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EFECTS OF ROADSIDE FRICTION ELEMENTS ON TRAVEL PERFORMANCE AND LEVEL OF SERVICE IN KIGALI

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Abstract: Providing efficient mobility is the cornerstone of the socio-economic development, however, the performance of the road transport systems in the developing countries' cities has been reduced and affected continuously due to the increase in road users both motorized and non-motorized and roadside friction elements. Recent researches revealed that efficiency in urban transport is affected by different factors associated with roadside activities. In most developing countries, cities, including Kigali City, a proliferation of roadside friction elements affect travel performance measures in the locations where these elements occur. This study attempts to analyze the effect of dynamic roadside friction factors on traffic performance measures such as speed and level of service using data collected from Kigali urban roads. Data collected included spot speed data, road condition data, traffic, and roadside elements data. All data were collected in the field over six road-stretches covering different functional classes of roads in Kigali City. Key roadside friction (RSF) elements that affect traffic performance were selected based on ANOVA results and a sensitivity analysis was carried out to quantify the impact of roadside friction factors on speed and level of service. Moreover, relationships of speed, density, and flow were developed taking into account typical dynamic roadside friction elements. Overall, it was found that roadside friction factors affect travel performance in the locations where they occur and their effects are not only on two-lane roads but also on four-lane roads. The models developed in this study take into consideration roadside friction factors, and therefore they can be used to predict operating mean vehicle speed and density. To minimize the effects of roadside friction factors on traffic performance, the research-based information and findings from this study can be used in setting out guidelines while imposing some restrictions to eradicate an occurrence and the proliferation of roadside friction elements.

Keywords: roadside friction factors (RSF), travel performance, and level of service (LOS).

1. Introduction

Roadside friction (RSF) elements have become a serious factor causing congestion and poor traffic operation in urban and rural road networks in developing countries (Salini *et al.*, 2014; Harison *et al.*, 2016; Pal and Roy, 2016). Many urban roads in developing countries cities have a low level of service (LOS) and hence poor performance due to some activities that take place on and alongside roads (Rao *et al.*, 2016). In Rwanda, the increase in

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population growth and economic activities has contributed to an increase in vehicular traffic and travel demand (Zyl *et al.*, 2012). Harison *et al.* (2016) observed that one of the factors affecting traffic mobility is roadside friction (RSF). (Pal and Roy, 2016) found that pedestrians moving randomly across the carriageway affect traffic operation even if traffic volume is low. Road designers often assume that pedestrians cross roadways at designated pedestrian crossings, which include intersection crosswalks. However, pedestrians routinely cross the street at mid-block locations (Plankermann, 2013), it is important to identify all pedestrian needs for designing their comfort ways (O'Flaherty, 2006).

Chiguma (2007) and Hidayati *et al.* (2012) noted that roadside friction factors have been defined as all those actions related to the activities taking place by the sides of the road and sometimes within the road, which interfere with the traffic flow on the travel way. Dynamic roadside friction factors that are commonly found in developing countries include, but not limited to pedestrians, vendors, bicycles, and parked non-motorized and motorized vehicles (Chiguma, 2007; Hidayati *et al.*, 2012). (Bella, 2013; Mahona *et al.*, 2019) observed that static factors such as T-junctions and bus-stops also contribute to traffic congestion. However, static factors can be treated by improving the geometric features of roads that would improve the level of services (LOS) (Nyantakyi *et al.*, 2014). In the analysis of the effect of roadside friction factors on congestion on some road links in Kumasi, Ghana, (Obiri-Yeboah *et al.*, 2019) included static roadside friction factors such as vegetable market, lay-bye, fuel station, mechanic shop, vulcanizing activities, and mini-mart together with some dynamic factors such as walking pedestrians and crossing pedestrians. In concluding their study, Obiri-Yeboah et al. (2019) proposed additional lanes on the studied roads. However, Pal and Roy (2016) noted that measures taken to improve road geometry have not been successful in enhancing the LOS in some countries like India.

Hidayati *et al.* (2012) categorized roadside friction into five classes: Very low (<100 per hour), Low (100-299 per hour), Medium (300-499 per hour), High (500-900 per hour) and Very High (>900 per hour). Further, the roadside friction impact is quantified by the impact elasticity (Bhat *et al.*, 2019), which is simply the ratio of the percentage change in a specific result of input to the percentage change of the output parameter. A sensitivity analysis is normally done when calculating impact elasticity. The impact elasticity greater than 0.5 is high impact, 0.2 to 0.5 is moderate impact, 0.05 to 0.20 is low and less than 0.05 is a negligible impact (Odoki, 2016). Patel and Joshi (2014) found that the capacity of the urban arterial road is greatly affected by the effect of lane width, presence of NMV (Non-motorized vehicles) and effect of roadside friction factors (RSF).

The famous Greenberg's traffic model assumes a nonlinear relationship between flow speed (u) and flow density (k) (HCM, 2000), but this model did not consider RSF factors and motorcycles, which are a common phenomenon in developing countries like Rwanda. In his research, while he had been doing mathematical for traffic flow and traffic density in Kigali roads, (Idrissa, 2017), found that the current famous speed-density model relationship ($u = u(k)$) was observed to be not perfect to predict traffic condition in Kigali urban roads. Recent studies in India developed speed prediction models taking into account roadside friction factors. For instance, (Gulivindala and Mehar, 2018) incorporated into the model events/hr to represent the effects of roadside friction, while Salini *et al.* (2014) considered the effects of the number of cars, two-wheelers, and three-wheelers as well as dwell times, number of pedestrians per minute, number of parking maneuvers, number of vehicles parked on sides of the carriageway, and influence of time of parking and un-parking vehicles. In (Dar es Salam and Chiguma, 2007) developed a speed prediction model that considered roadside friction factors during actual conditions. All these models take consideration of typical friction elements of both dynamic and static.

