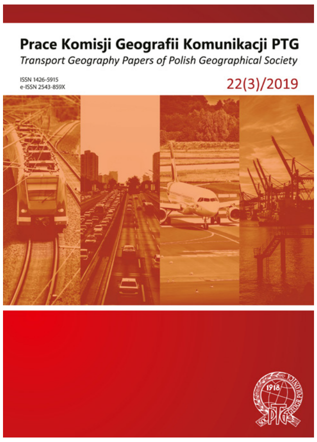

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ASSESSMENT OF RAILTRACK GEOMETRY OF IDDO – MUSHIN CORRIDOR LAGOS REGION

Ocena geometrii torów kolejowych korytarza Iddo-Mushin w Lagos

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Abstract: Railway transport is a primary asset to trade, industry and commerce development of nations hat demand among others, a safe transit and optimal maintenance. Track performance remains an important index towards measuring track degradation. Thus, in this study the rail track geometry model was adopted to analyze the quality of Iddo – Mushin rail corridor towards safe rail transport system. Geometric parameters of interest include vertical irregularities, horizontal irregularities, cross-level, twist and track gauge. The parameters were calculated from a 3-dimensional data collected using Tachymetric Surveying approach covering Mushin, Yaba, Ebute-Meta and Iddo terminus. It should be noted that despite the high standard used as regards to the design and construction of the Iddo-Mushin rail track facilities, several derailments have occurred over time due to rail geometry deformation with high probability incidents along the Iddo – Ebute-Meta corridor. It was also discovered that the Iddo-Mushin axis can only permit average train speed of about 80 km/h, using the Polish Railway Synthetic Coefficient for safe rail transportation system. The synthetic assessment approach is simple and facilitate a continuous measurement of geometric parameters along railway track. Proper maintenance and upgrade of the rail track system mechanisms to support the incremental trasport demand and services as a result of socio-economic growth and development of Lagos mega city, is therefore suggested.

Key words: Track geometry, Track degradation, Synthetic Coefficient, safe speed

1. Introduction

Railway eases the industrialization process through a wide comprehended system with array of infrastructures intended to support and guide the train in a safe and economic manner at cheaper rate since its carrying capacity can easily be increased through additional wagons. Proper rail safety maintenance and service depends on several rail transport engineering design standards that cover diverse technical and operational standards like track quality index, permissible curve radii limits, permissible track gradient limits, types of rail track facilities including platform heights, among others (Obi, 1986; Agunloye, Oduwaye, 2011).

Thus, operational consideration of track maintenance exercise whilst minimizing maintenance costs depend on the dynamic interaction between the vehicle and track, in terms of safety, comfort and cost apprehensions. Safety and comfort considerations emphasize the point at which effective maintenance is in place to reduce wear and tear on train, faster speed and prevent derailment for a smoother ride; while economy consideration entails the period at which the maintenance costs must be minimized, without neglecting the need to preserve a suitable margin of safety and to limit the rate of irreversible deterioration.

Railway maintenance procedures were usually based on appropriate infrastructure maintenance of high safety standard with less concern on economic cost issues. Unfortunately, the competitive economic environment and budget limitations of the contemporary transportation system are forcing railway infrastructures to optimise operation and maintenance procedures while still assuring high safety standards, most especially in the highly developed world. Optimising maintenance requires among others track degradation estimation and its consequences, in the form of cost. (Caetano, Teixeira, 2013; Weston et al., 2015; Soleimanmeigouni et al., 2016).

One of the main components of rail system infrastructure towards safety and less operating expenses remains the rail track structure and its maintenance. For example, *in 2006, 65%* of the *maintenance cost was allocated to the track and platforms in the Netherlands*, this is necessary in to avoid train infrastructure turnout failures among others (Al-Douri et al., 2016).

Track geometry consists of important parameters that describe the layout and path of the track which are designed to meet specific longitudinal profile, alignment, gauge, cross level (or super-elevation irregularity) and twist criteria towards ensuring optimal comfort and safety (BS EN 13306, 2017; EN 13848-1, 2008; Sato, 1997). Thus, the track geometry are described by the nominal geometry and irregularities. The nominal track geometry consists of vertical curvature, horizontal curvature, gradient (i.e. slope of track), track gauge and cross level (cant) while track irregularities detailed the deviation of the actual track geometry from the nominal (designed) track geometry.

