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Research article

Awareness, adoption readiness and challenges of railway 4.0 technologies in a developing economy

Imoleayo A. Awodele[a,*], Modupe C. Mewomo[a], Angel M. Gento Municio[b], Albert P.C. Chan[c], Amos Darko[d], Ridwan Taiwo[c], Nathaniel A. Olatunde[e], Emmanuel C. Eze[f], Oluwaseyi A. Awodele[g]

[a] Construction Management and Quantity Surveying Department, Durban University of Technology, Durban, 4001, South Africa
[b] Organizacion de Empresas y CIM, University of Valladolid, Spain
[c] Department of Building and Real Estate, Hong Kong Polytechnic University, Kowloon, Hong Kong SAR, China
[d] Department of Construction Management, University of Washington Seattle, WA, USA
[e] Department of Quantity Surveying, Federal University Oye-Ekiti, Ekiti State, Nigeria
[f] Architecture and Built Environment, Northumbria University Newcastle, United Kingdom
[g] Department of Quantity Surveying, Federal University of Technology Akure, 340110, Nigeria

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ABSTRACT

The railway industry has witnessed increasing adoption of digital technologies, known as Railway 4.0, that is revolutionizing operations, infrastructure, and transportation systems. However, developing countries face challenges in keeping pace with these technological advancements. With limited research on Railway 4.0 adoption in developing countries, this study was motivated to investigate the awareness, readiness, and challenges faced by railway professionals towards implementing Railway 4.0 technologies. The aim was to assess the level of awareness and preparedness and identify the key challenges influencing Railway 4.0 adoption in Nigeria's railway construction industry. A questionnaire survey (was distributed to professionals in the railway construction sector to gather their perspectives on awareness of, preparation for, and challenges associated with the use of Railway 4.0 technologies. The results revealed that awareness of Railway 4.0 technologies was moderate, while readiness was low among the professionals. Using exploratory factor analysis, 10 underlying challenge constructs were identified including lack of technical know-how, resistance to change, infrastructure limitations, and uncertainty about benefits, amongst others. Partial Least Square Structural Equation Modelling (PLS-SEM) confirmed these constructs, with reliability and availability, lack of technical know-how, lack of training and resources, and uncertainties in benefit and gains having significant influence on awareness and readiness. The study concludes that focused efforts in training, infrastructure improvement, supportive policies, and communicating the advantages of Railway 4.0 are critical to drive adoption in Nigeria and other developing economies. The findings provide insights into tailoring Railway 4.0 implementation strategies for developing contexts.

* Corresponding author.
E-mail address: a.imole@yahoo.com (I.A. Awodele).

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1. Introduction

The railway industry is dynamic, revolutionary, and complexly driven just like construction and manufacturing industries [1–3]. Rail transportation projects has been found to be among the most intricate and challenging adventure [4]. Such complexity involved, the challenges and the multifaceted nature of the project require considerable planning to achieve a sustainable outcome [5]. A public transport mode according to Ref. [6] that is efficient is railway transportation. In the past decades, rail transportation systems have witnessed a dramatic change in the technology level, service qualities, speed, total length, etc. and recently, the demand for railway usage has greatly increased [6].

The current outlook of rail transport system provided access to passengers to commute in and between economic hubs [6], is also occupying an important position in the supply chain and providing sustainable drive towards economic growth [5]. Occasioned by big cities' traffic congestion challenges and environmental problems, such as New York cities, Tokyo, Beijing, London, etc rail transport is being considered as an environmentally friendly transport mode in many big metropolises [7]. The growing industrial need for long-volume and distance freight conveyances has brought about the increase in transport capacity most especially in countries that are blessed with abundance coalmines and other mineral resources [8].

Human society has been accustomed to technological advances and it is practically impossible to stop. Industrial revolution is a term that is used widely in the literature which began in United Kingdom before sweeping through Europe and the USA [9]. In the mid-1990, according to the account of [10] the third Industrial Revolution came to existence which witnessed the growth of internet and renewable energy [11] which avail the third industrial revolution with required infrastructure. Away from the hardware driven era, the third industrial revolution was software-led and particularly this development came after information technology. This rise in information technology brought about building information modelling. The fourth Industrial Revolution construction industry is unique and no longer driven by the hardware as witnessed during the earlier era, but a robust integration of human, software and hardware which rely heavily on the sophisticated advancement in internet connectivity, communication, information, and technology [11]. The integration of digitally controlled machines and people made the Fourth Industrial Revolution unique. According to Ref. [12] Industry 4.0 "is a confluence of ideas/trends and technology that aims to transform the way things are made".

