TEMPORAL TRENDS IN PEDESTRIAN CHARACTERISTICS

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ABSTRACT

The aim of this study was to determine pedestrian flow parameters needed in the design of pedestrian facilities. The study also modelled the flow parameters towards understanding pedestrian interaction problems especially with regards to their congestion and evacuation needs. Twenty-five locations across Kano metropolis were selected for study, thirteen locations from the city district while twelve sites were chosen from the Waje district. All the sites were high flow pedestrian locations that met the study objectives. The results indicated that adult women walked faster than their male counterparts in the city district while young males were faster than the female. The adult female recorded a mean speed of 73.90 m/min against 71.30 m/min for the adult male. The characteristics of the pedestrian in the city district are Speed 67.30 m/min; density 11.23 Ped/m^2 and volume 33.60 Ped/m/min. In the Waje district, however, the male pedestrian whether adult or young walked faster than their corresponding female counterparts with speed of 71.45m/min for the adult male and 59.90 m/min for the adult female. The young male was faster than the young female by 17.9%. The pedestrian characteristics for the Waje district indicated a combine speed of 60.21 m/min; density of 8.72 Ped/sqm and volume of 30.92 Ped/m/min. The pedestrians in the city district had a higher flow rate, higher density and higher speed than those of the Waje district. This means the city district is a little more concentrated than the Waje district in terms of pedestrian flow. The aggregate characteristics of pedestrians in the metropolitan area gave the following parameters: Speed 68.92 m/min; density 10.03 Ped/m^2 and volume 32.33 Ped/m/min. The predictive models for Kano showed a free flow speed of 59.86 m/min and a maximum flow rate of 72.40 Ped/m/min. Comparing the Kano pedestrian model with other countries it was found that the Kano pedestrian walked slower than pedestrians from Singapore and the United States.

Keywords: Pedestrian characteristics; Density; Walking speed; Young Male, Adult Male.

1. INTRODUCTION

In most urban cities of the world, walking is the ultimate transport mode in downtown areas. The location of urban facilities adjacent to each other, coupled with increasing population of vehicles and the lack of space in the urban environment to build elaborate parking systems invites the use of walking for pedestrians to reach their destinations. In any case, walking is needed in order to complete trips inside central business areas (CBA's). Pedestrian flow is a complex system. It may consist of one-directional movement, two-directional movements, and other self-organising phenomena. Pedestrian movement is important in the analysis and design of transportation facilities, such as walkways, traffic intersections, crosswalks, markets, and other public buildings. Therefore, it is necessary to understand the characteristics of pedestrian flow in various scenarios. These pedestrian problems including various self-organization phenomena and evacuation design are continually being investigated together with models to reproduce pedestrian bahaviour. Among the various pedestrian facilities, crosswalks with traffic signals are considered as complex and critical ones. The operational efficiency and safety performance of vehicular traffic and pedestrian flows are a very important concern at these facilities where different users have to share the same space. Their geometry and configuration including width, position and angle directly affects the safety, cycle length and resulting delays for all users.

In the Kano urban environment, pedestrian-vehicular conflicts are common. At market places, schools, universities, downtown shopping areas, high density residential locations and industrial lots pedestrianized traffic are a common sight. Therefore, it is important to understand pedestrian behaviours, which are significant for the planning and design of pedestrian facilities especially during peak hours when there are massive pedestrian flows. One of the important factors affecting the behaviour and property of pedestrian flow in walkways is the dimensions and layout of those walkways. In fact, the design and layout of walkways are not as regular as those of roadways and are more complex, in that those walkways may have several openings, uncertain boundary or internal obstacles, and support the movement in several directions. Thus, the flow patterns existing in walkways need to be studied for Kano metropolis.

Kano is highly populated and it is an industrial centre manufacturing products for the region and distributing same to neighbouring states and beyond. Kano thus has a large transient population. The objectives of this paper are to examine the changes in pedestrian characteristics with time over the period of the day and to study the macroscopic features of pedestrian flow.