Track geometry degradation is a complex phenomenon affected by dynamic loads with the rate of degradation being a function of time and/or usage intensity, superstructure, among others (Sadeghi, Askarinejad, 2010; He et al., 2014). During the train operation, the track quality starts to degrade as a result of interaction of several effective parameters like the cumulative of track loads (MGT), time, and speed, among others. Lichtberger (2005) opined that the initial track quality, the initial settlement and the deterioration rate are the major parameters of track quality deterioration.

Track degradation model differs in structural and geometrical and ranges from the simple to comprehensive ones based on parameters of interest (Sadeghi, Askarinejad, 2007). Structural model is based on the progression of defects in the physical structure, like ballast settlement, wear and corrugation (Kim et al., 2018; Soleimanmeigouni et al., 2018; Sato, 1997) while a geometrical model is based on the reflection of the actual state of rail track condition considering the track structural defects in terms of optimal comfort and safety considering important parameters that describe the layout and path of the track with well-defined specific criteria. Such parameters include longitudinal profile, cross level, cant, alignment, among others (Zhang et al., 2000).

Rail track geometry is an important aspect of railway construction upon which the degradation of many other track components is closely related. It is also often as an index in track safety, maintenance and renewals tactics (Madejski, Grabczyk, 2002; Esveld, 2001; Jovanovic, 2004; Lyngby et al, 2008; Bowman, 2015; Martey, Attoh-Okine, 2018).

Over the years, urban rail system has been a part of Lagos Mega city transport system plan to ease the movement of commuters from the interior to the city center. Unfortunately, despite numerous attempts to revamp the entire 3505km narrow gauge track in Nigeria, including the double narrow gauge track of Lagos railway corridor towards an enhanced rail track performance, several derailments have occurred over time along the Iddo-Mushin rail track, due to geometric deformation (Jaekel, 1997; Adesanya, 2010). These deformation have being significant and have led to some noted transportation hazard or discomfort such as derailment and reduced speed of trains (Fig. 1). It is in the realization of an effective and efficient as well as safe public rail transportation system in Nigeria that made rail track geometry assessment becomes imperative.

Thus, the main aim of this study is to access and analyze the rail track geometry of part of the Lagos Metropolis along the Iddo – Mushin corridor (Fig. 1). This corridor connects major residential settlements and neighborhoods to Lagos Central Business District (CBD), the commercial nerve center of Nigeria and her environs. This is necessary for safe and efficient urban rail transport system planning, design, maintenance and management purposes.

Fig. 1. Snapshots of derailment along part the Iddo-Mushin rail track.

Source: thisdaylive.com

2. Regional Setting

The study area is located at Iddo Railway Terminal junction along the rail lines all through to Mushin Railway Terminal which covers a distance of approximately 7 km in length within Lagos mainland and Mushin local government area (LGA) of Lagos State. The starting point is Iddo terminal, which is located at 542386.555mE,715207.825mN and the end point in Mushin is located at 540284.984mE, 721409.048mN (Fig. 2). The rail system between Iddo and Mushin under spotlight consists of four train stations namely Mushin, Yaba, Ebute-Meta and Iddo terminus (Fig. 3). These stations are all stopping points for the transit service and are primarily used for loading and off-loading of passengers and goods. The Iddo-Mushin railine passes through Lagos Mainland and Mushin area which is located in Central part of Lagos, Nigeria. The coastal lowlands which dominate the Lagos landscape form part of a wider stretch of the coastal zone of southern Nigeria (Adeoye, 1998). According to Badejo (2009), the mode of landform evaluation in Lagos has been largely influenced by physico-climatic factors, which include rainfall amount, intensity and distribution character of vegetation. These factors exert dominant influence upon the dynamics of coastal landform processes in the area. In understanding the landform types of Lagos, vegetation and soil types have served as important indications of the spatial pattern of the landform.

Socio-economic activities in the study area (Iddo-Mushin rail track) span across Lagos mainland and Mushin LGA of Lagos state, a well populated area include industries, institutions and commercial activities in the various markets in the area. The rail transport provides the movement of people and freights from/to various terminals adjacent to those markets. Such as the White Sand Market (Iddo), Iddo Garage Market (Iddo), Iddo Whole Sale Market (Iddo), Ori-Eru Market (Oyingbo), Tejuosho Model Market (Yaba), Sabo Model Market (Yaba), Yaba Kee Klamp (Yaba), Mushin Market (Mushin), Papa Ajao Market (Mushin), Odo Ashimowo Market (Mushin).

