Surrogate Safety Assessment of Crosswalks Incorporated Intersection

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Abstract— *Vehicle-Pedestrian interaction has the tendency of increasing the crash rate as the number of pedestrians and vehicles increases on the roads. Models exist that predict the rate of road accident crashes using traffic counts without taking into considerations intersection designs implementations that can influence crash rate. Moreover, pedestrian crash database records are often sparsely available. A surrogate safety measure is therefore necessary to evaluate safety implications of different intersection designs and traffic control strategies as a means of proactive safety solution. In this research, three traffic control strategies were modelled for a crosswalk incorporated four-way intersection. The traffic network was implemented as unsignalized intersection, signalized fixed time traffic control and as Fuzzy Intelligent Traffic Control (FITC) using VerkehrInStadten-SIMulationsModell (VISSIM) traffic simulator. Trajectory files from the network were analyzed and the potential interaction between vehicles and pedestrians at these intersections were quantified using surrogate safety parameters. The results indicate the safety status of each traffic control strategy.*

Keywords— Vehicle, Pedestrian, surrogate, crosswalk, road, simulator;

I. Introduction

The place where two or more roads meet or cross each other is called an intersection. Intersections with traffic controls such as stop signs, markings or managed by authorized personnel are referred to as controlled intersections [10]. Intersections controlled by automatic traffic signals are called signalized intersections. Intersections that are not controlled by traffic signs, markings, authorized personnel or automatic traffic signals – leaving priority and traffic flow at the discretion of the road users – are referred to as uncontrolled intersections [25]. Increase in vehicular traffic without adequate provision for pedestrians can lead to increased road traffic crashes and injury. Inadequate provision for pedestrian needs in roadway design and land-use planning makes pedestrian increasingly susceptible to road traffic injury [2].

A pedestrian crossing is a point on a road where pedestrians traverse the road [22]. Pedestrian crossings, sometimes referred to as crosswalks, may be found at intersections or along road stretches. Marked crossings are designated by markings on the road, commonly white stripes. Signalized crossings include automatic traffic signals control that indicates to pedestrians when they should cross the road.

It is then clear that a pedestrian has to share roads, streets, roundabouts, walk ways and such likes with other users like motorbikes, bicycles, vehicles and co-pedestrians as the case may be. This makes the safety of lives a serious issue that deserves road safety considerations [1]. Pedestrians are categorized as vulnerable road users [5]. Pedestrian crossing control presents a challenge for town planners and transportation professionals given the need to accommodate pedestrians safely in an interactive manner with other users of the transportation infrastructures [17].

A. Road Traffic Crash

A road traffic crash is a collision or incident involving at least one vehicle in motion, on a public road or private road to which the public has right of access, resulting in at least one injured or killed person [22]. Included in these are: collisions between road vehicles; between road vehicles and pedestrians; between road vehicles and animals or fixed obstacles or with one road vehicle alone. Included are collisions between road and rail vehicles [25]. During planning for new infrastructures for vehicular traffic, it is a common thing to make predictions of future traffic situation to enable prioritization among various projects. This often times exclude prediction for safety implications.

This work therefore reviewed safety implications of vehicle pedestrian interaction through literatures and modelled three different traffic control strategies at a crosswalk incorporated four-way intersection and evaluate their potential safety implications.

II. Literature Review

Understanding of safety traffic situation is of practical importance when planning for road infrastructures. Quantitative models of vehicular traffic had long been incorporated in various town planning works without corresponding modelling of pedestrian traffic and the associated safety implications [14] [22]

[13] Conducted a survey of pedestrian/vehicular crash in a tertiary hospital in South Western part of Nigeria. A total of 184 patients with a mean value of the ages of 31.4 years were studied; the mortality rate was 31.0%. This obviously demands attention; pedestrian safety has always been a major issue in any country. According to [18], pedestrian crash rate was highest from 2011 through 2013, which is 14% as reflected in Table 1.