Rwanda is one of the developing countries where road geometric improvements on existing roads have not resulted in improved LOS. According to Rwanda Today Newspaper Editorial of Saturday, January 10, 2015, it was stated as follows "A snapshot of Kigali during rush hour suggests that, if nothing is done now, the country could soon suffer chronic traffic jams as the number of cars increases" (Rwanda Today, 2015). Although Kigali Today Newspaper on Saturday, June 30, 2012, pointed out that traffic congestion in Kigali is yet to exceed the international limit of 20 minutes during rush hour, Namata (2012) observed that there is already traffic congestion around ChezLando Road and Rwandex-Sonatube with traffic stopped delays exceeding 30 minutes. Further, (Zyl *et al.*, 2012) noted that 19% of trips were by motorcycle-taxis which create a new type of friction when parking, taking off and picking up passengers.

In connection with the foregoing, this paper attempts to extend the analysis of the effects of RSF on traffic performance measures such as speed and level of service based on current Kigali traffic conditions. Unlike previous studies, this study attempts to add to the existing literature by identifying and treating each RSF element separately in the analysis. In this case, each RSF element is classified according to the type of movement and how it interacts with other road users. Dynamic roadside friction elements considered in this study are motorcycle parking maneuvers, four or more wheelers parking maneuvers, bicycles, pedestrians crossing the road carriageway, pedestrian standing and street vendors within 1.0 m around the road, and pedestrians walking on road shoulders. Although motorcycles and bicycles are all two-wheelers, motorcycles are motorized so that drivers can adjust speed into the traffic stream. However, this makes motorcycles drivers overconfident in the traffic stream and they can encroach into a traffic stream forcing it to reduce speed. While bicycles are non-motorized so sharing the same lane with motorized traffic or cycling on the roadside or the shoulders, brings much attention to drivers' perception. Pedestrian categorization was based on pedestrian movement types. For example, pedestrian crossing road carriageway through non-designated pedestrian crossing areas affect drivers' psychology and causes a brutal reduction of speed and hamper smooth traffic flow.

2. Methodology

2.1. Study Area Description

The study roads are the main roads of Kigali City, where often haphazard traffic movement, parking, and un-parking, movement on carriageway shoulders and carriageway crossing movements are common due to attractions caused by roadside activities, urban commercial and social activities. The studied road stretches were of different functional classes located in three districts in the city of Kigali namely NYARUGENGE, GASABO, and KICUKIRO districts as shown in Table 1. The study area was subdivided into areas with higher friction road stretch areas (Road stretches I, III, and V; see Fig. 1) and areas outside of the high friction road stretch areas (Road stretches II, IV, and VI; see Fig. 1).

2.2. Methods

The locations for spot speeds were chosen so that drivers were unaware that this study was being conducted. The total sample size for spot speeds study was 288, the total survey hours were 8 hours during 2 days for each road section of the six road sections surveyed. Continuous video recordings using video scouts cameras were taken because, in these section areas, movement is very frustrating for direct manual counting using a stopwatch. Recorded videos were later displayed on the computer for counting and data processing. The samples of speed data, traffic, and RSFs counts were taken at the same time simultaneously during working days excluding special days events such as days football matches and exhibitions. To understand the variability of travel speed and LOS within and outside the target area of the study stretch, two sets of data were collected using "speed radar gun/speeders" and data on different types of vehicles were collected using video scout cameras. One set of data was collected within the high friction road stretch areas and another set of data was collected outside of the high friction road stretch areas.

Three spot speed readings were collected every 5 minutes during the time hours' target from 2:00 PM to 6:00 PM covering peak rush hours of 5: 00 PM. A sample size of 144 (3x12x4; where 3 stand for three spot speed reading; 12 times per hour for 4 hours each day) was used this part of the study. Classified road users and RSF elements' counts were carried out by the author and trained enumerator using the standard format of Rwandan vehicle classification (Bizindavyi, 2014), which is currently used and is based on (HCM, 2000). Before undertaking field data collection, a reconnaissance survey was conducted by visiting proposed study areas.

Table 1

Description of Selected Road Sections and their Respective Road Stretches

Road Class	Road Characteristics	Road Code	Class (HCM)	Length	Number of Road Stretches	Stretch Area's Name
National Road	Two-lane Road without media	NR15	Class I	3 km	I and II	Kicukiro Centre & Kicukiro IPRC
District Road (Kigali-Gasabo)	Two-lane Road without media	KG 11 Ave	Class II	4.6 km	III and IV	ChezRando & Amahoro Stadium
National Road	Four-lane load Section with media	NR3	Multilane	3.1 km	V and VI	Nyabugogo & Muhima-Yamaha