2. LITERATURE REVIEW

Pedestrian movement is a multifaceted phenomenon. Unlike vehicles, pedestrians are not completely channelized in their movement. They therefore exhibit features that are different from vehicles. Pedestrian research dates back to the late 1930's. Different researchers with varied motives and background have looked into the problem of pedestrian flows. When individual pedestrian movements have been of concern, microscopic models are applied such as the work of Blue and Adler (2001), Burstedde et al. (2001), Fukamachi and Nagatani (2007), Guo et al. (2010) amongst others. Where crowds of pedestrians need to be analysed or pedestrians flow in a stream-like fashion macroscopic models are best suited for analysis. Efforts in this direction are presented by Chandra and Bharti (2013) and summarized in Table 1.

Table 1: Pedestrian Characteristic Study for Different Countries.

Source	Country	Pedestrian flow type	Facility	Speed-Density relationship
Older [7]	Britain	Shoppers	Walkway (Indoor)	v= 1.31-0.34k
Navin and Wheeler [8]	USA	Students	Walkway(Outdoor)	v=2.13-0.79k
Fruin [9]	USA	Commuters	Walkway(Outdoor)	v =1.43-0.35k
Lam *et al*. [10]	China	Mixed	Walkway (indoor)	v=1.29-0.36k
			Walkway (outdoor)	$v=e^{0.38-0.57k}$
			crosswalk	$v=1.47e^{-0.347k2}$
Virkler and Elayadath (11)	USA	Mixed	Walkways (indoors)	$v=1.01e^{-0.247k}$ k <1.07
				v=0.61ln(0.432/k) k >1.07
Teknomo [12]	Japan	Mixed	Crosswalks (Simulation)	v=1.02-0.36k (One way)
				v=1.2-0.217ln(100k) (Two way)
Sarkar and Janardhan [13]	India	Mixed	Walkways (Indoor)	v = 1.46 -0.35k
Tanaboriboon and Guyano (14)	Thailand	Mixed	Walkways (Indoors)	v = 1.2 -0.22k
Tanaboriboon *et al*. [15]	Singapore	Mixed	Walkways (Indoors)	v = 1.23-0.26k

Pedestrian characteristic study trends shown in Table 1 give a chronology of research in the area. Fruin (1971) considered pedestrians inside the Port Authority Bus Terminal and Penns Station in New York City that carried no baggage. Wilson and Grayson (1980) focussed their study on the relationship between pedestrian speed, age and gender. They noted that the males walk faster than the females by 3.78% with the walking speed declining with increasing age. Polus et al. (1983) investigated the properties and characteristics of pedestrian flow on sidewalks in Haifa (Israel) and found that walking speeds of men were significantly greater than those of women. The study by Griffiths et al. (1984) revealed that the crossing speed at un-signalized crossing produced a mean walking speed of 1.72 m/s for the young, 1.47 m/s for the middle-aged, and 1.16 m/s for the elderly. Also Tanaboriboon et al. (1986) investigated school age children in Singapore in crosswalks and found their crossing speeds to be similar to the elderly pedestrians at 0.9 m/s. Similarly, Tanaboriboon and Guyano (1991) observed walking speeds on a signalized intersection in Bangkok and found crossing speeds of male pedestrians to be 1.31 m/s and those of female pedestrians to be 1.23 m/s. In a Swedish study on pedestrian characteristics, Bowman and Vecellio (1994) opined that 15 percent of the older pedestrians crossed at speeds below 0.7 m/s. In a Canadian study by Coffin and Morrall (1995), they recommended a design speed of 1.0 m/s to be used at mid-block crossings with a large proportion of older pedestrians. Further studies by Knoblauch et al. (1996), Tarawneh (2001) and Carey (2005) all found higher crossing speeds by younger pedestrians than the older age groups with consistent higher speeds for males than females. The Manual of Traffic Studies (1999) recommends a pedestrian crossing speed of 1.1 m/s to 1.2 m/s while the US Institute of Transportation Engineers (ITE) suggests speed of 0.75 m/s at a location with higher proportion of older pedestrians. This value is expected to accommodate 87% of pedestrian population. The crosswalk speeds given in the Highway Capacity manual HCM (2010) are based on the proportion of older (above 65 years) in the total pedestrian stream. For less than 20% elders, it suggests a speed of 1.2 m/s and above that it is taken as 1.0 m/s. The Manual on Uniform Traffic Control Devices (MUTCD, 2003) suggests a standard value of 1.21 m/s to allow users to walk from the curb to the far side of the travelled way.