Table 1: Pedestrian Fatality Rate from 2004-2013 [18]

Year	Total Fatalities	Pedestrian Fatalities	Percentage of Pedestrian to Total Fatalities
2004	42,836	4,675	11%
2005	43,510	4,892	11%
2006	42,708	4,795	11%
2007	41,259	4,699	11%
2008	37,423	4,414	12%
2009	33,883	4,109	12%
2010	32,999	4,302	13%
2011	32,479	4,457	14%
2012	33,782	4,818	14%
2013	32,719	4,735	14%

A five year (2007 – 2011) range crash report from across Nigeria is represented in Table 2. This five year range report recorded average of 5.0 fatality rate per 100,000 population.

Table 2: Pedestrian crash data in Nigeria [24]

Year	Number of cases	Number killed	Fatality rate per 100,000 population	Fatality rate per 10,000 vehicles
2007	8,477	4,673	9	NA
2008	11,341	6,661	6	NA
2009	10,854	5,693	5	NA
2010	5,330	4,065	4	NA
2011	4,765	4,327	4	6
Average	8,153	5,084	5	NA

For the purpose of this research, pedestrian crash data was obtained from road safety command in Kano. This report recorded 495 pedestrian/vehicular crashes from 2007 to 2014 in Kano State.

Many studies have examined the effect of various intersection and traffic characteristics that impact pedestrian safety based on the available crash values, and field observations [7][8]

Microscopic traffic modelling is a technique that takes into consideration the detail characteristics of the entity in view. It is a tool that can be used to bring to picture the interactions between the traffic components and the pedestrians [3]. Modelling can be used to measure or quantify situations to enable prediction or projection of future situations of the system being represented by a model.

[15] Made use of micro-simulation software (VerkehrInStadten-SIMulationsmodell (VISSIM) to analyze delays resulting from varying pedestrian and vehicle volumes on a network of three intersections in Portland. From a pedestrian's point of view, free operation was found to be always beneficial due to lower pedestrian delays. However, from a system wider perspective, free operation was found to be beneficial only under low-medium traffic conditions, while coordinated operation showed higher performance under heavy traffic conditions, irrespective of the volume of pedestrians. Investigation into Safety and efficiency trade-off was not considered but one of the areas of recommendation for further research.

A. Traffic Safety Evaluation Parameters

[19] Highlight the factors for seeking improved pedestrian facilities as defect in any or combination of the following Traffic Evaluation Parameters: Level of service (LOS) pedestrian waiting time, Pedestrian Crossing time, Crash rate and Vehicular delay. Of paramount importance to this research is crash rate and its potential implications.

1) Crash Rate

Crash rates is an effective tool to measure the relative safety at a particular location. The calculation of crash frequency (crashes per year) divided by vehicle exposure (traffic volumes, or roadway length) results in crash rate. Crash rate analysis can be a useful tool to determine how a specific roadway or segment compares to an average roadway on the network. A count of the number of crashes is often inadequate when comparing multiple roadways of varying lengths and/or traffic volume. Crash rate is often used to prioritize locations for safety improvements when working with limited budgets and trying to achieve the greatest safety benefits with limited resources [9] [12]. Exposure is often represented by number of vehicles using the route or by the length of the roadway. Where traffic volume data is unavailable, other information can be used to provide exposure information.

One often-used factor is the length of the roadway segment on each route studied [4].

2) Surrogate Safety Assessment Model (SSAM)

SSAM is a safety tool box that utilizes the microscopic traffic simulation vehicle trajectories to generate safety performance measures. According to [11] the safety parameters are:

a. Minimum Time to Collision (TTC) is the minimum time-to-collision value observed during the potential conflict. This estimate is based on the current location, speed, and future trajectory of two objects at a given instant. TTC value is defined for each time-step during the conflict event. A conflict event is concluded after the TTC value rises back above the critical threshold value. This value is recorded in seconds.