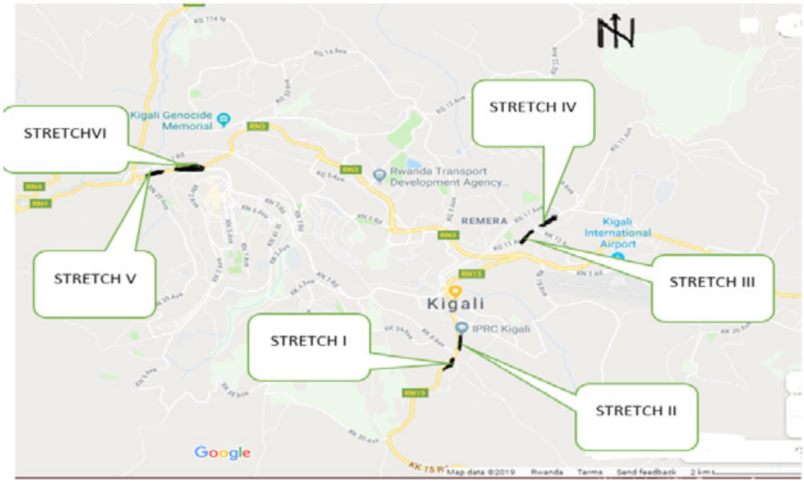

Fig.1 .
Kigali City Roads with indicated Case Study Roads with Their Respective Stretches
Source: Adopted from the Google Map of the study area (2019)
https://www.google.rw/maps/@-1.9413041,30.0597266,14z

2.3. Roadside Friction Factors' Impact Analysis

2.3.1. Impact on Speed

The operational speed, i.e. 85th percentile, speed was determined from field data to measure traffic effectiveness and Level of Travel Performance (LTP). The impact-elasticity was computed using Eq. (1) and Eq. (2).

$$RSFI_S = \frac{\text{\% Change in (\%RSF) between corresponding Stretches}}{\text{\% Change in Operational Speed between corresponding Stretches}} \text{ x } 100 \tag{1}$$

$$MTI_S = \frac{\text{\% Change in MT between corresponding Stretches}}{\text{\% Change in Operational Speed between corresponding Stretches}} \text{ x } 100 \tag{2}$$

where:$RSFI_S$:Impact of Roadside Friction Factors on speed, and MTI_S: Impact of motorized traffic on speed.

2.3.2. Impact on Level of Service

LOS determination and evaluation were carried out as suggested by HCM 2000, (HCM, 2000) as well as in HCM 2010 (HCM, 2000). The Impact of roadside friction factors and the increase of motorized traffic on LOS was calculated using Eq. (3) and Eq. (4).

$$RSFI_S = \frac{\text{\% Change in (\%RSF) between corresponding Stretches}}{\text{\% Change in Operational Speed between corresponding Stretches}} \text{ x } 100 \quad (3)$$

$$MTI_{LOS} = \frac{\text{\% Change in MT between corresponding Stretches}}{\text{\% Change in Time Spent Following or Density between corresponding Stretches}} \text{ x } 100 \quad (4)$$

where: $RSFI_{LOS}$: Impact of Roadside Friction Factors on Level of Service and MTI_{LOS}: Impact of motorized traffic on Level of Service.

2.4. Relationships between Traffic Flow Parameters and Roadside Frictions

The relationships were developed using simple regression or multiple linear regression analysis techniques as follows, Eq. (5), Eq. (6) and Eq. (7):

$$\text{Density} = f(D, V, V_B, V_M, V_{PEDC}, V_{MPC}, V_{VPM}, V_{PSS}, V_{PedWS}) \quad (5)$$

$$\text{Speed} = f(V, V_B, V_M, V_{PEDC}, V_{MPC}, V_{VPM}, V_{PSS}, V_{PedWS}) \quad (6)$$

$$\text{Flow} = f(S, V, V_B, V_M, V_{PEDC}, V_{MPC}, V_{VPM}, V_{PSS}, V_{PedWS}) \quad (7)$$

The explanations of the variables are given in Table 2.

Table 2
Variables from Eq. (5), Eq. (6) and Eq. (7)

Symbol	Parameter Description	Unit of Measure
D	Density	Veh/km
S	Hourly average speed	km/hr
V	Vehicles flow	Veh/hr
V_B	Bicycles flow	Bicy/hr
V_M	Motorcycles flow	Motc/hr
V_{PEDC}	Pedestrian crossing road per 100 m	PedC/hr/100m
V_{MPM}	Motorcycle parking maneuvers per 100 m	Motc/hr/100m
V_{VPM}	Vehicle parking maneuvers per 100 m	Veh/hr/100m
V_{PSS}	Pedestrian standing and street sellers in 1 m around the road per 100 m	PedSS/hr/100m
V_{PedWS}	Pedestrians walking on the road shoulder	Ped/hr/direction

3. Data Presentation and Analysis

The data obtained during the data collection on-road sections during 15 minutes-intervals were converted into hourly rate values. For this purpose, relationships suggested in HCM 2010 between the peak 15-minute values and the hourly rate values were used.

Spot speeds data are presented after statistical analysis as shown in Table 3 and Fig. 2. Cumulative speed graphs were developed for both stretches marked within the selected roads, superimposed and represented in Fig. 2. It was observed that operational speed was much restricted within the friction area (Stretch I, III and V) to indicate poor traffic performance with the value of 20 km/hr, 21 km/h, and 30 km/h with standard deviation 5 km/h, 6 km/h and 6 km/h, respectively. The operational speed of areas with less friction (Stretch II, IV and VI) was 37 km/hr, 45 km/h, and 50 km/h with the standard deviation of 8 km/h, 10 km/h and 9 km/h (see Table 3), respectively. There was an opportunity for overtaking in stretches II, IV and VI than in I, III and V.

For the road stretches I, III, V and II, the traffic operated at the poor performance with operational speeds less than 40 km/h, while road stretches IV and VI operated in good condition with an operating speed higher than the 40 km/h threshold.