3. DATA COLLECTION

This study involves a comprehensive data collection for twenty-five pedestrianized locations within Kano Metropolis. Thirteen locations were identified in the city district while twelve locations were outside the city district called the Waje District. The pedestrians were observed for speed and flow as well as their walking behaviour. All the observation points were sidewalks along road corridors. Pedestrian behaviour were segregated into male, female, adult and the young. To determine the speed of a pedestrian, a measured course was predetermined and a randomly picked pedestrian was timed over this measured course of 30m. The 30m measured course was used because pedestrians consistently covered this distance without changing their behaviour. The flow rate was measured every 30minutes by noting the number of pedestrians that passed the observation points during the observation period which lasted from 8.00 AM to 6.00 PM daily for seven days during the month of July 2013. The speed and flow rate measurements were manually captured while video technology was used for observing the pedestrian behaviour. In all cases, the observation period was during daylight, weekdays and weekends and during normal weather conditions for a typical pedestrian behaviour. The sample size for the city district was 15,106 while that of the Waje district was 9,093.

4. RESULTS AND DISCUSSIONS

4.1 Results

The results of the volume study for both districts are shown in figures 1 and 2. In figure 1, all the sites except BUK new site exhibit similar trends. At the start of the day, pedestrian volumes are low and they rise steadily during the day to a maximum during the evening rush period. The university trend is however dissimilar. Maximum volumes are observed during the early hours corresponding to lecture period rush hour and decline steadily during the day as other activities such laboratories, take prominence and off campus students depart the university campus. Yankura site gave the maximum flow rates across the day, doubling the observed values for any site at a particular point in time. Kurna follows with high flow rates. It is a high density residential area. If the study was extended to night periods, Kurna will still see high pedestrian flows because activities in the area extend well into the night.