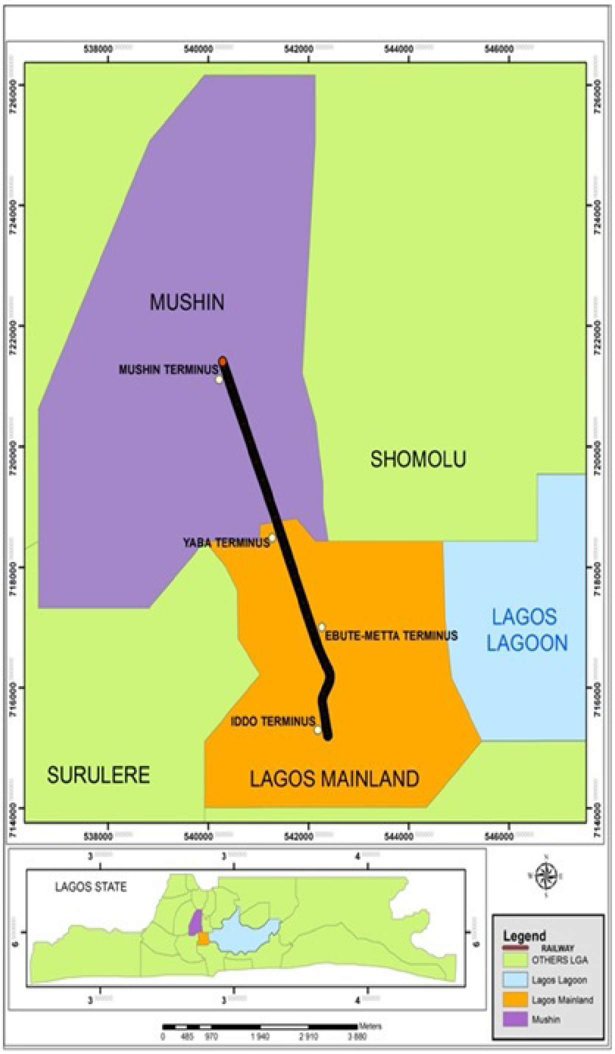

Fig. 2. Iddo-Mushin rail track (Lagos Environs).

Fig. 3. Snapshots of part the Iddo-Mushin rail track.

3. Research Methodology

This study employed a quantitative approach to examine rail track geometry and safe speed maintenance optimization (Creswell, 1994; Greene, Caracelli, 1997) along Iddo-Mushin rail track corridor. Pre-processing data stage entails a reconnaissance visit to familiarize with the project site and examine the best logistics plan towards successful execution of the study. During the field reconnaissance, a sketch map was drawn to depict the approximate configuration of the site in terms of controls point (Tab. 1) and stations selection were drawn to have the general picture of the rail track, not to scale. The approach was carried-out in order to precisely capture the 3-dimensional data of the rail track using the Tachymetric Surveying method with the aid of a Total Station and Promark Global Positioning System device (500 dual frequency). The captured dataset were process in the laboratory using AutoCAD and South NTS.COM 1 for Total Station and Mobile mapping and GNNS Solutions for Global Positioning System.

Appropriate dataset for origins (controls points coordinates) were also sourced from the Nigerian Railway Corporation (NRC) and the Office of Surveyor General (Lagos state). Other supportive tools used on the field comprises of the Reflector and pole, Measuring Tape, Nails and bottle corks. In addition, the accuracy level of the control points was carried out through in-situ computation of angles and distances between controls points using Geospatial Survey Map 7 software (Tab. 2).

Tab. 1. Characteristics of Control Station.

STATION	EASTING (m)	NORTHING (m)	HEIGHT (m)
YTT 18/64	541746.236	715038.632	4.008
YTT 18/65	542211.639	714918.973	4.025
YTT 18/66	542478.458	715028.652	4.167

Source: Office of the Surveyor General, Lagos.

Tab. 2. Control Check from Computed Value.