Different names have been used for the 21st-century industry [11]. adopted the term Construction 4.0, and for the purpose of this study, we adopt Railway 4.0 (Railway Industry 4.0) for the digitalization of railway construction process [11] which is synonymous to Industry 4.0 as used by other studies. An incorporation and integration of multifaceted technologies is what is known as Construction 4.0 technology [13,14]. According to Ref. [4] the implementation or deployment of new technologies and digital reconfiguration of processes is known as Industry 4.0. In other words, deployment of new technologies and digital transformation of railway processes, operations and infrastructure is known as Railway Industry 4.0. [15] described the concept of Industry 4.0 as a process of utilizing information, communication, technology and internet to incorporate people into intelligent or smart machines so that their interaction can bring about modernization and transformation of the existing process.

Human managerial burdens are lessened [13] and safety issue that is characterized by pre- Industry 4.0 revolution era are addressed through Construction 4.0 [12]. Productivity and efficiency during construction can be enhanced through the adoption of Construction 4.0 technologies [16]. Through total and complete automation of manufacturing and manufacturing processes [14], submit that challenges or problem associated with the pre-Industry 4.0 can be solved easily. Another benefit that can be derived from Railway 4R is that automation and digitalization of business processes can help to facilitate the work of employees and most importantly it will positively influence the company's results [17].

However, it seems that there hasn't been much research done in this area in underdeveloped nations. The few research projects such as [11,18] on the concept of Industry 4.0 in developing nations, particularly South Africa and Nigeria, have focused primarily on the readiness of construction workers to adopt Industry 4.0 technologies. In Nigeria, readiness for the adoption of Construction 4.0 technologies and awareness was undertaken by Ref. [11]. From the study carried out in South Africa by Ref. [18], Construction 4.0 was demonstrated as a catalyst towards construction supply chain resilience and an inoculation amid Covid-19 epidemic. There exist research gaps that need exploration particularly on the continent of Africa, such as Nigeria. Nigeria pride herself in terms of huge natural resources, Nigeria is undoubtedly the largest oil producer in Africa, and She is rank among the top ten leading oil producers in the world [19]. The country is a critical economic player in the African continent as it has enormous economic potential. In fact, Africa's largest economy is Nigeria and is believed to be the future economic power as it ~~and~~ has the potential to be ranked among the ten largest economies of the world [20]. In spite of this, it is still categorised as a low-income nation. With a growing population of about 240 million people [21], Nigeria makes up the list of the top ten most populous country in the world). Due to Nigeria's large endowment of natural resources, population, and coupled with land mass, sustainable railway infrastructure is important in Nigeria. Such railway infrastructure that could transport people and resources from one point to another in an efficient and environmentally friendly manner is needed in Nigeria. The state of Nigeria railway infrastructure according to Ref. [22] has been described as moribund.

Industry 4.0 technologies and their use in railway administration and construction have recently become the focus of study in developed countries [23]. Industry 4.0 technology acceptance is more prominent in other industries, such as manufacturing, but less so in the aspect of railway. For instance, augmented reality technology in construction industry was examined by Ref. [24]. Reference [11] evaluated Nigeria's understanding, adoption readiness, and adoption barriers for Construction 4.0 technologies. Also, application of Internet of Things (IoT) in the construction industry by Ref. [24]. Nevertheless, studies that looked at the adoption readiness, obstacles, and awareness of railway 4.0 in an emerging economy are limited or almost not in existence. Therefore, the purpose of this study is to investigate the level of awareness, preparedness for adoption, and challenges associated with railway 4.0 technologies in the developing economy. To address this gap, we planned and proposed following research objectives (ROB) and questions (RQ):

ROB1: To assess the level of awareness of Railway 4.0 technologies in a developing nation.
ROB2: To evaluate the level of implementation preparedness towards Railway 4.0 technologies in a developing nation.
ROB3: To identify and examine the challenges of Railway 4.0 technologies in a developing nation.

Questions (RQ).

RQ1. What is the level of awareness of Railway 4.0 technologies in a developing nation?

RQ2. What is the level of implementation preparedness towards Railway 4.0 technologies in a developing nation?

RQ3. What are the challenges of Railway 4.0 technologies in a developing nation?

This was motivated by the need to determine the level of knowledge among professionals in railway construction regarding railway 4.0 technologies, their readiness for adoption, as well as the challenges associated with their application.

2. Literature review

2.1. Concept and main components of railway 4.0 technologies

Though a broad term, Industry 4.0 is a new era that presents the fourth Industrial Revolution which focuses on real-time data, smart digital technologies, automation, interconnectivity, and machine learning [25]. The German government describes it as a new technical era for manufacturing that links production technology with intelligent production processes using data, CPSs, services, and Internet of things (IoT) [26]. As a result, it aims to revolutionize sectors like industry, the built environment, healthcare, energy, and urban areas or cities. The foundation upon which the industry 4.0 concept is standing are large data connection, and communication [4]. Technology and information communication are the driving forces behind this digital transformation. The railway industry like other industry is embracing these game changer (disruptive) technologies such as: Automation and robotics, the Internet of Things (IoT), Big Data Analytics (BDA), edge or cloud computing, Building Information Modelling (BIM), block chain, 5G digital twins, Artificial intelligence, 3D printing, machine Learning, Virtual Reality (VR), Smart Sensors, Augmented Reality (AR), Cybersecurity, modelling and simulation, and smart decision support among others [27–31] to revolutionize and enhance the essential changes needed to aid the required evolution. A generic term for the deployment and adoption of these technologies is “Industry 4.0”, “Railway 4.0”, or “Digital Railway”.