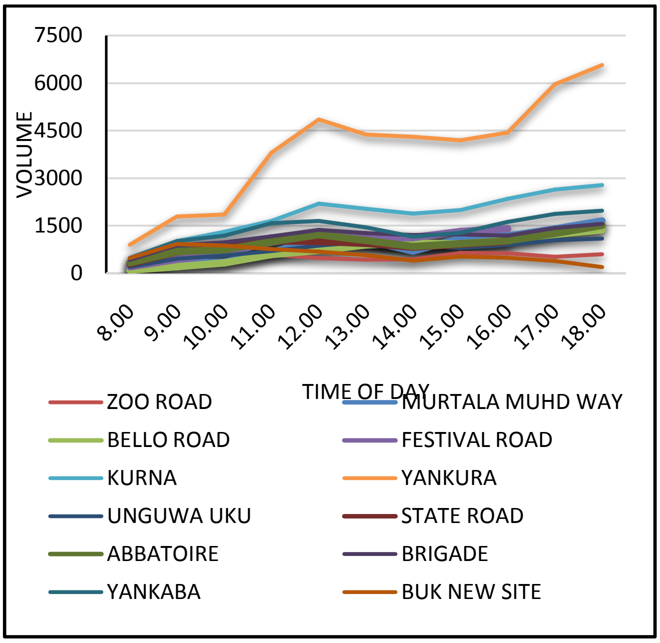

Figure 1: Pedestrian Volume Trends for Waje District

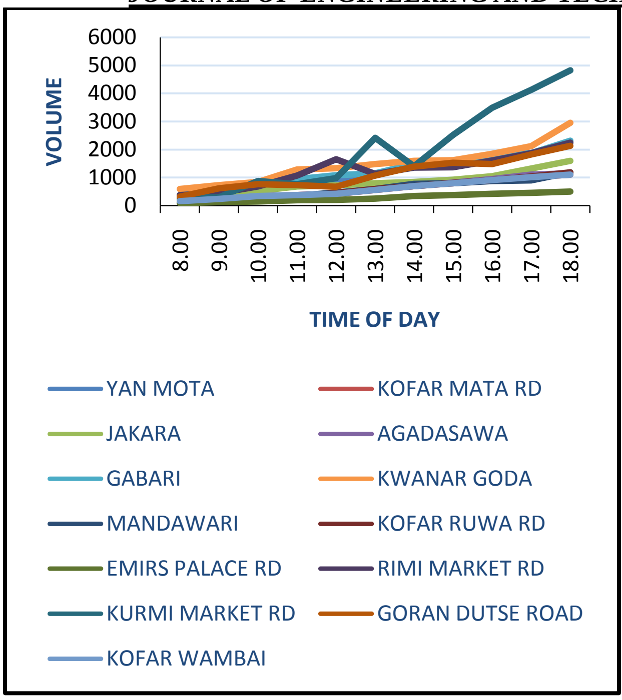

Figure 2: Pedestrian Volume Trends for City District

Figure 2 shows the pedestrian flow trends for the city district of Kano. Kurmi market recorded the highest flow rates for the city district. Like Yankura in the Waje district, Kurmi market is the single most important attraction point in the city, with large surges of pedestrian flows within and outside the market. The market is located in the popular high density residential neighbourhoods in Kano city. All the other locations in the city exhibit similar trends in the pedestrian movement.

4.1.1 Flow-Speed-Density Relationship: In order to see the relationships between the pedestrian flow parameters, dispersion plots were used for the bivariate flow-density, speed-density and speed-flow. Functions for these plots were derived in accordance with Alhassan and Edigbe (2011) and Alhassan (2013). The aggregated data for the two districts were used to demonstrate the plots and the corresponding functions obtained which are shown in Figures 3a, b, c respectively. The flow-density plot is very useful in understanding congested flow situations in pedestrian evacuations as well as everyday congested situations. This could reveal system constraints and hence development of counter measures for amelioration schemes. For the volume–density plot shown in Figure 3a, there is a clear increase of volume with increase in density. This rises to the maximum value called critical density above which congested conditions manifest. This plot could therefore be used to indicate congested situations on pedestrian facilities. The model equation for the flow-density plot is

$$q = -0.1385k^2+59.757k-5.8482$$

The speed-density plot is shown in Figure 3b and it's used to understand the maximum speeds that could be sustained without congested conditions forming. The relationship between the speed and density is linear with speed decreasing with increased density. The speed-density model for the whole of Kano Metropolis is

$$u= -0.1373k+59.547$$

The quality of the flow could be gleaned from the relationship between speed-volume. This could lead to level of service criteria development for pedestrian schemes. The speed–volume relationship is quasi-quadratic, indicating decrease of speed with increase in volume. The model equation for the speed-volume relationship is obtained as

$$u = -1E\text{-}07q^2 -0.0023q+59.503$$

The detailed features obtained for the remaining 25 sites are summarised in Tables 2 and 3 respectively for both Waje and City Districts.