FROM	Bearing	Distance (m)	ΔE(m)	ΔN (m)	Easting (m)	Northing (m)	TO
					541746.236	715038.632	YTT 18/64
YTT 18/64	104^0 25′ 08″	480.540	465.403	-119.659	542211.639	714918.973	YTT 18/65
YTT 28/65	67^0 39′ 16″	288.482	266.819	109.679	542478.458	715028.652	YTT 18/66

It should be noted that procedure of acquiring the traversing 3-dimensional data include:

i. Establishment of Benchmark point from control point YTT18/66 using Promark 500 dual frequency GPS.
ii. Differentiation of the Benchmark point along Iddo – Mushin Terminus at 25m interval from the origin point at Iddo (LS1 and RS1) to endpoint (LS 268 and RS 268).
   Where, ΔE(m) = Change in Easting = Distance x Sin(α); ΔN(m) = Change in Northing = Distance x Cos(α)
iii. Acquisitions of the sample point three-dimensional coordinates (Easting, Northing and Height) along the Iddo – Mushin rail corridor using the Total Station (Sokkia SET 510) commenced at Iddo (BM1) terminus ended up at Mushin station (Fig. 4).
iv. X, Y and Z coordinates obtained were automatically adjusted by the Total station using the starting and closing control points while the adjusted and the final coordinates were used for the track quality index (TQI) analyses.

Furthermore, the data processing processes involve the computations and deductions of track geometry parameters from collected X, Y and Z coordinates dataset. Based on the Tachymetric Surveying methodology and available dataset, parameters of interest include track gauge, track twist, horizontal irregularities (curvature) and vertical irregularities (longitudinal profile), due to their impact on rail safety and maintenance.

Calculated track geometry parameters are:

i) Horizontal irregularity which measures the deviation of the rails from the nominal centerline in the lateral direction. It is mathematically expressed as:
   Horizontal irregularities (HI):
   $$\text{Sin}\alpha_1, \text{Sin}\alpha_2, \text{Sin}\alpha_3, \ldots \text{Sin}\alpha_n \quad \text{(i)}$$
   Where α = deflection angle – angle measures the departure of the rails from its directed horizontal alignment.
ii) Vertical irregularity is defined as the vertical deviation of the rails from the nominal elevation of the track. It is expressed as:
   Vertical Irregularities (VI):
   $$H_{L1} - H_{L0}, H_{L2} - H_{L0}, H_{L3} - H_{L0} \ldots H_{Ln} - H_{L0} \quad \text{(ii)}$$
   Where H_L = Height level of the track for every sample point interval; H_0 = Height level of the track from a nominal reference point.
iii) Twist measures is the difference in the superelevation between two points of the rails taken at a separate fixed distance. It is quantitatively expressed as:
   $$\text{Twist (T)} = (H_{L1} - H_{R1})\text{Sin}\alpha_1, (H_{L2} - H_{R2})\text{Sin}\alpha_2, (H_{L3} - H_{R3})\text{Sin}\alpha_3 \ldots (H_{Ln} - H_{Rn})\text{Sin}\alpha_n \quad \text{(iii)}$$
   Where, α = deflection angle; H_L = Height level of the left rail at every sample point interval and H_R = Height level of the right rail at every sample point interval.
iv) Track gauge specifies the differences of the inner distance between two rails measured at the top surface of the railhead. It is expressed as;
   $$\text{Track Gauge (G)} = \sqrt{((E_{R1} - E_{L1})^2 + (N_{R1} - N_{L1})^2)} \quad \text{(iv)}$$
   Where, E_R and E_L = Easting coordinates of the right and left rail; N_R and N_L = Northing coordinates of the right and left rail.

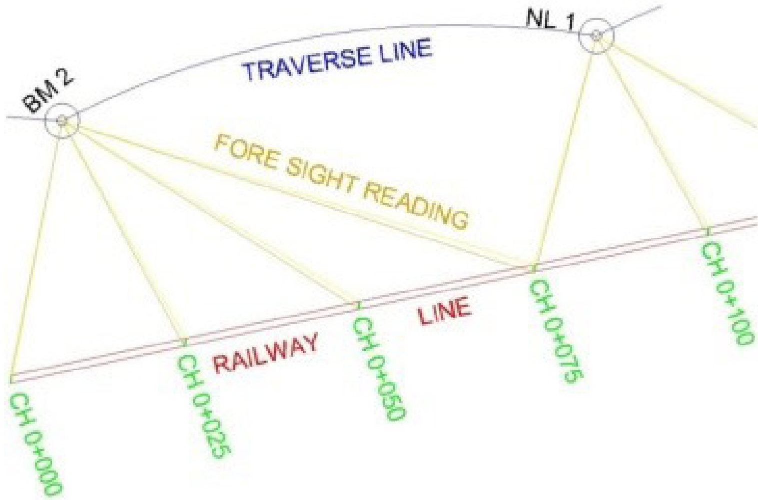

Fig. 4. 3-dimensional data acquisition along railway line.

