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Study on the Effects of Pavement Condition on Level of Service of the Road Segments

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Abstract

The study was conducted to investigate effects of pavement condition index on level of service of the road segments in Mbeya region Tanzania. Field measurements of vehicle speeds, vehicle volume, lane width, should width, vertical grades and side clearance, were conducted for the purpose of determining level of services (LOS) of the road segments. Pavement defects were identified and defects quantities and severity were measured and analyzed for the purpose of determining pavement condition indices (PCI). For this study five two-lane class III highway road segments were analyzed to determine LOS and PCI. The results indicated that LOS for the road segments ranged from C to E. LOS C was for Mwahala–Igawilo road segment, LOS D was for Kabwe–Isanga and Uyole–Nanenane and LOS E was for Mbalizi–Ifisi and Iwambi–Mbalizi. The LOS C is characterized by restricted flow and level of comfort and convenience are noticeably declining and LOS E is unstable flow at or near capacity with poor levels of comfort and convenience. In order the vehicles to operate at high level of comfort and convenience the road geometric features of the road segments for this study needs to be upgraded to meet minimum requirements but also introduction of climbing lanes in areas with steep slopes. For pavement condition, the current PCI rating for Mwahala–Igawilo was determined to be good, for Kabwe–Isanga and Uyole–Nanenane was fair and for Mbalizi–Ifisi and Iwambi–Mbalizi was very poor. From the PCI rating it was investigated that, Mwahala–Igawilo road segment requires preventive maintenance, for Kabwe – Isanga and Nanenane – Uyole requires rehabilitation and for Mbalizi–Ifisi and Iwambi–Mbalizi requires major rehabilitation or reconstruction. The effect of pavement condition on LOS for this study is expressed in equation as PFFS = 0.243PCI + 55.5 where percentage free flow speed (PFFS) is the measure of LOS for two lane class III highways.

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From the equation it is indicated that as pavement condition deteriorate, the LOS is also deteriorate. It is important to incorporate pavement condition in the determination of LOS of the road segments.

Keywords: Level of Service; Pavement condition index; quality of the road; pavement defects; patching; ruts; pavement cracks; traffic volume; free flow speed; percentage free flow speed; riding comfort.

1. Introduction

The level of service (LOS) and pavement condition index (PCI) are two approaches used to express riding comfort on the road segments. The level of service express riding comfort through traffic operation characteristics and pavement condition index express riding comfort through level of deterioration of the road pavement. The two approaches have the same function, but each of them has its own parameters during determination. The common parameter used to determine pavement condition index is the deduct value obtained from analysis of severities and extents of pavement defects/distresses. The type, severities and extents of road pavement defects are measured on site [1]. However, PCI is also used to determine pavement performance and plan for maintenance and reconstruction of the particular road segment [2]. The level of service (LOS) measures traffic flows governed by travelling speeds and congestions or delays [3]. The measures of performance of vehicle operation along the road segment is through determination of LOS, which is computed from vehicle travelling characteristics and geometric properties measured on site [3]. The level of service is used to plan for improvement of road geometric features of the road segment, maintenance and construction of alternative routes [4]. Due to existence of similar function between LOS and PCI, some researchers have indicated relationships between the two approaches. In this regard, Chan and his colleagues 2010 [5], explained that the driver can decrease vehicle speed in order to safely maneuver through the rutted zone. The decreased speed along the road segment results into vehicle congestion and delays which cause reduction of level of service. The relationship is that the reduction of level of service is due to poor pavement condition caused by rutted pavement. Vladan Ilic, (2015) [6] investigated that time costs vary indirectly as a function of pavement condition which means that the pavement condition affects the speed of driving, and therefore, the amount of time required to complete a specific trip after a road condition threshold have been reached. This indicates that regardless of the ideal cross section dimensions and geometric features of the road segments but the pavement condition affects the vehicle performance which affects level of services significantly. For this study, mathematical equation have been developed to express relationship between percentage free flow speed (PFFS) and pavement condition index (PCI) of the road segment. The PFFS is used to determine level of service of class III two lane highways [3]. The relationship between LOS and PCI will assist the engineers to estimate the level of service of the road segment and plan for improvement of both riding quality and vehicle flow characteristics.

1.1. Level of Service of the Road Segment

Level of service (LOS) of the road facility is a qualitative measure used to relate the cross-sectional properties and geometric features of the road segment with the quality of traffic operation characteristics. The quality of traffic operations provided by road segment under specific traffic demand is measured by means of a level of service. The level of service characterizes the operating conditions of vehicles on the road segment in terms of travelling speed, travel time, freedom to maneuver, vehicle interruptions, passenger comfort, density, delay and convenience [3, 7]. The level of services have been grouped into five categories and are indicated by the letter "A" to "F" on which level of service "A" represents least congested facility and "F" the most congested facility [3]. LOS is needed by traffic engineers and transportation planners when planning for new and rehabilitation or reconstruction of existing highway facilities. The highway facilities on which level of services can be determined includes freeway, two-lane highways, multi-lane highways, signalized and un-signalized intersections, ramps, etc [3]. Table 1 shows limiting conditions of each level of service of the road segment.

Table 1: Limiting conditions for level of services (LOS) of the highway segment [3]

Level of Services	Flow condition	Travel speed	Driving comfort
A	Free flow, interruption is caused by vehicle breakdown	Drivers' decision	Very high physical and psychological
B	Reasonable free flow	Slightly reduced due to limited freedom to maneuver	Relatively high
C	Stable flow	Governed by speed of other drivers and roadway characteristics	Decreased perceptibly
D	Stable flow	Severe restrictions caused by frequent stops	Poor
E	Unstable, as the roadway operate at capacity	Low	Very poor
F	Highly unstable due to constant jam	Very low speed caused by stop and go	Extremely poor