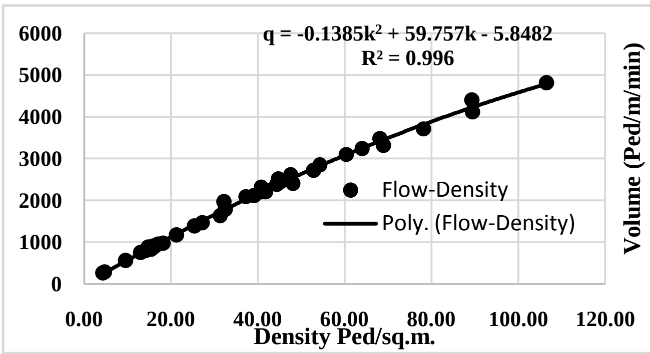

Figure 3a: Pedestrian Flow-Density Relationship for Kano Metropolis

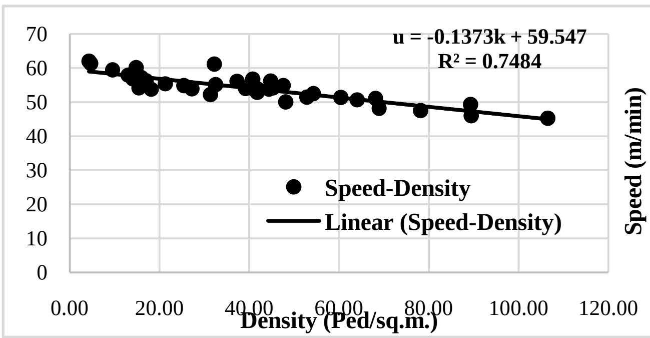

Figure 3b: Pedestrian Speed-Density Relationship for Kano Metropolis

From Table 2, three corridors stand out for their high pedestrian volumes and densities. These are Zoo road, Yankura and Kurna corridors. These corridors exhibited much lower walking speeds than was observed for other corridors for all categories of pedestrians. This could be attributed to conflicts resulting from cross flows, the presence of minimarkets, narrow downtown road encroached by hawkers and the prevalence of high low income groups.

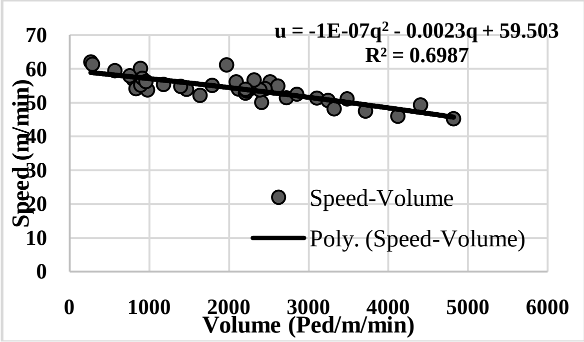

Figure 3c: Pedestrian Speed-Volume Relationship for Kano Metropolis

The walking speeds, however, were above the mean walking speed observed for the Waje area. Corridors with characteristically high walking speeds include Bayero University, New Campus, The abattoir, Brigade and Murtala Muhammad Way. It is much straight forward to attribute reasons for these observations. In BUK, majority of the population are young and of middle age, and in addition, elderly persons are few. Furthermore, most persons are time conscious and are moving towards a target. Abattoir is essentially a meat market, no special reasons were found for the particularly high walking speeds but generally pedestrians walked purposely both towards and away from it. The fire service area is a sensitive area. On call, the fire brigade uses the access area to reach call areas. In addition, there is a train crossing barrier adjacent to the fire service for in-coming trains. Pedestrians' conscious of this walk briskly along the corridor to avoid being hurried over by security personnel. In Brigade, men were particularly noted to walk much faster than their female counterparts. However, the area recorded the highest combine walking speed for all categories of pedestrians with a speed of 78 m/min. In most cases, pedestrians were observed to want to catch a minibus or in hurry to go to work. In the evening the contrary occurred where pedestrians walked faster to reach home after work. Female pedestrians at Brigade recorded a low walking speed of 42 m/min.

Table 3 shows the results for the City District of Kano. Here only Kurmi market has results that are comparable to Zoo road corridor in Waje District. The pedestrian flow and concentration clearly demonstrates its importance as an attraction point. The flow and concentration in the whole area averages 33.60 Ped/m/min and 11.23 Ped/m/min respectively and compares with 32.33 Ped/m/min and 10.03 Ped/m^2 for Kano Metropolis. Generally pedestrians in the City walked faster than their counterparts in the Waje area. The summary of the results for both Waje and City districts are presented in Tables 4 and 5 respectively.