Table 3
Basic Statistics for Speeds

Road Code	RN15		KG11 AVE		NR3	
Stretch	**I**	**II**	**III**	**IV**	**V**	**VI**
Average mean	14	31	13	34	22	39
Standard deviation	5	8	6	10	6	9
Range	35	45	31	55	43	54
Minimum	0	10	0	0	5	18
Maximum	35	5	31	55	48	72
85th Percentile	20	37	21	45	30	50
Number of data	288	288	288	288	288	288

Table 4 presents the Kigali urban traffic composition. The results show that motorcycles take a high portion of 60.56% to 67.17% of traffic stream while public transport is just 1.04 % to 2.42% in the traffic stream of main roads in Kigali. Motorcycles also take a lion share of 35% to 65% of all road users (motorized and non-motorized) in Kigali roads.

RSFs have an impact on the performance of the road system in Kigali. For instance, Fig. 3 shows on average the high portion of 51.49 % RSFs of total road users caused NR3-Stretch V (Nyabugogo) to operate at the poor performance while on NR3-Stretch VI (Muhima-Yamaha) operated at good performance with a low portion of 4.71 % RSFs of total road users. Also, Fig. 3 shows the percentage of roadside friction factors (RSF) against the motorized traffic flow for each hour vis a vis of hourly mean speed. Road Stretch I and II with 20 % to 30% of RSFs with the mean speed that ranges between 20km/h to 30 km/h. The motorized traffic flow in road stretch III was found to be high, thus both internal and external frictions have a high effect on mean speed. Then hourly mean speed for the road stretch III ranges between 8km/h to 16 km/h while for the road stretch IV, it ranges between 20km/h to 38km/h. Further, Fig. 3 presents analyzed results for NR3-Stretch V showed a high concentration of RSFs of 47 % to 52 % with hourly mean speed ranges between 19km/h to 26km/h while the NR3-Stretch VI was found to have fewer RSFs with proportion ranges between 4% to 6% and the mean speed ranges between 36km/h to 42 km/h. Other traffic condition measures are summarized and represented in Figs. 4a, 4b, and 4c. As presented in Table 5, the two-lane road KG11 Ave-Stretch III was found to operate at LOS E and the KG11 Ave-Stretch IV was found to operate at LOS D. The four-lane road NR3-Stretch V was found to operate at LOS F and a density of 36 to 45 pc/km/lane while the NR3-Stretch VI was found to operate at LOS D and a density of 17 to 20 pc/km/lane.

Table 4

Kigali Urban Traffic Stream Composition

Traffic Group/Categories	Road NR15	Road KG11 AVE	NR3
Bicycles	5.55%	0.91%	4.86%
Motorcycles	60.59%	61.13%	67.17%
Cars, pick-ups, jeeps, 4WDs, and Minibuses	30.67%	35.68%	23.72%
Coasters and Buses	1.04%	1.78%	2.42%
Light goods vehicles, Medium trucks, heavy trucks, and trailer trucks.	2.16%	0.51%	1.86%

From Table 6 and Fig. 3, it can be noted that at the Kicukiro Center (NR15-Stretch I), Kicukiro IPRC (NR15-Stretch II) and Nyabugogo (NR3-Stretch V) roadside friction class is very high because RSFs hourly rate is greater than 900 RSFs/hour and greater 20 percent. At the ChezRando (KG11 Ave-Stretch III) roadside friction class is Medium (300-499 RSFs/hour; percentage ranges between5-10) and near the Amahoro stadium (KG11 Ave-Stretch IV), the class is low (100-299 RSFs/hour; 3-5 percent). At the Muhima-Yamaha (NR3-Stretch VI) the roadside friction class is also low (100-299 RSFs/hour; 3-5 percent).

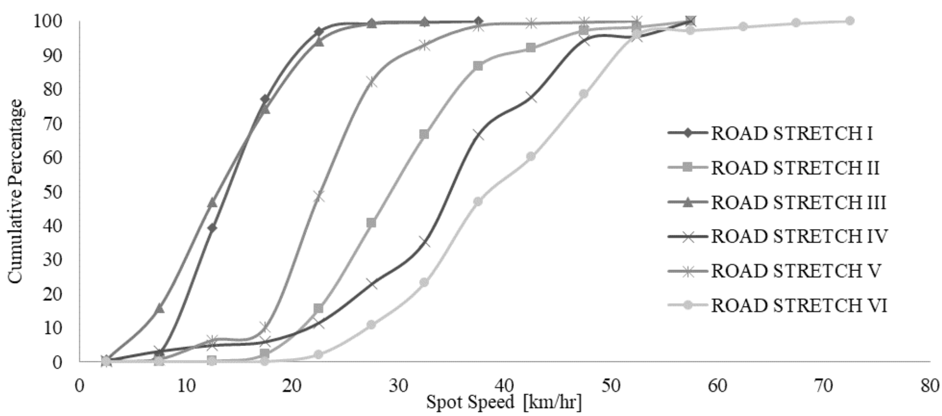

Fig. 2.