The geometric parameters which are considered during analysis of level of service includes width and number of lanes, shoulder width and lateral clearance, terrain, grade, no passing zone and access density [3, 11]. Generally, unstandardized geometric parameters affects vehicle performance along the road segments. However, vehicle flow parameters have great impact to vehicle performance along the road segment especially for the mixed traffic. In this regards, high percentage of heavy vehicles (busses, trucks, recreational vehicles and trailers) reduces LOS on which it is difficult to maintain the same speed as passenger cars and difficult to maneuverer in case of emergency and overtaking in many situations. Heavy vehicles in traffic stream are converted into passenger car unit by using vehicle equivalent factors [3]. Traffic operations are significantly affected when grades of more than 3% are longer than 400m and the effect of heavy vehicles on such grades is much greater than that for passenger cars. The no passing zones are the areas along the road segment which are restricted to overtake on one or both directions. The no passing zone are indicated on road segments due to poor visibility of the coming vehicles, geometric restriction for overtaking and maneuvering and areas where the human activities are high along the road side and other side frictions [10]. On these areas the level of services are affected due to vehicle queuing which leads to congestion and jam. In the absence of field data, the no passing zone of 20% for level terrain, 50% for rolling terrain and 80% for mountainous terrain are suggested to be adopted [3]. Driver population consisting of commuters are familiar with the road conditions and has knowledge of hazards on the road segment and most likely to be careful resulting into reduction of accidents [3]. Driver population factor ranges from 1.0 for commuters and 0.85 for mixed traffic as its lower limit. Speed is the rate of motion in distance per time and is expressed in kilometers per hour or miles per hour. Speed is affected by many geometric parameters such as lane width, number of lanes, sight distance, vertical grades and side frictions. Travel speed increases with decrease in traffic volume but also varies with the type of roads in which it is higher along freeways, expressways and highways and lower along street roads [8]. However high speed increases the severity of the accidents [9]. Vehicle flow or volume is the number of vehicles passing a point during a specified period of time which is usually one hour and it is expressed in vehicles per hour. Field measurements upon counting vehicles per day crossing at an appropriate location and a peak hour volume per day per week is used to get peak vehicle flow rate. The analysis of level of service is based on peak flow rates occurring within the peak hour and it is because of substantial short-term fluctuations which usually occurs during an hour [3]. The peak hour factor is used to adjust the vehicle fluctuations occurring between 15 minutes intervals within the peak hour. For rural highways, the peak hour factor ranges between 0.75 and 0.95 [12]. Density is a ratio of rate of flow to free flow speed and is expressed by passenger car per kilometer per lane. The density increases as flow speed decreases within a road segment which eventually results into congestion or jam. The level of service is very much deteriorated as vehicle density increases. For two lane highways, the jam density mainly occurs due to vehicle break down, delays at junctions and access roads which makes difficult to maneuver especially for heavy vehicles caused by restricted road geometric characteristics [3]. Congestion along the road segment causes physical and psychological discomfort to drivers and passengers which increases accident rates along the road segment. The vehicle flow rates may be different within the lanes of the roadway segments depending with social and economic activities of the areas where the particular road segment is serving. The variations may occur within hours a day, within days a week and seasonal a year. The ratio of vehicle flow rates per lane per direction is computed and is called directional split which is expressed in percentages. In the absence of field data, the directional split of 60/40 for rural and urban highways and 80/20 for recreational highways are suggested to be adopted [3].

1.2. Pavement condition

Pavement condition is the level of deterioration of the road pavement due to distresses/defects caused by axle loads and weather effects. Pavement condition index is a numerical rating used to measure the pavement condition and it ranges from 0 to 100 with 0 being the worst possible condition and 100 being the best possible condition [1, 13]. Pavement condition varies with time and with continuous application of the vehicle loads and weather changes on the existing pavement resulting into gradual deterioration to its salvage value. The change of riding quality of the pavement surface with time is called pavement performance. Pavement performance is affected by several factors which includes vehicle loadings, soil and pavement materials, weather and environment condition, construction process and maintenance practice. When pavement condition reaches unacceptable level, then it is considered that it has reached end of its serviceable life. Performance prediction and planned maintenance is important in order to ensure that the pavement reaches the acceptable condition at the end of its designed life [14]. Pavement distresses or defects includes alligator cracking, bleeding, block cracking, bumps and sags, corrugations, depressions, edge cracking, joint reflections, lane/shoulder drop-off, longitudinal and transverse cracking, patching and utility cut, polished aggregate, potholes, rutting, shoving, slippery, swelling, weathering and raveling [1, 13]. The PCI of the sample unit is calculated using distress quantities measured from site and converted to distress densities for each severity level. The densities are used to determine the deduct value and the PCI for each sample unit is obtained by subtracting deduct value from 100 [1, 13]. The pavement condition index can give a good indication of the vehicle riding comfort through the road network [10]. However, performance of road signs and markings along the road segment can also be used to provide indication to improve road user safety, reduced delays, improved riding comfort and confidence to drivers [15]. Apart from pavement conditions other factors which affects level of service of roadway facilities are weather condition such as heavy rainfall, fog and snow, vehicle types, vehicle conditions and short distances tight curves.

2. Investigation Procedure

The study involved field measurements and data analysis of road defects for determination of existing pavement conditions and traffic flow parameters, cross sectional dimensions and vertical grades for determination of level of services for the selected five road segments in Mbeya region. The road segments were Mwahala–Igawilo 2.44km, Kabwe–Isanga 2.59km, Nanenane–Uyole 3.24km, Mbalizi–Ifisi 5.07km, and Iwambi–Mbalizi 2.64km. According to HCM 2010 [3], the road segments for this study have been classified as class III two lane highways. The class III highways are characterized by portions of Class I or Class II highways that pass through small towns or developed recreational areas. On such segments, local traffic often mixes with through traffic, and the density of un-signalized roadside access points is noticeably higher than in a purely rural area. Class III highways may also be longer segments passing through more spread-out recreational areas, also with increased roadside densities. Such segments are often accompanied by reduced speed limits that reflect the higher activity level [3]. Table 2 shows physical cross sectional dimensions and vertical grades of each road segment. The measurement of level of service for class III highways, is conducted by determining percentage free flow speed (PFFS) where by drivers would like to make steady progress at or near the posted speed limit [3].

Table 2: Cross sectional elements for road segments

Road segment	Number of lanes	Lane Width (m)	Shoulder width (m)	Segment length (km)	Average vertical grade (%)	Terrain	Access points both Direction (%)	No passing zone (%)
Mwahala–Igawilo	2	3.5	1.1	2.44	3.76	Rolling	7.5	32
Kabwe–Isanga	2	3.5	1.2	2.59	3.10	Rolling	9.14	59
Uyole–Nanenane	2	3.5	1.1	3.24	1.20	Level	2.48	37
Mbalizi–Ifisi	2	3.5	1.2	5.07	1.18	Level	8.68	73
Iwambi–Mbalizi	2	3.5	1.1	2.64	4.31	Rolling	4.20	78

2.1. Investigation Approach

The field data survey included identification of defect types, measurements of severity and extent of each defect found on road segments for the purpose of determining pavement condition indices (PCIs). The measurement of pavement defects and analysis to determine pavement condition index followed the procedure stipulated in ASTM D 6433–11 [1] For the case of level of service, the parameters used for class III road segments included vertical grades, terrains, vehicle speeds, traffic volumes and no passing zone. The measurement of parameters for analysis to determine level of service followed the procedure stipulated in HCM 2010 [3]. The effects of pavement condition on level of service of the two-lane class III highways for this study was achieved through equating the PFFS obtained on each road segment with their corresponding PCI.

3. Results and Discussion

The analysis of the data for determination of level of services for this study were carried out based on the traffic flow parameters and geometric properties for class III two lane highways. However, the analysis of pavement condition indices of the road segment does not require classes of the highway.