Table 2: Summary of Pedestrian Features for Waje District

S/No	LOCATION	VOLUME	AVERAGE DENSITY	Mean Walking Speed (m/min)				
	WAJE DISTRICT	PED/m/min	PED/m^2	MALE		FEMALE		COMBINE
				YOUNG	MID-AGE	YOUNG	MID-AGE	MEN AND WOMEN
1	ZOO ROAD	90	1.48	66	77	67	67	61
2	MURTALA MUHD WAY	20	0.32	84	82	83	71	63
3	BELLO ROAD	15	0.39	47	52	39	46	38
4	FESTIVAL ROAD	20	0.33	70	75	57	59	60
5	KURNA	65	1.12	56	71	55	60	58
6	YANKURA	81	1.47	76	65	72	54	55
7	UNGUWA UKU	16	0.26	79	69	58	63	62
8	FIRE SERVICE	17	0.27	72	80	65	66	62
9	ABBATOIRE	18	0.25	83	72	76	70	73
10	BRIGADE	22	0.28	86	73	52	42	78
11	YANKABA	27	0.63	53	80	43	51	43
12	BUK NEW SITE	10	0.15	66	82	65	73	67

In the City district, male pedestrians generally walk faster than their female counterparts. However, adult females walked fastest, surpassing their male counterparts by 3%. The highest walk rate in the district was by adult female at 82.60 m/min while at the same time young female recorded the slowest walk rate at 57.40 m/min. The average density and volume observed for the district are 11.23 Ped/m^2 and 33.60 Ped/m/min respectively. Female pedestrians recorded the highest walk rate for the City district with a speed of 82.60 m/min. As would be expected they also recorded the lowest speed of 57.40 m/min.

In the Waje district, male pedestrians walked faster than their corresponding female counterparts walking a speed of 71.45 m/min for adult male and adult female of 59.90 m/min. Again the highest walk rate was recorded by male pedestrians with 79.33 m/min while the female pedestrians walk slowest with 46.17 m/min. The average density of pedestrians in the Waje district was 8.72 Ped/m^2 lagging the city District by 22%. Also the average volume for the Waje district was 30.92 Ped/m/min again lagging the city district by 4.2%.

Table 6 shows the results for the whole of Kano Metropolis which reveals that male pedestrians walked faster than their female counterparts with 74.18 m/min for male and 66.24 m/min for female giving a combined walking speed of 63.86 m/min. The average density for the metropolis is 10.03 Ped/m^2 while the average volume for the metropolis is 32.33 Ped/m/min

Table 3: Pedestrian Features for City District

S/No	**LOCATION**	**VOLUME**	**AVERAGE DENSITY**	**Mean Walking Speed (m/min)**				
	CITY DISTRICT	PED/m/min	PED/m^2	MALE		FEMALE		COMBINE
				YOUNG	MID-AGE	YOUNG	MID-AGE	MEN AND WOMEN
1	YAN MOTA	38	0.59	82	70	55	54	64
2	KOFAR WAMBAI	18	0.30	78	71	62	61	61
3	JAKARA	27	0.43	71	69	62	61	63
4	AGADASAWA	19	0.30	76	73	69	67	64
5	GABARI	39	0.57	76	75	63	62	69
6	KWANAR GODA	49	0.74	84	74	85	72	66
7	MANDAWARI	20	0.32	68	68	65	64	63
8	KOFAR RUWA RD	20	0.25	83	76	67	66	81
9	EMIR'S PALACE RD	8	0.13	73	71	64	61	62
10	KOFAR MATA RD	46	0.60	102	101	84	84	77
11	RIMI MARKET	37	0.54	78	74	74	68	69
12	KURMI MARKET	80	1.23	71	68	68	62	65
13	GORAN DUTSE RD	36	0.53	73	72	72	69	68