b. Minimum post-encroachment time (PET) is the minimum post-encroachment time observed during the conflict. PET is the time between when the first object last occupied a position and the time when the second object subsequently arrived at the same position. A value of zero indicates a collision. A conflict event is concluded when the final PET value is recorded at the last location where a TTC value was still below the critical threshold value. This value is recorded in seconds.

c. Initial deceleration rate (DR): *DR* is the initial deceleration rate of the second object, recorded as the instantaneous acceleration rate. If the vehicle brakes (i.e., reacts), this is the first negative acceleration value observed during the conflict. If the vehicle does not decelerate, this is the lowest acceleration value observed during the conflict. This value is expressed in meters per second, depending as specified in the corresponding trajectory file.

d. Maximum speed (MaxS) is the maximum speed of either object throughout the conflict (i.e., while the TTC is less than 1.5 sec). This value is expressed in meters per second,

e. Maximum relative speed difference (DeltaS). *DeltaS* is the difference in objects speeds as observed at tMinTTC (the minimum TTC value). More precisely, this value is mathematically defined as the magnitude of the difference in object's velocities (or trajectories), such that if $v1$ and $v2$ are the velocity vectors of the first and second objects respectively, then DeltaS = $\| v1 - v2 \|$. if both objects are traveling at the same speed, v and in the same direction, DeltaS = 0. If they have a perpendicular crossing path, DeltaS = $(\sqrt{2})\ v$. If they are approaching each other head on, DeltaS = $2v$.

f. *MaxD* is the maximum deceleration of the second objects, recorded as the minimum instantaneous acceleration rate observed during the conflict. A negative value indicates deceleration (braking or release of gas pedal). A positive value indicates that the vehicle did not decelerate during the conflict. This value is expressed in meters per second.

g. Clash types: *ConflictType*, describes whether the conflict is the result of rear-end, lane-change, or crossing movement. If link and lane information is not available for both objects, then the event type is classified based solely on the absolute value of the ConflictAngle. The type is classified as a rear-end conflict if ||ConflictAngle|| < 30 degrees, a crossing conflict if ||ConflictAngle|| > 85 degrees, or otherwise a lane-change conflict.

From literature, so far, it has been established that the rates of pedestrian/vehicular fatalities are very high and deserves appropriate attention. Researchers have identified lack of adequate pedestrian facilities, human factors (non-compliance drivers, prolong pedestrians delay), considerations for vehicular traffic without corresponding attention to pedestrian traffic and inappropriate traffic control strategy as major reasons for these fatalities [12] [6]. Hence, this paper models four-way intersection and implement three different control strategies and evaluate their safety implications.

III. METHODOLOGY

VISSIM Microscopic simulation software was used to implement the road traffic network, comprising of vehicle and pedestrian links as well as the flow entities. General process of road network model development comprises of network geometry designs, modelling of associated traffic parameters, placement of routing decisions, designing priority movement for conflict areas, geometry of intersection modelling with coding of conventional intersection characteristics and signal designs. All the intersection was modelled with crosswalks and each has stop lines placed before the intersection. The traffic networks were modelled as unsignalized (intersection without signal) and signalized with fixed time signal control allocation.

For Fuzzy intelligent traffic control model, MATLAB was interface with VISSIM to generate the signal control time that is based on prevailing traffic situation. Parameters such as vehicle traffic count, total number of pedestrians and pedestrian delay at crosswalk were fuzzily to generate the adequate time allocation for each lane. This made the signal control dynamic and traffic situation dependent.

The models were evaluated using several scenarios varying traffic parameters. VISSIM has the ability to record the movement of each vehicle and pedestrian with all of their associated attributes such as acceleration, direction, speed and export it to a trajectory file for further analysis. This trajectory file is used as input into the SSAM software for analyzing potential conflicts. The system projects the path of all vehicles and pedestrians and calculates the distance between adjacent objects in the network. Based on the surrogate safety measure, if a vehicle is in close proximity to another vehicle or a pedestrian, the value of TTC will be less than the critical value of 1.5 sec. Then, the SSAM identifies it as a dangerous situation and reports it as a potential conflict.
For every simulation run, the SSAM recorded individual conflict that were exported in comma separated value (CSV) file. The potential conflict through the analysis of trajectory file was used to calculate the crash rate. The results were discussed, comparison made with crash data from Kano, Nigeria.