3.1. Level of Service (LOS) of the Road Segments

The level of services of the selected five road segments were determined following the procedures stipulated in HCM 2010 [3] for class III two lane highways. For class III two lane highways the level of service is determined from percentage free flow speed (PFFS) obtained by dividing the average travel speed (ATS) with free flow speed of the vehicles. The free flow speeds for each road segment were computed using equation 1 [3].

$$FFS = S_{av} + 0.00776 \left(\frac{V}{F_{HV,ATS}}\right) \qquad (1)$$

Where: FFS – estimated free flow speed (mil/hr);

S_{av} – field measured average travel speed (mil/h);

V – total traffic demand on a segment (veh/h);

FHV,ATS – heavy vehicle adjustment factor for estimated average travel speed (ATS) given by:

$$F_{HV,ATS} = \frac{1}{1+P_T(E_T-1)+P_R(E_R-1)} \qquad (2)$$

Where: PT and PR – are proportional of trucks and recreational vehicles respectively (decimals);

ET and ER – are passenger car equivalent factors for trucks and recreational vehicles respectively.

For this study no recreational vehicles were found during field traffic studies. However, the composition of motorcycle (bodaboda) and tricycle (bajaji) in the mixed traffic for two lane highways under study were high. Therefore it is necessary to conduct in-depth study to investigate their effects on traffic flow characteristics in the mixed stream. The measurement of average vehicle speeds were conducted on site by recording time by using stop watch for each vehicle crossing a distance of 100m at specified visible location along each selected road segment. The speed of each vehicle were computed by dividing the distance with time taken and the frequency distribution curves were drawn as described in Manual of Transportation Engineering Studies [16]. The average travel speeds or median speed of vehicles were computed as 50 percentiles from the cumulative frequency – speed curves [17]. The average speeds computed for each road segments are Igawilo–Mwahala was 41km/h (26mil/hr), Kabwe–Isanga was 28km/h (17mil/h), Nanenane–Uyole was 38km/h (24mil/hr), Mbalizi–Ifisi was 34km/hr (21mil/hr) and Iwambi–Mbalizi was 35km/h (22mil/h). Figure 1 shows cumulative frequency – speed curves for selected five road segments for this study.

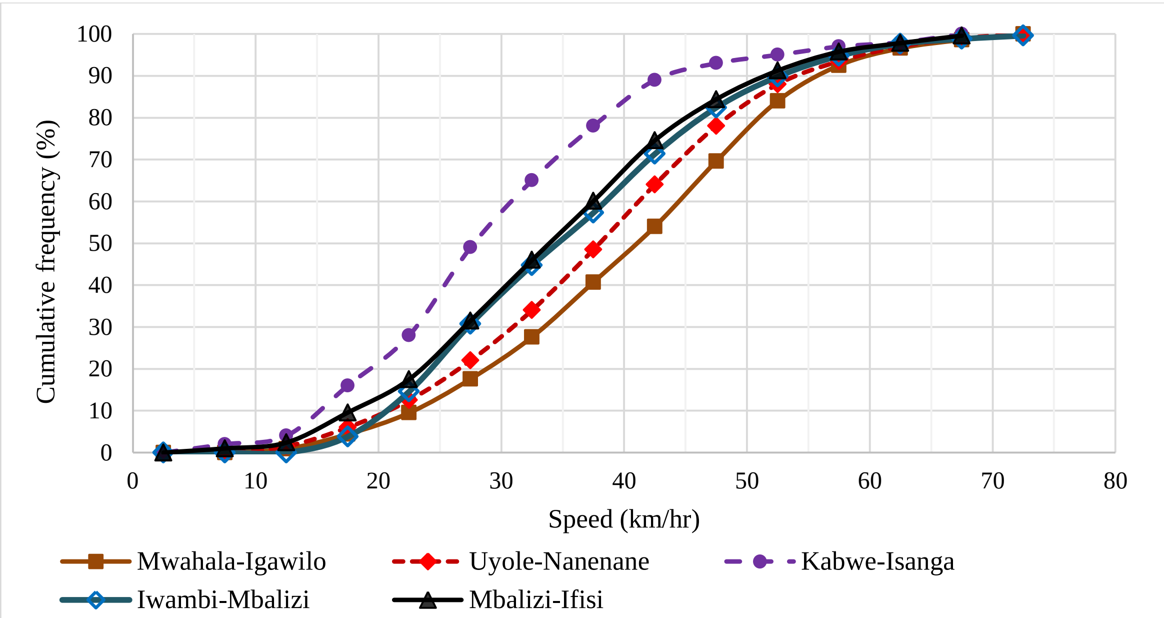

Figure 1: Vehicle speed curves for selected five road segments

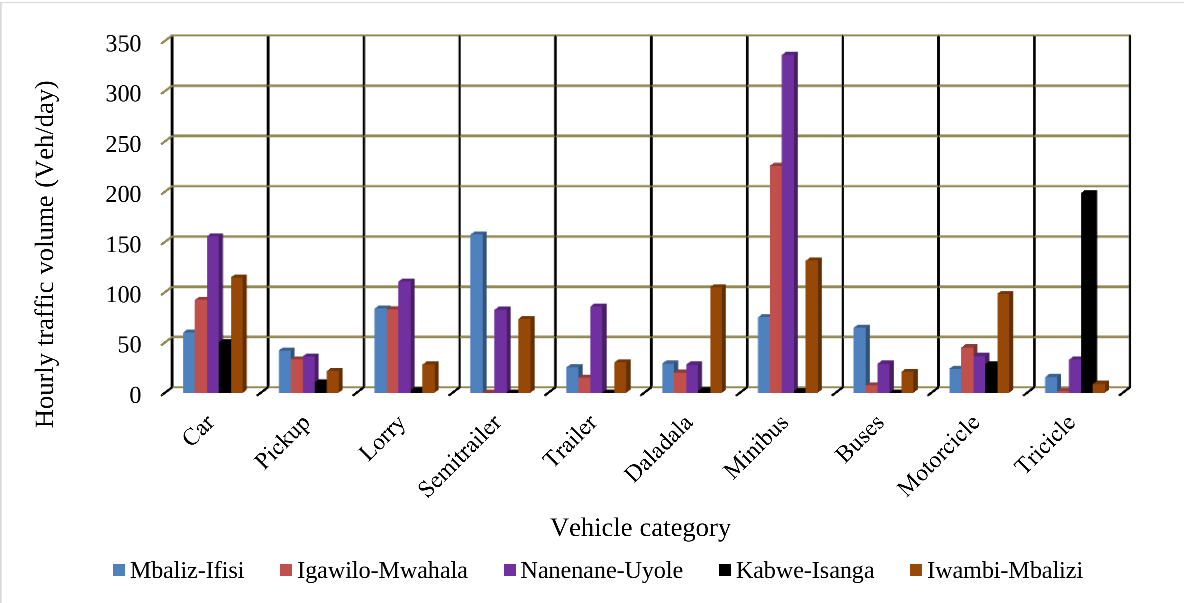

Figure 2: Average hourly traffic volumes for vehicle categories (Veh/hr)