Rail track quality assessment was carried out using the Synthetic Coefficient (*J*) track quality index method which was developed by the Polish Railways (Madejski, Grabczyk, 2002). The coefficient specifies the allowable deviation for different rail line speeds.

Synthetic coefficient track quality index (*J*) is based on the standard deviation of four different geometry parameters as given by equation (v):

$$J = S_z + S_y + S_w + 0.5 * S_e \quad (v)$$

where:

J = Synthetic Track Quality Coefficient; Sz = Standard deviation of vertical irregularities; Sy = Standard deviation of horizontal irregularities; Sw= Standard deviation of track twist; Se= Standard deviation of track gauge

The standard deviation for each parameter is calculated as

$$S = \sqrt{\frac{1}{n}} . \sum_{i=1}^{n} (x_i - \dot{x})^2 \quad (VI)$$

Where n is the number of signal along the track

X_i represents the value of geometry parameters at point i.

$\dot{x}$ is the average value of the measured signal.

The synthetic coefficient also specifies the allowable deviation for different line speeds (Tab. 3). If any values are exceeded, a remedial action is required to bring the track back to the appropriate level.

4. Results and Discussion

The total length of the rail track along Iddo-Mushin axis is 6675 m (≈ 7 km), which was divided into three corridors namely Iddo – Ebute-Meta, Ebute-Meta – Yaba and Yaba – Mushin covering a distance of 1500 m, 2550 m and 2625 m, respectively; with the Yaba-Mushin axis covering the farthest distance. Mean elevation along the Iddo-Mushin rail track is 7.76 m with the Iddo – Ebute-Meta, Ebute-Meta – Yaba and Yaba – Mushin corridors having mean elevation value of 5.54 m, 6.6 m and 8.54 m, respectively (Fig. 5).

Details of the rail track geometry parameters along the entire Iddo-Mushin rail track corridor as shown in Tab. 4, depicts that the mean horizontal irregularities and vertical irregularities of the rail-track along the corridor are relatively moderate 2.92 mm and 3.841 mm, respectively. The mean track gauge discrepancy and track twist along Iddo-Mushin rail track corridor are 0.003 mm and 0.039 mm, respectively.

At sub-corridor level along the Iddo-Mushin axis (Fig. 6), the mean horizontal irregularities of the rail-track along the Iddo – Ebute-Meta corridor has

Tab. 3. Allowable deviations for *J* coefficient.

Speed (km/h)	<20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	200
J Coeff. (mm)	>7.0	6.2	5.5	4.9	4.0	3.5	2.8	2.3	2.0	1.7	1.6	1.5	1.4	1.3	1.2	1.0	0.7

Source: (Madejski, Grabczyk, 2002).