Table 4: Summary of Pedestrian Features for City District

Location	Characteristics	Mean Walking Speed (m/min)				
		MALE		FEMALE		COMBINE
		YOUNG	ADULT	YOUNG	ADULT	BOTH
CITY DISTRICT	Mean Walking Speed	71.70	63.90	54.30	73.90	67.30
	Standard Deviation	6.30	5.90	7.10	8.20	6.80
	Range: High Low	81.30 69.8	72.10 62.10	66.50 57.40	82.60 70.20	69.20 52.90
	Density	11.23				
	Volume	33.60				
	Sample Size	15,106				

Table 5: Summary of Pedestrian Features for Waje District

Location	Characteristics	Mean Walking Speed (m/min)				
		MALE		FEMALE		COMBINE
		YOUNG	ADULT	YOUNG	ADULT	BOTH
WAJE DISTRICT	Mean Walking Speed	69.90	71.45	57.40	59.90	60.21
	Standard Deviation	5.31	4.15	3.16	4.49	3.43
	Range: High	79.33	77.72	66.13	68.38	79.88
	Low	65.47	63.29	46.17	43.91	47.52
	Density	8.72 Ped/m^2				
	Volume	30.92 Ped/m/min				
	Sample Size	9,093				

Table 6: Summary of Pedestrian Features for Kano Metropolis

Location	Characteristics	Mean Walking Speed (m/min)				
		MALE		FEMALE		COMBINE
		YOUNG	ADULT	YOUNG	ADULT	BOTH
Kano Metropolis	Mean Walking Speed	74.18	72.74	66.24	62.50	68.92
	Standard Deviation	5.63	3.78	3.61	4.74	4.82
	Range High	83.70	77.30	73.80	81.90	72.40
	Low	70.20	64.10	53.80	69.30	67.60
	Density	10.03				
	Volume	32.33				
	Sample Size	24,198				

Table 7: Comparison of Pedestrian Parameters between Kano and Other Countries

	COUNTRIES			
	Kano-Nigeria	Singapore	U.S.A.	Britain
	Speed-Density Equation			
u=f(k)	u=59.547-0.137k	u =73.9-15.3k	u=81.4-20.4k	u=78.6-20.2k
	Flow-Density Equation			
q=f(k)	$q=59.757k-0.1385k^2-5.85$	$q=73.9k-15.3k^2$	$q=81.4k-20.4k^2$	$q=78.6k-20.2k^2$
	Speed-Flow Equation			
q=f(u)	$q = -1E07u^2 - 0.0023u + 59.503$	q=u(73.9-u)/15.3	q=u(81.4-u)/20.4	q=u(78.6-u)/20.2
	Free-Flow Speed			
u_f , m/min	59.86	73.9	81.4	78.6
	Maximum Flow Rate			
q, Ped/m/min	72.4	89	81	78
	Average Walking Speed			
Kano 68.92 m/min		Singapore 74.0 m/min	Average US 82.5 m/min	

4.2 Discussion of results

The model equation for the speed-density predicts a free walking speed of 59.547 m/min and a critical density of 21.73 Ped/m^2. Current levels of flow indicate that Kano has a density of 10.03 Ped/m^2, Volume of 32.33 Ped/m/min and average aggregated speed of 68.92 m/min. The pedestrian flow problem in is still sparsely populated in spite of localised clusters of heavy flow. The city is gradually assuming a cosmopolitan outlook with pedestrians coming from diverse social leanings. In order to see how Kano compares with other countries around the world, Table 7 summarises the results from other countries and compares the functions and pedestrian features from these countries with Kano.

The parameters for the Kano pedestrian differs markedly from pedestrians of other countries. The pedestrian walks slowest among his peers in the Singapore and the United States. This may be due to distractive mode of walking, whereby pedestrians would exchange pleasantries with people that come along his path.