The peak traffic volumes and peak hour factors are important parameters for determination of level of service. The traffic volume studies were conducted for 12 hours a day for seven days and converted into vehicles per hour where by the peak hour volumes and peak hour factors were determined. Figure 2 shows the average hourly traffic volumes for vehicle categories. The vehicle volume studies and analysis of peak hour volumes and peak hour factors were conducted following the procedure stipulated in HCM 2010 and Manual of Transportation Engineering Studies [3, 16]. For mixed traffic, the counting was based on vehicle categories which is important for determining percentage of heavy vehicles which affects smooth flow of cars at desired speeds [3]. Equation 3 was used to estimate average travel speeds for class III two lane highways [3]. Table 3 gives the parameters used for estimation of free flow speeds and average travel speeds which includes peak hour traffic volumes, peak hour factors (PHF), directional split and composition of heavy vehicles.

$$ATS_{1,2} = FFS - 0.00776\left(V_{1,ATS} + V_{2,ATS}\right) - F_{np1,2} \qquad (3)$$

Where: ATS1,2 – estimated average travel speed (mil/h) for direction 1 and 2 respectively;

Fnp1,2 – speed reduction factor (mil/h) for no passing zone on direction 1 and 2 respectively;

V1,2 ATS – demand volume (veh/h) for direction 1 and 2 respectively, given by equation 4.

$$V_{1,2,ATS} = \left(\frac{V_{1,2} * \left(1 + PT(ET-1) + PR(ER-1)\right)}{PHF * F_G}\right) \qquad (4)$$

Where: PHF and FG – are peak hour factor and grade adjustment factor respectively

Table 3: Vehicle flow volume data

Road segment	Peak hour traffic volume (veh/h)	Peak hour factors (PHF)	% Trucks and Buses (PT1/PT2)	% Trucks and Buses (PTave)	Directional split (%)
Mwahala – Igawilo	469	0.80	17/26	23	38/62
Kabwe – Isanga	309	0.91	2/1	1.58	58/42
Uyole – Nanenane	1032	0.77	32/34	33	52/48
Mbalizi – Ifisi	678	0.75	42/47	44	54/46
Iwambi – Mbalizi	776	0.80	25/23	24	56/44

However, according to HCM 2010 [3] the demand adjustment factors for class III two lane highways is determined at directional maximum possible peak flows. Thereby the directional peak flows are divided by peak hour factors to get the directional demands for determination of demand adjustment factors which are passenger car equivalent factors for trucks and recreational vehicles and grade adjustment factor. The speed reduction factors for no passing zone are determined based on estimated directional volume for average travel speed used in equation 4. Figure 3 shows peak hour volumes and average hourly traffic volumes for the selected five road segments. The percentage different between peak hour volume and average hourly traffic volume are less than

20% for all five road segments. This indicates that the fluctuations of vehicle flow along the road segments are small and therefore the flows are steady.

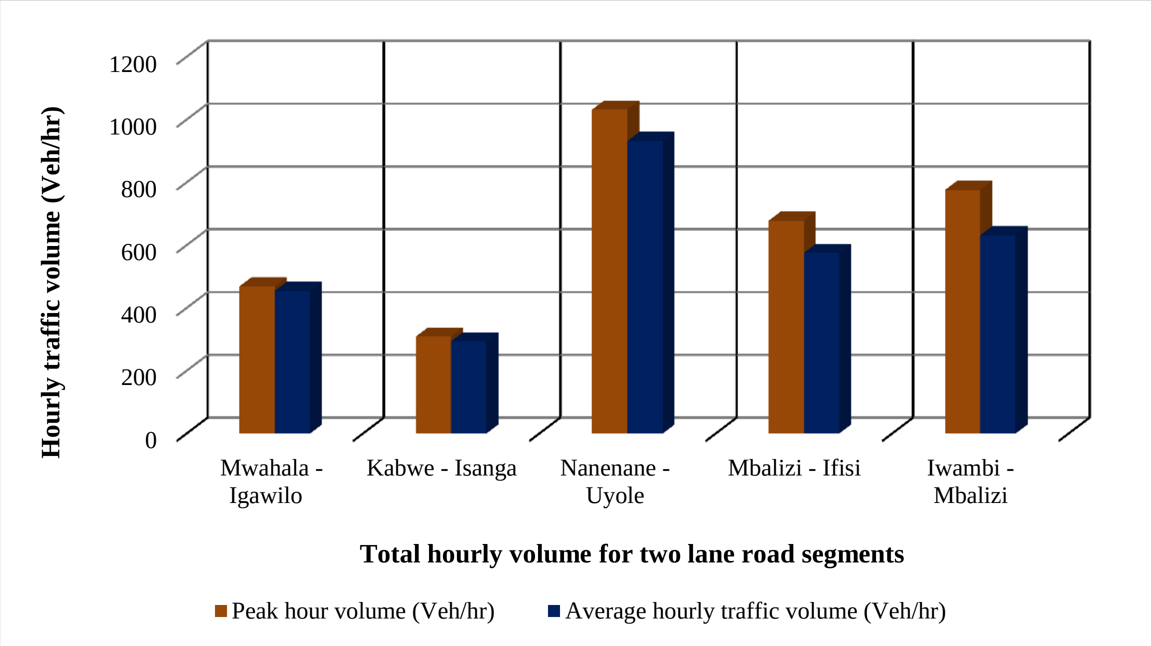

Figure 3: Two direction peak hour and average hourly vehicle volumes (Veh/hr)

The measure of effectiveness of class III two lane highway is by determination of percent free flow speed (PFFS). Equations 5 is used to determine PFFS which is used to determine level of service (LOS) for class III two lane highways [3]. Table 4 shows demand adjustment factors for each road segments.

$$PFFS_{1,2} = \frac{ATS_{1,2}}{FFS} * 100 \qquad (5)$$

Where: PFFS1,2 – percentage free flow speed for direction 1 and 2;

ATS1,2 – estimated travel speed for direction 1 and 2 (mil/hr);

FFS – estimated free flow speed (mil/hr).

Table 4: Directional demand adjustment factors

Road segment	Terrain	V1ET	V2ET	ET1	ET2	FG1	FG2	Fnp1,ATS	Fnp2,ATS
Mwahala to Igawilo	Rolling	220	366	2.26	1.33	0.77	0.88	0.58	0.76
Kabwe to Isanga	Rolling	204	135	2.3	2.56	0.75	0.7	3.01	2.57
Uyole to Nanenane	Level	697	643	1.1	1.1	1	1	0.31	0.31
Mbalizi to Ifisi	Level	488	416	1.21	1.28	1	1	2.07	1.82
Iwambi to Mbalizi	Rolling	548	423	1.75	1.95	0.96	0.91	1.78	1.45

Table 5 gives field measured average speeds (S_{av}), estimated free flow speed (FFS), estimated average travel speed (ATS) for both directions and estimated percent free flow speeds (PFFS) for both direction for each road segment for this study. The level of service apart from being affected by traffic flow parameters and geometric characteristics but also pavement condition affects LOS significantly. This is because it is difficult for driver to travel at desired speed along the road segment with poor pavement condition. The driver will make frequent breaks, travelling at low speed and difficult to maneuver and overtaking which may result into congestion, jam and accidents. However the road segment which is highly corrugated or rutted or severely potholed causes high vehicle operating costs due to frequent vehicle break down, accidents and fuel consumption.