Superimposed Cumulative Graphs

Table 5

Volume/Capacity Ratio, Percent Time Spent Following and Level of Service Analysis for the Case Study Roads Stretches

Road Code	**Stretch**	Level of Service Indicators	**Hour**				**Average**
			1	**2**	**3**	**4**	
			[2:00PM-3:00PM]	**[3:00PM-3:00PM]**	**[2:00PM-3:00PM]**	**[2:00PM-3:00PM]**	
NR15	**I**	Volume/Capacity	0.70	0.65	0.63	0.73	0.68
		Percent Time Spent Following	88.1	85.6	84.7	88.7	86.8
		LOS	**E**	**E**	**E**	**E**	**E**
	II	Volume/Capacity	0.48	0.45	0.50	0.52	0.49
		Percent Time Spent Following	78.2	78	78.3	80	78.6
		LOS	**D**	**D**	**D**	**D**	**D**
KG11 AVE	**III**	Volume/Capacity	0.74	0.70	0.74	0.75	0.73
		Percent Time Spent Following	88	86.3	87.7	88.4	87.6
		LOS	**E**	**E**	**E**	**E**	**E**
	IV	Volume/Capacity	0.46	0.46	0.50	0.50	0.48
		Percent Time Spent Following	73.2	73	75.4	75.8	74.4
		LOS	**D**	**D**	**D**	**D**	**D**
NR3	**V**	Density	36	39	38	45	40
		LOS	**F**	**F**	**F**	**F**	**F**
	VI	Density	17	20	19	19	19
		LOS	**D**	**D**	**D**	**D**	**D**

Table 6

Roadside Friction Classes

Roadside Friction Class	**Percentage**	**RSFs per hour** (Hidayati *et al.*, 2012)	**Case Study Areas/ Road Stretches**
Very Low	< 3	<100	-
Low	3-5	100-299	Amahoro Stadium (KG11 Ave-Stretch IV) and Muhima-Yamaha (NR3-Stretch VI)
Medium	6-10	300-499	ChezRando (KG11 Ave-Stretch III)
High	10-19	500-900	-
Very High	>20	> 900	Kicukiro Center (NR15-Stretch I), Kicukiro IPRC (NR15-Stretch II) and Nyabugogo (NR3-Stretch V)

Source: Data are based on on a percentage at Fig. 5 and RSFs per hour in Table 3

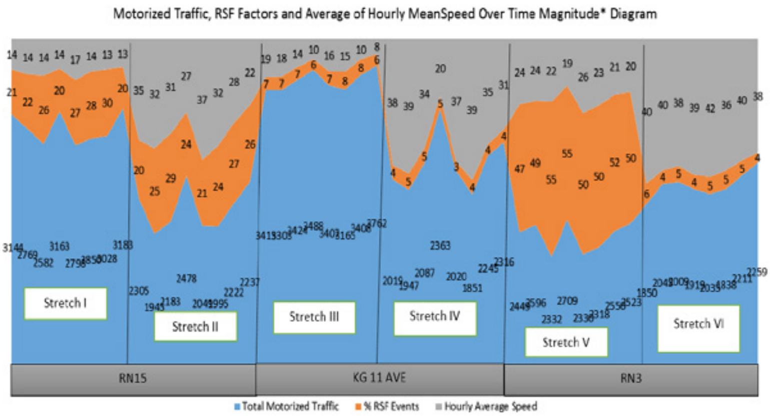

Fig. 3.
Relation of the Magnitude of Motorized Traffic (MT) and Roadside Friction Events with Speed Reduction
Note: The shaded area shows the magnitude of each variable

4. Results and Discussion

4.1. Impact of Roadside Friction Factors

To carry out impact analysis, firstly, a sensitivity analysis was done to calculate impact elasticity as per Eqs. (1) to (4). The analysis of data for roads KG11Ave-Stretch III &IV and NR3-Stretch V & VI, gave a difference in the percentage of RSF factors, the impact elasticity of RSF events on travel performance was calculated and results were tabulated in Tables 7 and 8. The RSF impact elasticity was high by comparing Stretch V&VI of Four-lane road of good condition. The negative sign describes a decrease in operating speed in an area with high RSF events in comparison to the area of low RSF events for the same road with the same geometric condition. For the NR15-Stretch I & II, the difference in operational speed was only governed by the magnitude of motorized traffic (motorcycles and vehicles) because the RSF events were of the same magnitude in terms of percentage, on these stretches, the effect was explained internally as hourly average speed variation to the magnitude of RSF percentages, see Fig. 3, Stretch I & II and for very high RSF class, see Tables 5 and 6. The impact of all RSF factors on travel speed on the case study roads ranges from moderate to a high level. So the impact elasticity of all defined RSF factors in Kigali roads during this study was found to be high level. RSF factors have a high impact on the speed in an area with a high increase in RSF factors in comparison to the area with a low volume of RSF factors, see Table 7. The two-lane road NR15-Stretch I was found to operate at LOS E and NR15-Stretch II was found to operate at LOS D. The impact of RSFs was at a high level for Level of Service, see Table 8. In the later table, a sensitivity analysis was carried out for each road through a comparison between road-stretches of the same road.