IV. IMPLEMEMTATION

The model for the implementation of this work was done in VISSIM and Intelligence control built in MATLAB.

A. *General simulation settings*

A four-way intersection with multiple lanes and pedestrian crossing was modelled so as to generate various traffic types, using various scenarios based on traffic volumes to measure objects interactions and evaluate the management of right of way amidst the road users. Vehicle volume ranges from 100 to 1000 on each link, at the increment of 100. The vehicle volume was based on average vehicle counts obtained from Federal Road Safety corps in Kano. Pedestrian volumes range from 20 to 120 at the increment of 10 on each pedestrian crosswalks across each link.
Simulation run length is 3600 sec. The simulation speed is set to maximum speed depending on the speed of the processor. The snapshot of this setting is in Figure 1.

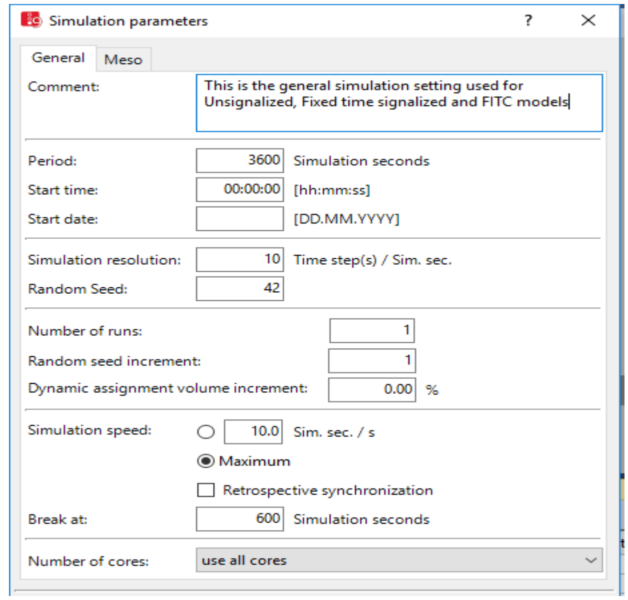

Figure 1: General simulation settings

B. *Vehicle Types*

Vehicle type is used to form a group of vehicles with the same technical driving characteristic. The vehicle type data take part in calculations of delays, emission and travel time. VISSIM provides the following default vehicle types which are: car, bus, HGV, motor bike and pedestrian (modelled as vehicle types)

Table 3: Summary of traffic compositions

Identification number	Types	Category	Length (m)	Width(m)	Relative flow
100	car	Different types of cars	3.75 – 4.7	1.85 – 2.07	0.5
200	HGV	Heavy Good vehicle	12.4	3.04	0.01
300	Bus	Bus	12.4	3.04	0.3
610	Bike Man	Male motor bike	1.77	0.63	0.09
620	Bike woman	Female motor bike	1.77	0.66	0.02
510	Pedestrian	Man	0.41 – 0.46	0.57 – 0.63	0.4
520	pedestrian	Woman	0.31 – 0.4	0.46 – 0.5	0.4
530	pedestrian	Parent	0.36	0.94	0.2

C. *The Models*

1) *Unsignalized Road network*

Figure 2 is model of a crosswalks incorporated four-way intersection road network without signal control. What exist here is a freeway operation stop signs. Vehicles stops for pedestrians using priority rules. There is no consideration for pedestrian delay and number of pedestrians on the crosswalk when using priority rules or conflict areas. Trajectory files obtained from various simulations for safety performance evaluation.