Table 5: Vehicle flow speed data

Road segment	Sav(mph)	FFS	ATS1	ATS2	PFFS1	PFFS2	PFFSave	LOS
Mwahala-Igawilo	25.6	32	25	25	78.68%	77.86%	78.27%	C
Kabwe-Isanga	17.3	21	14	15	68.27%	70.08%	69.17%	D
Uyole-Nanenane	23.6	34	23	23	67.82%	67.82%	67.82%	D
Mbalizi-Ifisi	21.1	29	19	19	65.98%	66.77%	66.37%	E
Iwambi-Mbalizi	21.5	31	20	20	63.28%	64.44%	63.86%	E

Therefore it is important to relate the pavement condition with the vehicle operational performance along the road segments. For this regard, the HCM 2010 have included pavement rating in the analysis of level of service of the cyclist facilities [3].

3.2. Pavement condition index

The pavement condition index (PCI) of the selected road segments were determined following the procedures stipulated in ASTM D6433-11 and UFC 3-270-08 [1, 13]. PCI is used by road agency, engineers and planners to predict future pavement performance, determine and prioritize pavement maintenance and rehabilitation needs, estimate repair quantities and evaluate the performance of different maintenance and rehabilitation techniques and materials [13, 18]. The evaluation and analysis of PCI on the road segments are required to be classified according to their functional classes such as street roads, highways etc and type of pavement materials used for construction such as asphalt, concrete, composite, paving blocks etc. The road segment having homogeneous characteristics in terms of construction history, construction materials, sectional properties are divided into sample units for identification and measuring of defect quantities and severities [1, 13]. The recommended size of sample unit is between 135m^2 and 315m^2 for asphalt pavement [1]. In order to get the PCI of the sample unit the following procedures as described in ASTM D6433-11 [1] are used.

i. Identification of distress type, quantity or extent and severity level and measuring the quantity for each distress type and severity.
ii. The densities for each severity level are computed by dividing the distress quantities with the area of sample unit multiplied by 100.

iii. The densities are used to determine deduct values (DV) obtained from the deduct value curves for each distress type and severity level.
iv. The deduct values for each sample unit are arranged in descending order from the highest to the lowest
v. The allowable number of deducts "m" are determined from the equation $m = 1 + (9/98)*(100–HDV) \leq 10$ where HDV is the highest deduct value for each sample unit.
vi. The number of individual deduct values is reduced to the "m" largest deduct values, including the fractional part. If less than "m" deduct values are available, all of the deduct values are used.
vii. The iterative process is conducted by reducing the individual deduct value through replacing 2 from right to left for the allowable number of deducts.
viii. A total deduct value (TDV) for each iteration and sample unit is computed by summing all individual deduct values.
ix. The TDV for each iteration and sample unit are corrected (CDV) by using deduct correction curves.
x. The pavement condition index (PCI) is obtained by subtracting maximum CDV from 100 such that PCI = 100 – CDV.

During determination of CDV, the Q is taken to be number of individual deducts with a value greater than 2. The pavement condition index (PCI) of the road segment is the average PCI of the sample units. Table 6 shows the PCI rating for asphalt and Portland cement concrete pavement [1].

Table 6: PCI rating [1]

Rating	Good	Satisfactory	Fair	Poor	Very poor	Serious	Failed
PCI	85–100	70–85	55–70	40–55	25–40	10–25	00–10

The PCI of the road segment is obtained by averaging the PCIs of the sample units. However due to different nature of distress type, then the unit of measurements are different such as area for alligator cracks, linear for longitudinal cracks and number for potholes [1, 13]. However, the rating of the pavement condition for the PCI scale indicated in table 3.4 are different for the two documents using similar procedure to assess pavement condition, such that for UFC 3-270-08 [13] the highest rating is excellent and for ASTM D6433-11[1] the highest rating is good. But also for UFC 3-270-08 [13] does not involve iteration process in determining maximum corrected deduct value (CDV_{max}) on which it is less complicated and less time consuming. Figure 4 shows percentage coverage of predominant pavement defects for each road segment.

The predominant defects for Mwahala–Igawilo road segment is edge cracking which cover 5% of the total area, Kabwe–Isanga are alligator cracking which covers 5.2% and weathering/raveling which covers 4% of the total area, Uyole–Nanenane are rutting which covers 8.2%, edge cracking which covers 4.1% and lane/shoulder drop off which covers 3.1% of the total area, Mbalizi–Ifisi are block cracking which covers 30%, alligator cracking which covers 7% and edge cracking which covers 3.8% of the total area and Iwambi–Mbalizi are alligator cracking which covers 24.1%, bleeding which covers 11.3%, block cracking which covers 16.6%, edge cracking which covers 4.6% and longitudinal/transverse cracking which covers 4.6% of the total area.

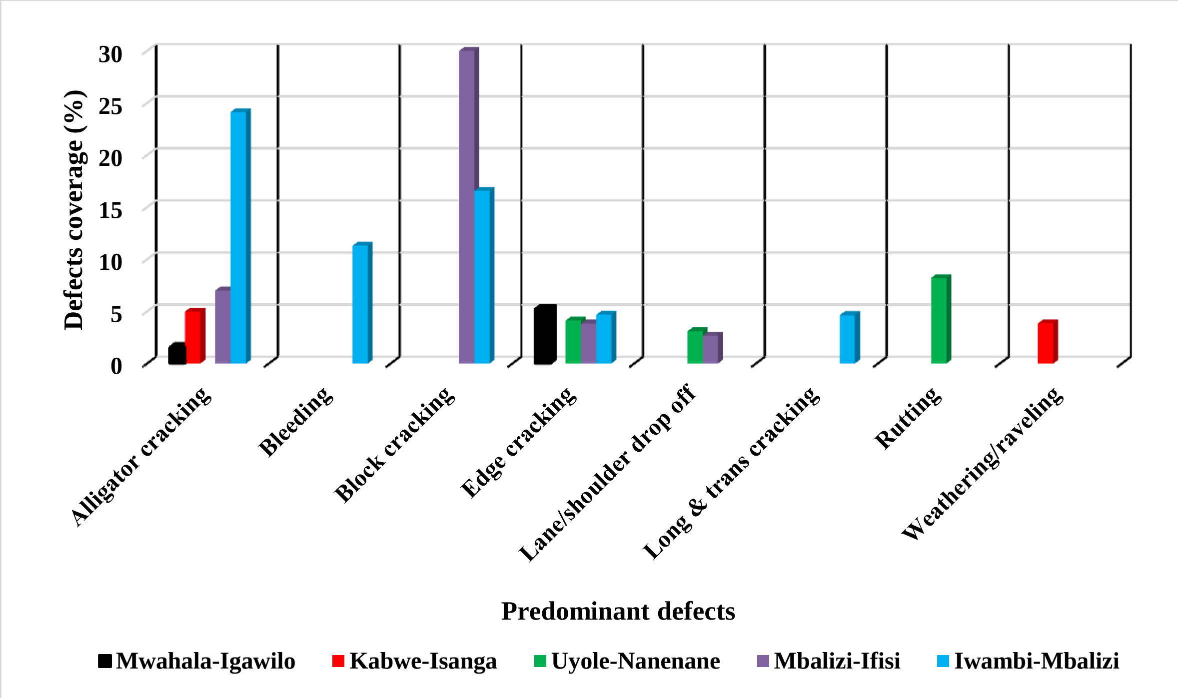

Figure 4: Summary of amount of predominant defects along the five road segments.

