attention from the Ghana Road Safety Commission and the Motor Traffic and Transport Division of the Ghana Police service. The research community also gets an understanding of the situation in Ghana and Sub-Saharan Africa to enrich technical discussions among traffic management experts.

A. Limitation and Future Direction

The crash data were highly reliable in the formulation of the problem but the study extensively relied on video footage because of the real-time reports it gave. However, undertaking the video experiment was not only an expensive venture but also stressful.

Future studies should do a disaggregated study of these intersections and the problems presented using machine

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learning to capture real-time conflicts. The authors intend to do further modeling of the identified bottlenecks. Extra research is required to understand pedestrian traffic violations at the intersections peculiar to different parts of the country. Further, the bottlenecks at the signalized intersections, such as in-lane food hawking, road encroachment by street vendors along the corridors, driver-pedestrian behaviors, and parking behaviors need alternative solutions. The depleted state of road markings presents an important problem in traffic management.

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