Table 7

Sensitivity Analysis of RSF Impact on Operational Speed

RSF Impact on Travel Performance						Increase of MT Impact on Travel Performance				
Road Code	**Road Stretch**	**% RSF Events**	**85^{th} Speed**	**Impact elasticity**	**Impact**	**Road Stretch**	**MT Volume**	**85^{th} Speed**	**Impact elasticity**	**Impact**
NR15	I	24.41	20			I	23517	20		
	II	24.39	37			II	17414	37		
	Change	0.02	-17			Change	6103	-17		
	%Change	0.08%	-46%	-0.001	-	%Change	26%	-85%	-0.31	Moderate
KG 11 AVE	III	7	21			III	27372	21		
	IV	4	45			IV	16847	45		
	Change	3	-24			Change	10525	-24		
	%Change	43%	-114%	-0.38	Moderate	%Change	38%	-114%	-0.34	Moderate
NR3	V	51	30			V	19807	30		
	VI	5	50			VI	16165	50		
	Change	46	-20			Change	3642	-20		
	%Change	90%	-67%	-1.35	High	%Change	18%	-67%	-0.28	Moderate

*Note: For example RSFIS= [((7-4)/7)*100]/[(21-45)/21)*100]= [(7-4)/7)]/[(21-45)/21)]=-0.38*

Table 8

Analysis of RSF's Impact on Level of Service

Road Code	**Stretch**	**LOS**	**% RSF Events**	**Average Time Spent Following or Density**	**Impact elasticity**	**Impact**	**MT Volume**	**Impact elasticity**	**Impact**
NR 15	**I**	**E**	24.41	86.8			23517		
	II	**D**	24.39	78.6			17414		
	Change		0.02	8.15			6103		
	%Change		0.08%	9%	0.009	-	26%	2.76	High
KG 11 AVE	**III**	**E**	7	87.6			27372		
	IV	**D**	4	74.4			16847		
	Change		3	13.25			10525		
	%Change		43%	15%	2.83	High	38%	2.54	High
NR 3	**V**	**F**	51	40			19807		
	VI	**D**	5	19			16165		
	Change		46	20.75			3642		
	%Change		90%	53%	1.72	High	18%	0.35	Moderate

Note: For example $RSFI_{LOS}$*= [((7-4)/7)*100]/[(87.6-74.4)/87.6)*100]= [(7-4)/7)]/[(87.6-74.4)/87.6)]=2.8*

4.2. Traffic Flow Parameters and Roadside Frictions Relationships

Non-linear models in Fig. 4 show there is a high correlation between speed and density and between flow and density while the correlation between speed and flow rate is not strong. A simple power model relationship between speed and density (Fig. 4 (a)) and the quadratic equation between flow rate and density (Fig. 4(c)) can be written as Eq. (8) and Eq. (9):

$$\text{Speed (km/h)} = 253.52(\text{D})^{-0.648}; (\text{R}^2=0.924) \tag{8}$$

$$\text{Flow rate(Veh/h)} = 464.15 + 13.988(D) - 0.0539(D)^2; (\text{R}^2=0.825) \tag{9}$$

Fig. 4 (b) shows a queue discharge flow in Kigali roads, which indicates the passing of traffic through a bottleneck. It can be seen that the relationship between mean speed and flow rate, is non-linear with a coefficient of correlation R^2=0.55561.

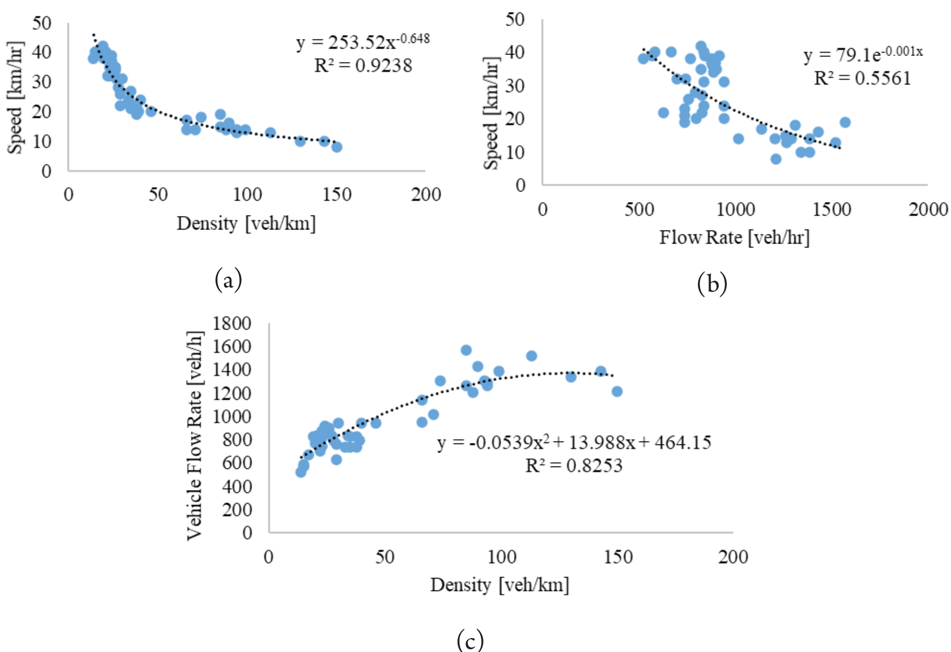

Fig. 4.
Relationships between Speed, Density, and Flow Rate on Uninterrupted-Flow Facilities

The key roadside friction factors which affect traffic performance were identified from the ANOVA results. As shown in Table 9, it was found that at 95 % confidence level motorcycles (P-value=0.000, t-stat value =5.718), bicycles (P-value=0.050, t-stat value =-2.303) and pedestrian crossing road carriageway through non-designated pedestrian crossing areas (P-value=0.007, t-stat value =-2.808) affect the density of the traffic stream. It was also noted that at 95 % confidence level bicycles (P-value=0.000, t-stat value = -4.859), pedestrian crossing road carriageway through non-pedestrian crossing ways (P-value=0.011, t-stat value = -2.638), pedestrian standing and street vendors within 1.0 m around the road (P-value=0.000, t-stat value =-4.212) and pedestrians walking on road shoulders (P-value=0.014, t-stat value =-2.570) affect the average speed of the traffic stream.