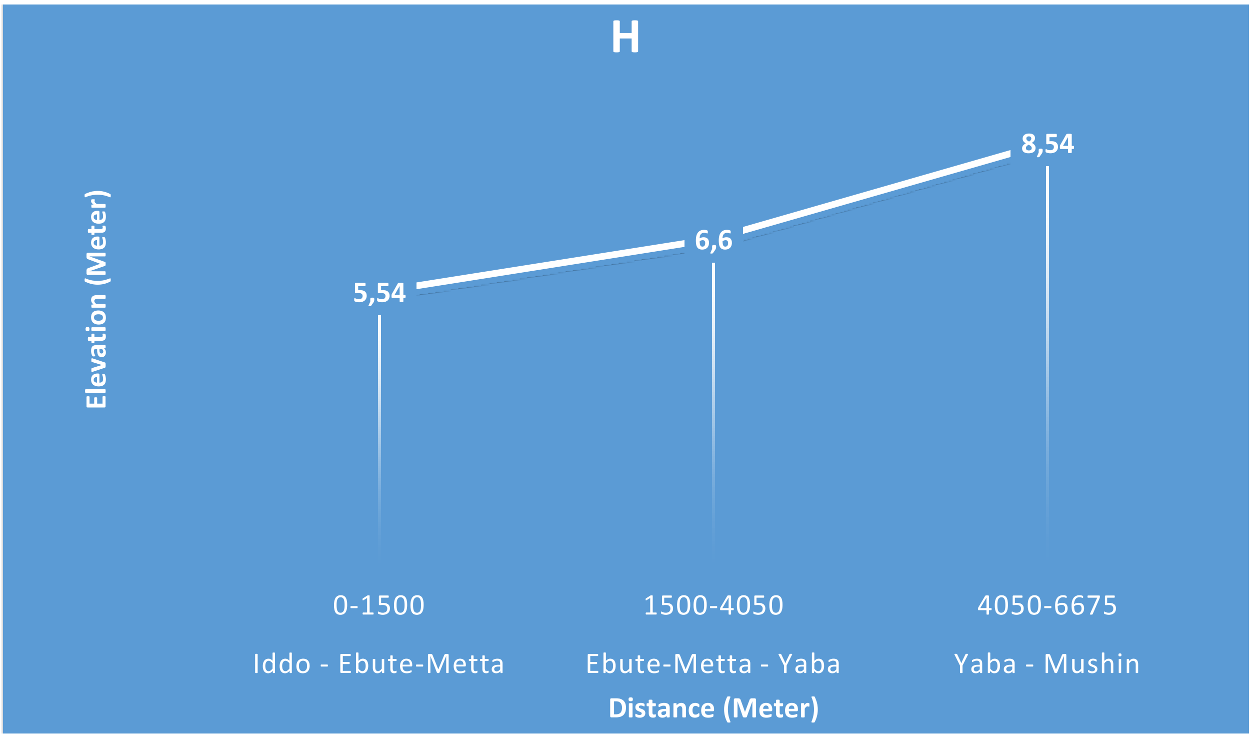

Fig. 5. Mean Elevation and rail track distance along Iddo-Mushin track.

Tab. 4. Characteristics of rail track geometry along the Iddo-Mushin axis.

	Track twist (mm)			**Track gauge discrepancy (mm)**			**Horizontal irregularities (mm)**			**Vertical irregularities (mm)**		
Rail Track Corridor	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
Iddo – Ebute-Meta	0	0.15	0.558	0	0.003	0.006	0.141	11.105	36.594	0	1.648	3.298
Ebute-Meta – Yaba	0	0.007	0.024	0	0.003	0.01	0.008	0.504	0.993	1.887	2.831	3.683
Yaba – Mushin	0	0.004	0.018	0	0.003	0.008	0.019	0.52	0.989	1.64	6.057	11.67
Iddo – Mushin	0	0.039	0.558	0	0.003	0.01	0.008	2.924	36.594	0	3.841	11.67

a relatively high irregularities (11.105) compared to other sub-sections. Thus, increased horizontal irregularities along the section will probably increase the centripetal force acting on the train as it moves along the curve which in turn increases the frictional force between the wheels and the rails. Horizontal irregularities also increase the pressure on the train to derail, especially at increased speed since the track alignment along the horizontal plane is a function of the track curvature.