Figure 2: Sample Road Network Scenario without signals

2) *Signalized Road Network*

A four-lane road intersection along state road, Nassarawa area in Kano, Nigeria, was modeled to implement the road network. The intersection comprises of Maiquan Road, Tarauni road, Farm Center road and State road.

The model of fixed time signal control is placed in Figure 3. For fixed time signal control, there were four signal heads for vehicles and four signal head for pedestrians' crosswalks. The signal heads are controlled by fixed signal time allocation programs.

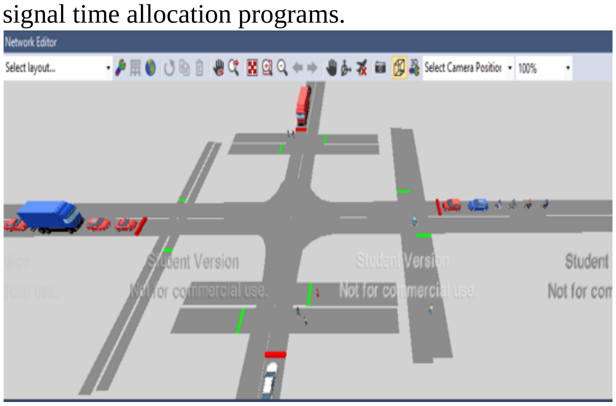

Figure 3: Fixed time traffic signal control Network

3) *Fuzzy Intelligent Traffic Control Network.*

For the implementation of intelligently influenced network, the following were the additional modeling procedures so as to obtain necessary information/data that can be inputted into the fuzzy reasoner for computation of appropriate signal time.

a. placement of detectors on various links for vehicle count

b. configurations to connect detectors to respective signal heads

c. Detectors identified vehicles and pedestrian types for data collection and transfer information to appropriate files.

d. The fixed time actuated program was replaced with FITC program from MATLAB using Common Object Module (COM) interface to control the signal timing allocation.

Figure 4 is the snapshot of the FITC model network.

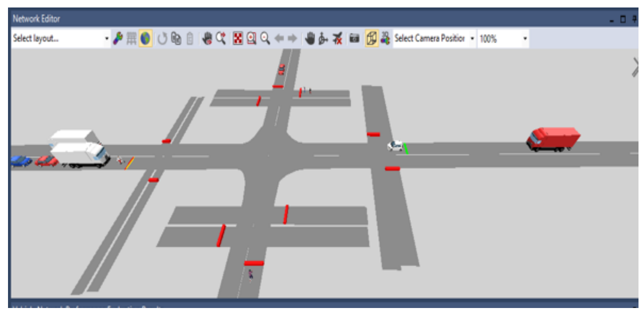

Figure 4: Model of FISC Road Network

V. Results and Discussions

A. *Trajectory file Analysis Result*

VISSIM trajectory files for unsignalized, fixed time traffic and FITC were analysed, the crash analysis report summary is represented in Tables 4 and 5 respectively. Maximum of Thirty-seven (37) potential crashes were reported for unsignalized network, while Five (5) potential crash cases were reported for fixed time and one (1) potential crash case was reported for FITC based on TTC <=1.5sec.

Table 4: Fixed Time Model Crash Report

SSAM 5Measurement	Minimum	Maximum	Mean	Variance
TTC	0.8	1.50	1.28	0.09
PET	1.20	4.10	2.12	1.40
MaxS	1.45	15.48	5.24	33.57
DeltaS	0.79	15.65	4.45	39.74
DR	-10.00	0.00	-4.52	21.54
MaxD	-10.00	0.00	-5.16	20.99
MaxDeltaV	0.41	15.39	3.86	41.80
Total potential Crash	Unclassified	Crossing	Rearend	lanechange
5	0	1	4	0

Table 5: FITC potential crash report

SSAM Measurement	Minimum	Maximum	Mean	Variance
TTC	0.9	0.9	0.9	0
PET	1.19998	1.19998	1.19998	0
MaxS	1.32762	1.32762	1.32762	0
Delta S	0.213702	0.213702	0.213702	0
DR	-10	-10	-10	0
MaxD	-10	-10	-10	0
MaxDeltaV	0.138099	0.138099	0.138099	0.138099
Total potential Crash	Unclassified	Crossing	Rearend	lanechange
1	0	0	1	0

The potential crash summary is presented in Table 6. The maximum potential crash count was obtained from unsignalized network.