It is important to determine percentage distribution of the defects found along the road segment in order to know the type of dominant defects and their severity. This will assist road agencies and decision makers to plan for maintenance budgets and use appropriate methodology to treat particular defects. This is because each defects and its severity level can be treated with different methodology which may affect budgets for equipment/tools, laborers and materials. Figure 5 shows histograms of defects percentage distribution for low severity along the five selected road segments.

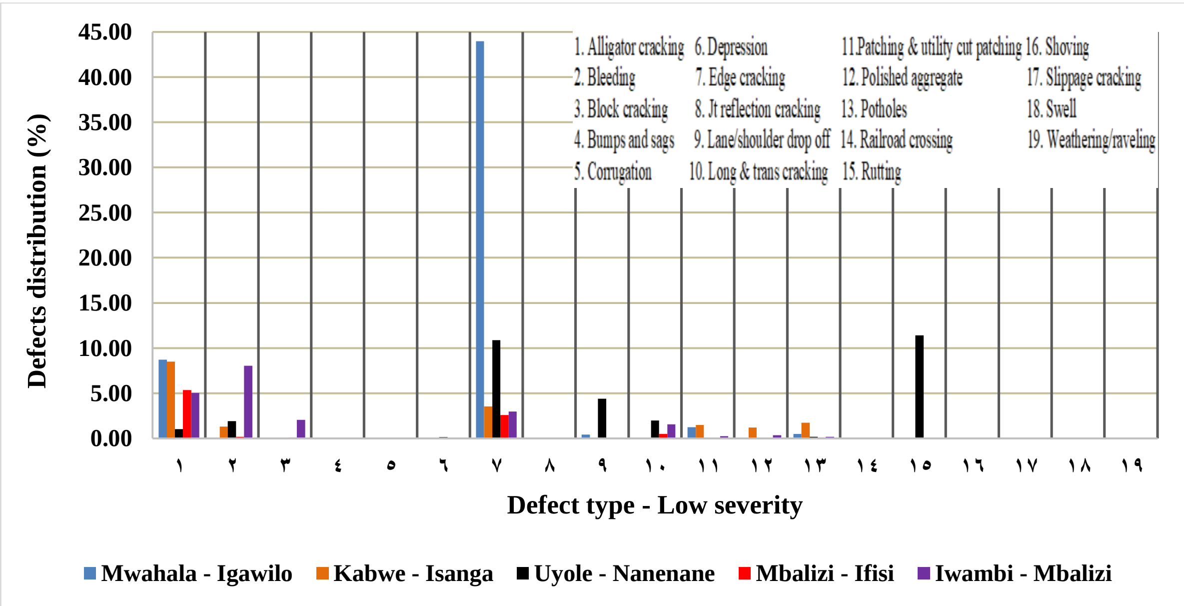

Figure 5: Charts of percentages distribution of defects for low severity and road segments

For Mwahala – Igawilo road segment the defects with high distribution are edge cracking and alligator cracking, while for Kabwe – Isanga are alligator cracking and edge cracking, for Uyole – Nanenane are rutting, edge cracking and lane/shoulder drop off, for Mbalizi – Ifisi are alligator cracking and edge cracking and for Iwambi – Mbalizi are alligator cracking, bleeding, block cracking and edge cracking.

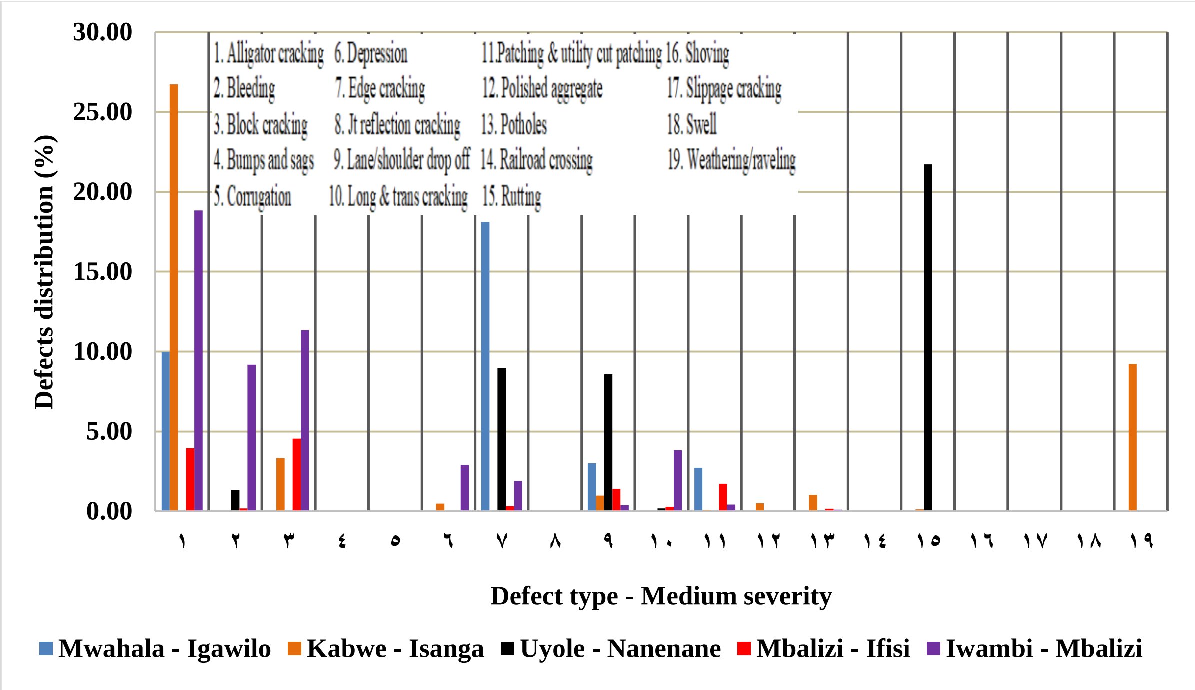

Figure 6: Charts of percentages distribution of defects for medium severity and road segments

Figure 6 shows histograms of defects percentage distribution for medium severity along the five selected road segments. For Mwahala – Igawilo road segment the dominant defects are alligator cracking and edge cracking, while for Kabwe – Isanga are alligator cracking and weathering/raveling, for Uyole – Nanenane are rutting, edge cracking and lane/shoulder drop off, for Mbalizi – Ifisi are alligator cracking and block cracking and for Iwambi – Mbalizi are alligator cracking, bleeding and block cracking. Figure 7 shows histograms of defects percentage distribution for high severity along the five selected road segments. The dominant defects found along Mwahala – Igawilo road segment is lane/shoulder drop off, while for Kabwe – Isanga are patching and utility cut patching and weathering/ravelling, for Uyole – Nanenane are edge cracking, lane/shoulder drop off and rutting, for Mbalizi – Ifisi are alligator cracking, block cracking, edge cracking and lane/shoulder drop off and for Iwambi – Mbalizi are alligator cracking and bleeding.