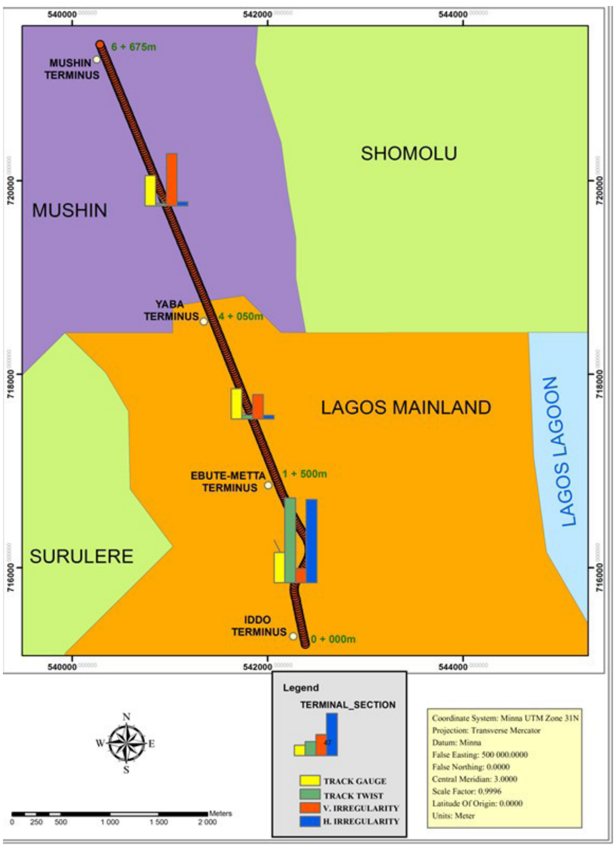

Fig. 6. Mean track geometric parameter (mm) distribution along Iddo-Mushin railway axis.

It can be observed that the mean severity of the track twist which is a product of track cross-level (super elevation) and alignments in the vertical and horizontal plane of a rail track is more noticeable within the Iddo – Ebute-meta corridor. Thus, this corridor is expected to experience defective rail transportation quality, comfort and safety due to amplified rail track vibration.

Along the Iddo-Mushin rail track the mean vertical irregularities (6.057 mm) at the Yaba – Mushin corridor is well marked. This can be attributed to higher elevations (8.54 mm) of the terminal section than other sections (Fig. 5), since changes in vertical irregularity is a function of difference in height levels. Thus, the probability of dynamic stress on the rail tracks most especially during excessive load event. Variation in the track inclination can also make passing trains shake and shudder.

The average track gauge discrepancy value is uniform throughout the rail track since the severity of the discrepancy is relative the same across the sections of the entire Iddo-Mushin axis with minimal risk from sudden or frequent bumps, most especially at interceptory points with road network at Mushin, Agege, Yaba, and Ebute-Metta, among others.

Furthermore, based on the Synthetic Coefficient (*J*) indicator which combines the rail geometric parameters (Vertical irregularities, Horizontal irregularities, Track twist and Track Gauge) shows that the entire Iddo – Mushin rail track has a coefficient of 2.82 mm (Tab. 5). The recommended maximum, average and minimum J coefficient for metro-rail line are 2.8 mm, 6.2 mm and 7.0 mm, respectively. Along the sub-corridor, the least coefficient of 1.26 mm was recorded along Ebute-Metta – Yaba corridor while the Iddo-Ebute-Metta corridor had the highest (3.57 mm).

Based on the J coefficient along the Iddo – Mushin rail track, the allowable deviation of track geometry correspond to rail safe speed of 85 km/h, on an

Tab. 5. Summary of the *J* coefficient (mm) along Iddo-Mushin railtrack

Railway Terminal Sections	Iddo – Mushin	Iddo – Ebute-Metta	Ebute-Metta – Yaba	Yaba – Mushin
J coefficient	2.82	3.57	1.26	1.48