5. CONCLUSIONS

From the 25 different locations used in this study, it may be concluded as follows:

The high density pedestrian concentrations in the Waje district include Yankura, Zoo Road and Kurna areas. In the city district high pedestrian concentration areas are Kurmi market, Kwanar Goda and Kofar Mata areas.

Adult women walked faster than their male counterparts in the city district while young males were faster than the female. The adult female recorded a speed of 73.90 m/min against the speed of 71.30 m/min for the adult male. The characteristics of the pedestrian in the city district are Speed 67.30 m/min; density 11.23 Ped/m^2 and volume 33.60 Ped/m/min.

In the Waje district, male whether adult or young walked faster than their corresponding female counterparts with speed of 71.45 m/min for the adult male and 59.90 m/min for the adult female. The young male was faster than the young female by 17.9%. The pedestrian characteristics for the Waje District indicated a combine speed of 60.21 m/min; density of 8.72 Ped/m^2. and volume of 30.92 Ped/m/min. The pedestrians in the city district had a higher flow rate, higher density and higher speed than those of the Waje district. This means the city district is a little more concentrated than the Waje district.

The aggregate characteristics of pedestrians in the metropolitan area gave the following parameters: Speed 68.92 m/min; density 10.03 Ped/m^2 and volume 32.33 Ped/min. The predictive models for Kano showed a free flow speed of 59.86 m/min and a maximum flow rate of 72.40 Ped/m/min.

Compared to other countries the Kano pedestrian walked slower than pedestrians from Singapore and the United States.

REFERENCES

Alhassan, H. M. and Ben-Edigbe, J. (2011b). Effect of Rainfall Intensity Variability on Highway Capacity. *European Journal of Scientific Research*, 49(1), 123-129.

Alhassan, H.M. (2013). Reliability of Single Lane Road Capacity Subjected to Rainfall Disturbances. *International Journal of Emerging Technology and Advanced Engineering.* Vol 3, Number 2, pp 587-594.

Blue, V.J. and Adler, J.L. (2001). Cellular automata micro simulation for modelling bi-directional pedestrian walkways, Transportation Research Part B 35 (3), pp.293–312.

Burstedde, C.; Klauck, K.; Schadschneider, A.; and Zittartz, J. (2001). Simulation of pedestrian dynamics using a two-dimensional cellular automaton, Physica A 295 (3-4), pp507–525.

Bowman, B.L. and Vecellio, R.L. (1994). Pedestrian Walking Speeds and Conflicts at Urban Median Locations. Transportation Research Record, Journal of Transportation Research Board No. 1438, pp 67-73.

Coffin, A. and Morrall, J. (1995). Walking Speeds of Elderly Pedestrians at Crosswalks. Transportation Research Record No. 1487, TRB, National Research Council, Washington DC, pp63-67.

Fruin, J.J. (1971). Designing for Pedestrians: A Level of Service Concept. Highway research Record, Number 355, pp1-15.

Fukamachi, M. and Nagatani, T. (2007). Sidle effect on pedestrian counter flow. Physica A, 377 (1) pp269–278.

Griffiths, J. D., Hunt, J.G. and Marlow, M. (1984). Delays at Pedestrian Crossings: Site Observation and the Interpretation of data. Traffic Engineering and Control 25, pp 365-371.

Guo, R.Y.; Wong, S.C.; Huang, H.J.; Zhang, P.; and Lam, W.H.K. (2010). A microscopic pedestrian-simulation model and its application to intersecting flows, Physica A 389 (3), pp.515–526.

Highway Capacity Manual (2000). Special Report No. 209. Transportation Research Board, Washington DC, USA.

Knoblauch, R.L., M.T. Putrucha and M. Nitzburg (1995). Field Studies of Pedestrian Walking Speed and Start-up time. Transportation Research Record No. 1538, TRB, National Research Council, Washington DC, pp27-38.

Lam, W. H. K., Morrall, J. F. and Ho, H. (1995). Pedestrian flow characteristics in Hong Kong. Transportation Research Record, Number 1487,pp56-62.