The percentage distribution for road defects along road segments for each severity levels for this study were computed based on the quantities of the defects found regardless of different unit of measurements. The unit of measurement for different defects are different in which some are measured in area such as alligator cracking, rutting, bleeding, others in number such as potholes and others in linear such as longitudinal and transverse cracking, edge cracking [1, 13, 18].

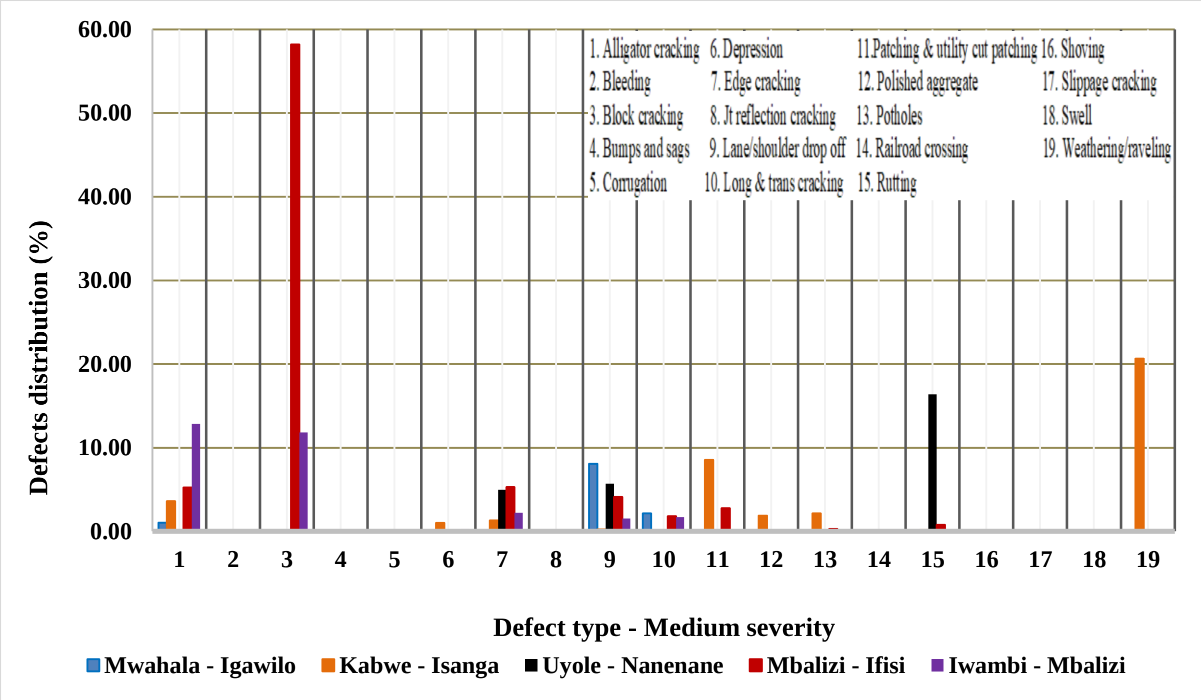

Figure 7: Charts of percentages distribution of defects for high severity and road segments

The conversion of the defect quantity into percentage distribution or percentage coverage is unrealistic. It is important for all defects to be measured in area and specifying depth. In this regard for example potholes can cover lager area than patching, since it is measured in number it indicates less coverage in terms of percentage of total quantity of defects found along the road segment. For linear cracking, the average width of the cracking should be determined for computation of the area of the cracks. The variation of different quantities are also caused by measurement procedures and tools used. In this case rut depth are measured by using straightedge five point scale and laser technology. The two approaches gives different results because the two methods cover different lane widths and use significantly different number of data points to calculate rut depth [19]. Regardless of different unit of measurements for different types of defects but also identification of some defects and severity level by using manual and automated approaches are challenging which may result into different PCI values. Table 7 shows the PCI values and condition rating for the five selected road segments.

Table 7: PCI values and condition rating

Road segment	Sample unit (m2)	Number of samples	Average CDV	PCI	Rating
Mwahala-Igawilo	308	55	13.9	86.1	Good
Kabwe-Isanga	294	62	35.4	64.6	Fair
Uyole-Nanenane	315	72	41.6	58.4	Fair
Mbalizi-Ifisi	315	112	60.2	39.8	Very poor
Iwambi-Mbalizi	315	61	67.9	32.1	Very poor

The results indicates that Mwahala–Igawilo road segment has scored good pavement condition with PCI value of 86.1, Kabwe–Isanga and Uyole–Nanenane have scored fair conditions with PCI values of 64.6 and 58.4 respectively, Mbalizi–Ifisi and Iwambi–Mbalizi have scored very poor pavement conditions with PCI values of 39.8 and 32.1 respectively. The pavement condition along Mbalizi–Ifisi and Iwambi–Mbalizi segments call attention for immediate rehabilitation as they are not safe for driving. This is because condition rating are very poor caused by high amount of alligator cracking, block cracking and edge cracking which results into unsafe driving and frequent vehicle breakdown.

Table 8: PFFS and PCI values for five road segments

Road Segment	Igawilo–Mwahala	Kabwe–Isanga	Uyole–Nanenane	Ifisi–Mbalizi	Iwambi–Mbalizi
PFFS	78.3	69.2	67.82	66.4	63.9
PCI	86.1	64.6	58.4	39.8	32.1

The values of percent free flow speeds (PFFS) and pavement condition indices (PCI) for each five road segments were used to determine their relationship. Table 8 gives the values of PFFS representing the level of services (LOS) of two-lane class III highways and pavement condition indices (PCI) representing level of deterioration of pavement surfaces. The poor riding comfort and performance of traffic operation along a road segment caused by travelling delays, difficult to overtake and maneuver, traffic congestion/jam, accidents and high vehicle operation costs are very much influenced by level of pavement deterioration. Figure 8 is a graph showing the relationship between PFFS and PCI of the five road segments.