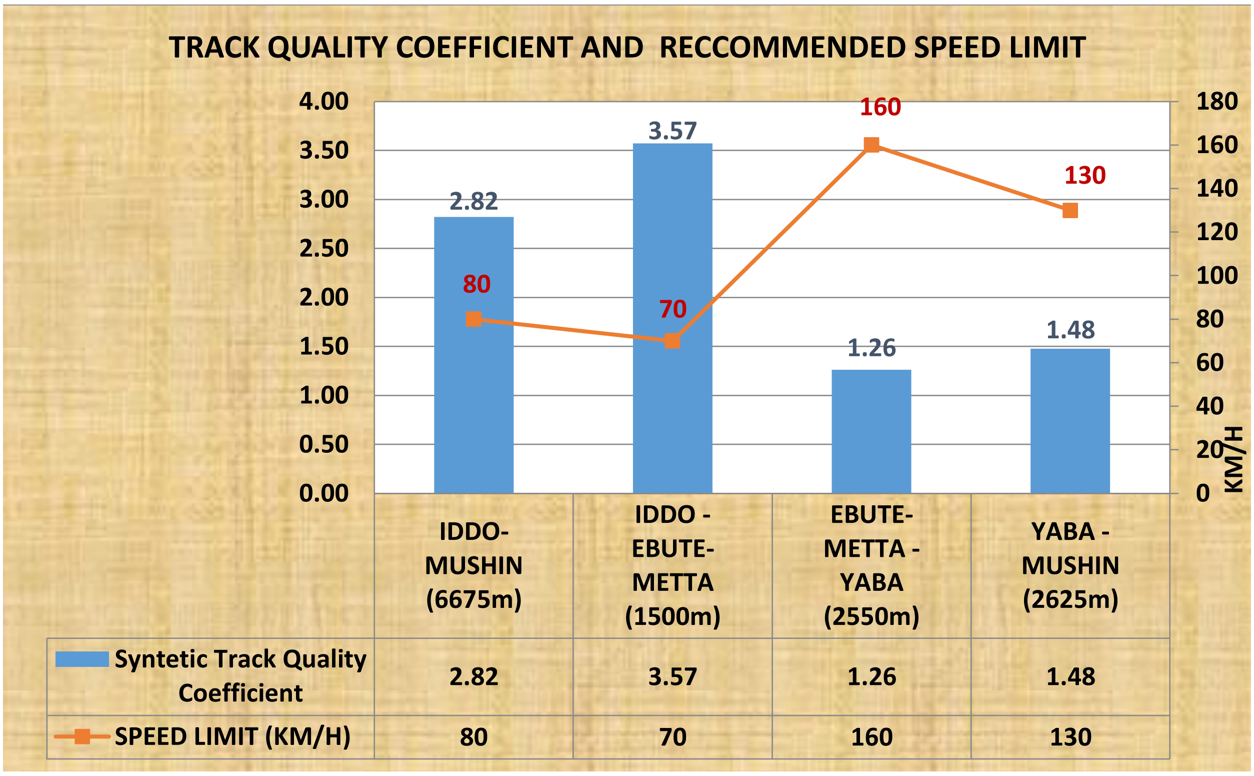

Fig. 7. Synthetic track quality coefficient and speed limits at rail station.

average rail speed of 116.67 Km/h ±38.62. Unfortunately, the deteriorated state of the rail track will cause increased vibration of the trains at speed above 70km/h, this will also result into passenger's discomfort and services deliverables. Along the corridor allowable track geometry deviation correspond to vehicular speed limits of about 70 km/h, 160 km/h and 130 km/h, for Iddo – Ebute-meta, Ebute-meta – Yaba and Yaba – Mushin corridor, respectively (Fig. 7).

It should be noted that the permissible speeds over any section of the rail track are calculated on the basis of safety and passenger comfort but for operational purpose the achievable speed is more advisable. Dina and Raji (2016) observed that average speed of 40 km/h with maximum speed of about 53 km/h and minimum speed of 20km/h are common within Lagos district narrow gauge track. Discrepancies relating to level crossing and curves are also noted to be insignificant contributor to rail speed in the region.

Conclusions

This study was borne out of the need to address issues relating to safety and sustainable development in railway transportation system in order to diversify the means of moving people and goods safely. Rail track geometry quality affects the safety of transportation, this project was carried out with the main aim to access and analyze the rail track geometry from Iddo – Mushin in order to determine the rail track quality index as to maintain a safe rail transport system along the axis.

The analyses carried out showed that the severity of the track twist and horizontal irregularities are higher between Iddo – Ebute-meta than other terminal sections within the Iddo-Mushin rail track axis, with average train speed less 116 km/h. Other parameters measured include track gauge discipancy and vertical irregularities. The result shows that there is a strong correlation between the track twist and horizontal irregularities which implies that any further deformation on the horizontal irregularities may increase the twist of the track. Thus, once the defect of the track reaches the threshold limit, tamping are usually carried out to reduce the amount of standard deviation and the track geometry deterioration. It should also be noted that beyond high track gradient, sharp curves , track buckling and worn out railway infrastuture, poor maintanance culture constitute to the poor rail track performance in Nigeria.

Thus, it is expected that the ongoing goverment intervention plan and the planned Lagos Rail Mass Transit programme will go along way to restore the stain matainance culture and enhance the rail track performance and service delivery in Lagos narrow gauge track and environs.

The following suggestions are recommended;

i. Tamping should be carried out on the rail track to repair the defects in railway geometry as a result of deformation of supporting materials such as ballast and sleepers.
ii. Validation and maintenance work should be carried out regularly on the railway for entire rail tracks lengths in Nigeria for safety and sustainable development purposes.
iii. There is need for greater awareness to be created at all levels of government on the benefit of rail transportation development in the economic development of the nation.
iv. Public enlightenment and involvement of all stake holders in Railway system development is essential.

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