Table 9

Results of MLRA of Best Fit Models for Density and Speed Prediction taking into Account Typical RSF Factors

Model	Equation	ANOVA test statistics for model fit
1	Speed (Veh/hr)=253.52(D)$^{-0.648}$	(R^2=0.92)
2	Flow rate(Veh/h)=464.15+13.988(D)-0.0539(D)^2	(R^2=0.825)
3	Density(Veh/km)=0.043(V)+0.032(V_M)-1.587(S)-0.040(V_B)-0.009(V_{PEDC})	(R^2=0.976, R^2_{Adj}=0.95, F=343.41 and P< 0.05)
4	Speed (Veh/hr)=43.456-0.258(D)-0.033(V_B)-0.002(V_{PEDC})	(R^2=0.899, R^2_{Adj}=0.892, F=130.80 and P< 0.05)
5	Speed (Veh/hr)=72.956-0.025(PCU)-0.015(V_{PSS})-0.005(V_{PedWS})	(R^2=0.83, R^2_{Adj}=0.82, F=71.43 and P< 0.05)

4.3. Evaluation of the Density, Speed Relationships

The relationship between density and traffic parameters (S, V), roadside friction factors (V_{PEDC}, V_{MPM}, V_{VPM}, V_B, V_M, V_{PSS}, V_{PedWS}) indicates varying degrees of relationships. Table 9 presents all possible significant relationships. Model 3 performs well in correlating (R^2=0.976) the density value, with speed, flow rate, bicycle rate, and pedestrians crossing the road carriageway rate. Model 4 has a coefficient of correlation (R^2) of 0.899 and it correlates well with the speed value with density, bicycle rate and pedestrians crossing road carriageway rate. Model 5 has (R^2) of 0.83. Also, this equation shows well in correlating the speed value with density, bicycle rate and pedestrians crossing road carriageway rate. All models above provide how well future outcomes are likely to be predicted as depicted by the R^2- & $R^2_{-Adjusted}$ value, and other ANOVA statistics compared to the models developed in India and Tanzania (with R^2 values are 0.75 and 0.691respectively) (Chiguma, 2007; Salini *et al.*, 2014).

4.4. Density, Speed Models Validation

Plots were drawn with predicted values as ordinates and the observed values as abscissa. The plots for different models are shown in Figs. 5, 6 and 7. Ideally, all the points both observed and predicted should lie on this line if there was no variation between the values (Washington *et al.*, 2011). Model 3 was found to be more accurate to account for the effect of roadside friction to visually observe the difference between the obtained and the estimated values. However, it was also observed that the amount of scattering was very low. In the case, speed prediction models, slightly scattering was observed. These might be due to a combination of minor errors in data collection and normal conditions of the variance of speed in urban areas due to multiple factors and small unusual maneuvering of drivers in the road. The comparison of the predicted value and the observed values from Models 3, 4 and 5 are presented in Figs. 5, 6 and 7.

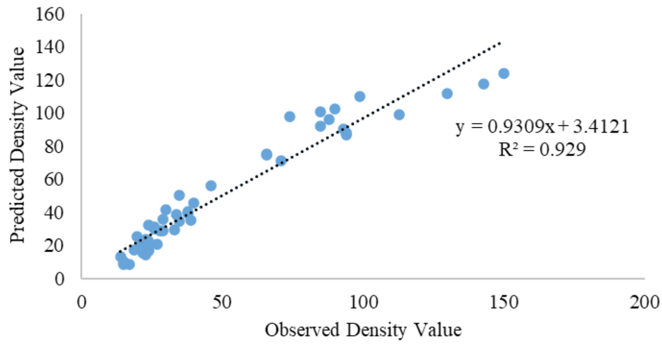

Fig. 5.
The Plot between Predicted and Obtained Density Values (Model 3)