Table 6: Potential Crash summary

Vehicle Volume	**Pedestrian Vol.**	**TTC Value(sec)**	**Total Clash**	**Traffic control**
4000	968	<= 1.5	1	FITC
4000	968	<= 1.5	5	Fixed time
4000	968	<=1.5	37	Unsignalized

a) Crash Rate Analysis

Crash rate (per million entering vehicles) takes into account the total number of crashes compared to the average traffic volume. Crash rate for the fixed time, FITC system and real life crash cases was computed and compared to assess the safety improvement of the system. According to [21], crash can be computed according to Equation (1)

$$\text{Crash rate}=\frac{N}{(\sum ADT)*3\ years*365\ days*10-6} \quad (1)$$

where,

ADT = is the average daily traffic entering the intersection

N = the total number of crashes at the particular location

Kano municipal crash analysis result based on Equation (1) is represented in Table 7.

Table 7: Kano five-year crash rate

Year	Avg. daily vehicle count	Crash cases	crash rate
2014	8474	28	3.02
2013	7868	36	4.18
2012	7950	21	2.41
2011	7412	17	2.09
2010	8999	24	2.44
		Five years' crash rate average	2.83

From Table 8, the crash rate of FITC system has the smallest crash rate. This indicates that it is a safer system.

Table 8: Real life crash rate and Potential Crash rate from simulated traffic

	Traffic count	Crash rate
Fixed time	9936	1.84
Fuzzy Int.	9936	0.37
Real life crash rate	8948	2.83

VI. Conclusion

This research has demonstrated that it is possible to intelligently take into consideration the interest of various road users in signal time allocation at signalized intersections. It is also clear from this research that effective traffic control strategies can adequately reduce crash rate and thereby improve safety.

References

[1] Akomolafe B. (2014) Transport Leave a Comment Daily Newswatch, http://www.mydailynewswatchng.com/author/web-officer-2/ July 17, 2014

[2] Agarwal, N. K., (2011) Estimation of Pedestrian Safety At Intersections Using Simulation and Surrogate Safety Measures. *University of Kentucky Doctoral Dissertations.* Paper 835.

http://uknowledge.uky.edu/gradschool_diss/835 retrieve on 5/10/2015

[3] Alexandersson S. and Johansson E. (2013) Pedestrians in Microscopic Traffic Simulation Comparison Between Software Viswalk and Legion for Aimsun; Department of Civil and Environmental Engineering Division of GeoEngineering, Chalmers University Of Technology Othenburg, Sweden pp 69-75

[4] Alluri P., Haleem K., Gan A, Lavasani M. and Saha D. (2015) Comprehensive Study to Reduce Pedestrian Crashes in Florida; Research Center Florida Department of Transportation 605 Suwannee Street, M.S. 30 Tallahassee, FL 32399 0450

[5] Armsby, P. M. (1996) An intelligent pedestrian device: social, psychological and other issues of feasibility. PhD thesis, Middlesex University. http://eprints.mdx.ac.uk/9847/ retrieved on October 10th, 2014

[6] Aworemi, J. R., Abdul-Azeez, I. A., Olabode, S. O.(2010) Analytical study of the causal factors of road traffic crashes in southwestern Nigeria International Research Journals Vol. 1(4): 118-124 May 2010 http://www.interesjournals.org/ER

[7] Bonisch C. and Kretz T. (2009) Simulation of Pedestrians Crossing a Street PTV Planung Transport Verkehr AG Stumpfstra_e D-76131 Karlsruhe pp 1-9

[8] Chertock A., Kurganov A., Polizzi A. And Timofeyev I. (2014) Pedestrian Flow Models With Slowdown Interactions *Mathematical Models and Methods in Applied Sciences* World Scientific Publishing Company 24(2):249–275.