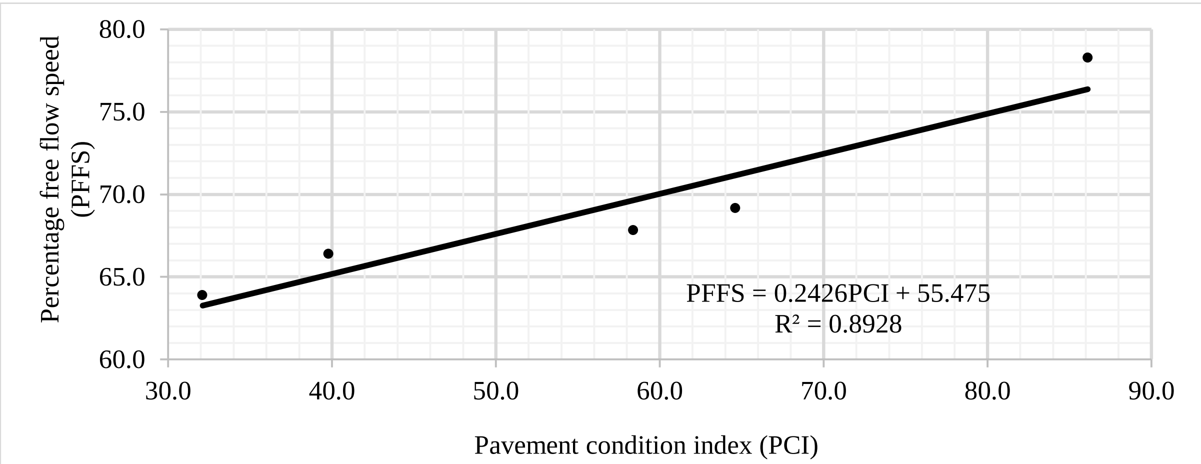

Figure 8: Graph of PFFS and PCI values for the five selected road segments

For this study the effects of pavement condition index (PCI) on level of service (LOS) of the two-lane class III highways have been expressed by equation 6. The percent free flow speed (PFFS) is the measure of LOS.

$$PFFS = 0.243PCI + 55.5 \quad (6)$$

The equation is not one to one function because level of service is determined by combination of several geometric and traffic parameters. Therefore, in order to have best estimation of performance of traffic operation along a particular road segment, the pavement deterioration level should be included as one of the important parameter. However HCM 2010 have included pavement rating in the analysis of level of service for cyclist facilities [3] on which it should be extended to other highway facilities.

4. Conclusion and Recommendation

Highways are basic facilities for mobility of people, goods and items, they bridge communication from one place to another and they facilitate social and business interaction within and between towns. In order the highways to have best vehicle flow operation performance and prolong the service to design life, they need to be regularly maintained and rehabilitated. The results from data analysis indicated that the level of services for the road segments are “C” for Mwahala–Igawilo with PFFS of 78.27%, “D” for Kabwe–Isanga and Uyole–Nanenane with PFFS of 69.17% and 67.82% respectively and level of service “E” for Mbalizi–Ifisi and Iwambi–Mbalizi with PFFS of 66.37% and 63.86% respectively. The road segments needs to be improved in order to increase the vehicle flow performance along the road segments. However, for most road segment for this study, the amount of heavy vehicles in the mixed stream is high ie from 23% to 44% average except for Kabwe–Isanga road segment which is 1.58%. In order to minimize effects of slow moving heavy vehicles especially in areas with steep slopes the climbing lanes are recommended to be constructed. The results for pavement condition indicated that pavement condition for the road segments are good for Mwahala–Igawilo with PCI of 86.1, fair for Kabwe–Isanga and Uyole–Nanenane with PCIs of 64.6 and 58.4 respectively and very poor for Mbalizi–Ifisi and Iwambi–Mbalizi with PCIs of 39.8 and 32.1 respectively. The results of pavement condition performance revealed that maintenance to treat edge cracking and alligator cracking is required for Mwahala–Igawilo road segment. For Kabwe – Isanga and Nanenane – Uyole, rehabilitation are required which may include surface overlays to treat rutting, alligator cracking and edge cracking. For Mbalizi – Ifisi and Iwambi – Mbalizi, major rehabilitation or reconstruction are required because the pavements are highly damaged with large percentage of alligator cracking and block cracking. The effect of pavement deterioration on smooth vehicle flow performance for this study was expressed in terms of equation as PFFS = 0.243PCI + 55.5 where PFFS is the measure of LOS for two-lane class III highways. From this equation it is indicated that as pavement condition deteriorates, the level of service of the particular road segment is also decreased. It is important to incorporate pavement condition in the determination of level of services of the road segments.

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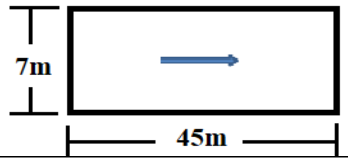
Annexes

Table A1: Field survey defect data and determination of PCI for a unit sample

ASPHALT SURFACED ROADS AND PARKING LOTS CONDITION SURVEY DATA SHEET FOR SAMPLE UNIT

BRANCH: TANZAM **SECTION:** NANENANE–UYOLE **SAMPLE UNIT:** 3 **SURVEYED BY:** DALALIA MAYILALI, BENARD SILLAH & DUWA HC **DATE:** 28/05/2020 **SAMPLE AREA:** 315m^2

Sketch



1. Alligator cracking 6. Depression 11.Patching & utility cut patching 16. Shoving
2. Bleeding 7. Edge cracking 12. Polished aggregate 17. Slippage cracking
3. Block cracking 8. Jt reflection cracking 13. Potholes 18. Swell
4. Bumps and sags 9. Lane/shoulder drop off 14. Railroad crossing 19. Weathering/raveling
5. Corrugation 10. Long & trans cracking 15. Rutting

Distress & Severity	**Quantity**									**Total**	**Density %**	**Deduct value**
15H	1*15	1*7.5								22.5	7.14	56.0
2M	2*7									14	4.44	8.5
7M	6.5	10	2							18.5	5.87	10.0
9H	2	5								7	2.22	7.0
Iteration	**Deduct Values**									**Total**	**Q**	**CDV**
1	56.0	10.0	8.5	7.0						81.5	4	46
2	56.0	10.0	8.5	2						76.5	3	48
3	56.0	10.0	2	2						70	2	52
4	56.0	2	2	2						62	1	**62**

Maximum CDV	62
PCI = 100 – 62	**38**
Rating	**Very poor**

Figure A1: Edge cracking (left) and alligator cracking and edge cracking (right) for Mwahala–Igawilo road segment

Figure A2: Alligator cracking (left) and edge cracking (right) for Kabwe–Isanga road segment

Figure A3: Rutted pavement surface for Nanenane–Uyole road segment

Figure A4: Alligator and edge cracking (left) and alligator cracking and patching (right) for Mbalizi–Ifisi road segment

Figure A5: Edge cracking (left) and alligator cracking and pothole (right) for Iwambi–Mbalizi road segment