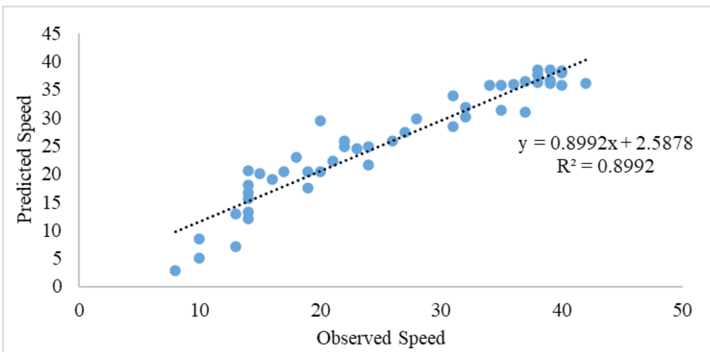

Fig. 6.
The plot of the Observed against Predicted Speed Values from Model 4

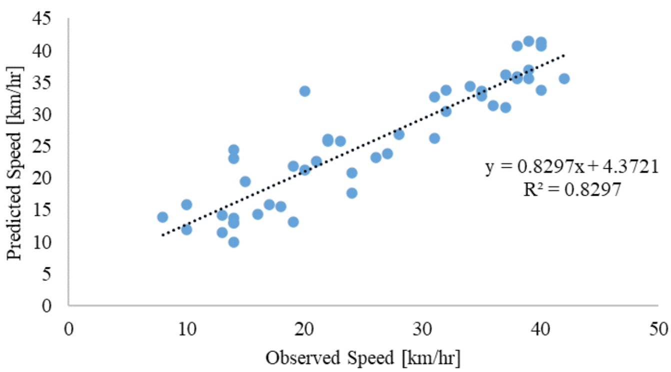

Fig. 7.
The Plot of the Observed Against Predicted Speed Values from Model 5

5. Conclusion and Recommendation

Order in the transport system helps all road users to pass along or cross efficiently, smoothly and safely. Haphazard movements contribute to lower LOS and hence congestion. RSF elements stimulate disorder and interrupt movements in the transport system. In this study, it was found that the impact of RSFs is moderate to high on speed and mostly high for Level of Service. For a four-lane road, low speed enhances the ideal increase of density and slow-motion of vehicles to safely interact with all road users. The models developed in this study take into consideration roadside friction factors, and therefore they can be considered to be appropriate for predicting operating mean vehicle speed and density. For Kigali and similar urban areas in developing country cities to minimize the effects of roadside friction factors on traffic performance and level of service, the authorities in charge of urban and transport planning can use research-based findings reported in this study and similar studies to impose some restrictions on the occurrence of roadside frictions. This effort should be accompanied by proper design of the road friction points to minimize the effects of roadside friction factors on traffic performance and the level of service.

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References

Bella, F. 2013. Driver perception of roadside configurations on two-lane rural roads: Effects on speed and lateral placement, *Accident Analysis and Prevention* 50: 251-262.

Bhat, M.A.; Bali, E.S.; Lohani, D.T. 2019. Impact of roadside frictional elements on average travel speed and level of service for an urban two-lane street, *International Journal For Technological Research In Engineering* 6(7): 5186-5188.

Bizindavyi, L. 2014. *Rwanda Feeder Roads (Unpaved roads-District class 1 and 2) Standards. Final Report. Rwanda Feeder Roads Standards*. Rwanda Transport and Development Agency. Rwanda. 27 p.

Chiguma, M.L.M. 2007. *Analysis of side friction impacts on urban road links.* PhD Dissertation, KTH School of Architecture and the Built Environment. Stockholm, Sweden, Royal Institute of Technology, Sweden.

Gulivindala, P.; Mehar, A. 2018. Analysis of Side Friction on Urban Arterials, *Transport and Telecommunication Journal,* 19(1): 21-30.

Harison, A.; Bellal, A.; Suryavanshi, S. 2016. Side Friction Problems in State Highways, *International Journal of Innovative Research in Science, Engineering, and Technology* 5(6): 9652-9656.

HCM. 2000. *Highway Capacity Manual*. National Research Council. Inc.USA. Washington. DC.

Hidayati, N.; Liu, R.; Montgomery, F. 2012. The Impact of School Safety Zone and Roadside Activities on Speed Behaviour: the Indonesian Case, *Procedia-Social and Behavioral Sciences* 54: 1339-1349.

Idrissa, K. 2017. Mathematical study for traffic flow and traffic density in Kigali roads, *International Journal of Mathematical and Computational Sciences* 11(3): 104-108.

Mahona, J.; Mhilu, C.; Kihedu, J.; Bwire, H. 2019. Factors Contributing to Traffic Flow Congestion in Heterogenous Traffic Conditions, *International Journal for Traffic and Transport Engineering* 9(2): 238 - 254.

Nyantakyi, E.K.; Owusu, P.A.; Borkloe, J.K. 2014. Methods for the Assessment of Performance Indication Measures at Amakom Intersection and Their Application in Micro Simulation Modeling, *International Journal for Traffic and Transport Engineering* 4(1): 35-51.

Obiri-Yeboah, A.A.; Amoah, A.S.; Gbeckor-Kove, M.S. 2019. Analysis of congestion on some Road link Section using Roadside Friction in Congestion Index in Kumasi, *International Journal for Traffic and Transport Engineering* 10(1): 31-40.

Odoki, J. B. 2016. Case Study: HDM-4 adaptation for analyzing Kenya roads. Paper presented at the *International Conference on Transport and Road Research*. 16-18th March 2016, Kenya.

O'Flaherty, C.A. 2006. *Transport-Planning-and-Traffic-Engineering*. Elsevier. Amsterdam. 561 p.

Pal, S.; Roy, S.K. 2016. Impact of Roadside Friction on Travel Speed and LOS of Rural Highways in India, *Transportation in Developing Economies* 2(2): 9p.

Plankermann, K. 2013. *Human Factors as Causes for Road Traffic Accidents in the Sultanate of Oman under Consideration of Road Construction Designs*, Doctoral Dissertation, University of Regensburg, Regensburg, Bavaria.

Rao, A.M.; Velmuruganb, S.; Lakshmic, K.M.V.N. 2016. Evaluation of Influence of Roadside Frictions on the Capacity of Roads in Delhi, India. In *Proceedings of the World Conference on Transport Research - WCTR 2016*.

Rwanda today. 2015. Traffic jams in Kigali show a need to address public transport mess. Editorial Journal. Available from the internet:<https://www.theeastafrican.co.ke>.

Salini, S.; George, S.; Ashalatha, R. 2014. Effect of Side Frictions on Traffic Characteristics of Urban Arterials, *Transportation Research Procedia* 17: 636-643.

Washington, S.P.; Karlaftis, M.G.; Mannering, F.L. 2011. *Statistical and Econometric Methods for Transportation Data*. NewYork, Taylor & Francis Group.

Zyl, N.V.; Swanepoel, L.; Venter, B.; Pretorius, T.; Merwe, J.V.D. 2012. *Consulting services for the planning and design of a public transport system for Kigali city*. Rwanda, Rwanda Ministry of Infrastructure (MININFRA).