[9] Clifton K. J., Burnier C.V., and Akar G. (2009) Severity of Injury Resulting from Pedestrian–Vehicle Crashes: What can we learn from examining the built environment? *Transportation Research Part D,* www.elsevier.com/ locate/ trd.

[10] Fisher C. (2013) http://planphilly.com/articles/2013/01/07/voice-automated-pedestrian-

signals- get-mixed- reviews. Retrieve, November 29th 2013

[11] High Way Capacity Manual (HCM) (2000) Transportation Research Board, National Research Council, National Academy of Sciences, Transportation Research Board, National Academies, Washington DC.

[12] Hunter W. W., Stutts J. C., Pein W. E., and Cox C.L., (2012) Pedestrian and Bicyclist Intersection Safety Indices Final Report Publication Number: FHWA-HRT-06-125, www.fhwa.dot.gov/publications/research/safety/pedbike/ retrieved 12/07/2014

[13] Ifesanya A.O., Afuwape D, Okoje VN, Agunloye A, Odole O, Okolo CA, Alonge T. O Unintentional injury outcomes secondary to pedestrian traffic crashes: a descriptive analysis from a major medical center. Prehosp Disaster Med. http://www.ncbi.nlm.nih.gov/pubmed/20066649#(retrieved september 9th, 2014)

[14] Johansson F. (2013) Microscopic Modeling and Simulation of Pedestrian Traffic Department of Science and Technology, Linköping University, SE-Norrköping, Sweden.

[15] Kothuri S. M. (2014) Exploring Pedestrian Responsive Traffic Signal Timing Strategies in Urban Areas, Portland State University, http://pdxscholar.library.pdx.edu/open_access_etds May 10th 2016

[16] Markowitz F and Montufar J. (2012) Developments in Automated Pedestrian Detection, http://www.ite.org/membersonly/techconference/2012/CB12C2503.pdf

[17] Montufar J. (2013); Development of a National Pedestrian Crossing Control Guide Transportation Research Board, Washington D.C

[18] National Highway Traffic Safety Report (NHTSA) (2013) http://www.nhtsa.gov/NCSA September 24, 2013

[19] NZ.(2015) Transport Agency, all rights reserved https://www.nzta.govt.nz/assets/resources/pedestrian-planning-guide/docs/guidelines-selection-of-pedestrian-facilities.pdf retrieved August 23rd ,2013

[20] Odeleye J. A. (2002) Zebra Crossing and Pedestrian Safety Management in Road Traffic Environment in Metropolitan Lagos, Nigeria 15th ICTCT workshop measures and their effects. Czech Republic. pp 1-8

[21] ODOT (2011) Protocol For Vissim Simulation, Oregon Department of Transportation https://www.oregon.gov/ODOT/TD/TP/APM/Add15A.pdf, Retrieved on August 23rd , 2013

[22] Papacostas C.S. and Prevedouros P. D. (2008) Transporation Engineering and Planning, third Edition, Prentice-Hall of India Private Limited

[23] PTV (2011) VISSIM Traffic flow simulation – Technical Description, PTV Planung Transport Verkehr AG. Germany. https://www.scribd.com/document/334457119/Vissim-8-Manual-pdf

[24] Sumaila, A. F. (2013). Road crashes trends and safety management in Nigeria, www.nigeriawatch.org/media/html/WP6VitusV6Final.pdf

[25] WHO (2013a) Pedestrian Safety- a Road Safety Manual for Decision-Makers and Practitioners. www.who.int/roadsafety/projects/manuals/pedestrian_manual.pdf September 4, 2013

[26] WHO (2013b), Global Status Report on Road Safety Supporting a Decade of Action www.who.int/...injury.../road_safety_status/2015/GSRRS2015_Summary_EN_final.pdf September 4, 2013