2.2. Area of digital application in railway 4.0 technology

In rail transport, there are many areas calling for digitalization: electronic or e-ticketing, digital platforms required for predictive maintenance of railway lines, mobile applications, signalling, electronic bill of lorries, rolling stock and remotely managed transport are major areas requiring digitalization [4]. Various authors have identified area of digital application in the railway sector. For instance, Ref. [32], examined application of blockchain in the railway industry. Visual inspection system for railway by Ref. [33], systematic review of Artificial Intelligence (AI) application in railway for tackling railway challenges by Ref. [34], integration of Automatic Train Operation (ATO) technologies in railway transport [6], digital twin, AI and Building Information Modelling application for solving railway transport issues by Ref. [35].

2.3. Awareness and adoption readiness

Awareness is the first prerequisite towards implementation or adoption. Awareness is said to be an information or knowledge or perception about a particular phenomenon. In the developed economy, awareness about new technological innovation and adoption is apparent in the literature [13]. Health and manufacturing sector among others are thriving in the adoption of industry 4.0. However, construction and railway industry have not experienced the same rate of adoption. While construction industry in a developed economy context seems to be making good progress about new technological innovation and adoption, the experience in the developing economy context is different [36].

[37] described readiness as the preparedness of an organization to start a developmental process while [38] on the other hand defined maturity as the level of an organization when compared to analysed process. In Turkey [39], examined the awareness of the manufacturing firms and their approach to Industry 4.0 and found that manufacturing firms will only adopt and use technologies that they are most important or familiar to them.

Likewise [40], in India investigated the readiness of manufacturing industries in adopting Industry 4.0 innovations. The study concludes that there is significant relationship between readiness and the benefits achieved through the implementation of Industry 4.0 [26]. in Ireland, appraised the current levels of incorporation of Industry 4.0 readiness among small, medium and micro enterprises. While an ample majority are not implementing any Industry 4.0 projects currently, the study finds that there is a high level of awareness of Industry 4.0 and digitalization. In South India, inhabitants were asked about their opinion on general awareness of Industry 4.0 concepts, the study gathered that general awareness is quite low, which resulted to inability to form any opinion regarding effects of such new trends on working and personal life [41].

2.4. Challenges of railway 4.0 technologies

Transitioning from one way of doing things to another usually comes with associated challenges. In the same vein, transitioning from traditional railway to railway 4.0 will be faced with challenges and previous research [25,42] on Railway 4.0 have identified different challenges of Railway 4.0. Construction SMEs in Japan face challenges adopting industry 4.0 technologies, according to Ref. [43]. These include security issues, market transparency for technology, organizational structure, satisfaction with the current system, support and championship from top management, industry cluster, market uncertainty, cost, relative advantage, compatibility, and complexity. A thorough literature research was conducted by Ref. [25], and the authors identified 17 barriers to industry 4.0 adoption among construction enterprises. "Cost of Industry 4.0 transition", "resistance to change", "lack of management support for I4.0 transition", "lack of skilled labor", "lack of standardization", "data protection and cybersecurity", "uncertainties in benefits and gains in terms of labor and workforce", "fragmented and conservative nature of the construction industry", "poor knowledge management", "poor planning and programming practices", and "high accident rates in the cons". Low technical expertise of construction experts, legal and contractual concerns, poor communication among project parties, indisposition towards investing in research and developments programs, high cost of training towards technology adoption, and a lack of performance requirements for personnel were challenges of implementation of Industry 4.0. Lack of a digital strategy, combined with resource scarcity, a lack of standards, and inadequate data security, were listed by Ref. [42] as the challenges to Industry 4.0 implementation in small and medium-sized construction firms.

Reference [44] assert that lack of training and resources are the two significant challenges to the adoption of industry 4.0, in South Africa. Identifying and incorporating technologies, Supply Chain Sustainability, Obsolescence Management, Reliability and Availability, Customer Buy-in, Staff Buy-in, Cybersecurity and Interoperability are some of the challenges listed by Ref. [45] as impeding the adoption and implementation of digital railway 4.0. In a bid to unravel the challenges associated with Railway 4.0 technology, the challenges of Railway 4.0, as discussed from the literature, were incorporated into the questionnaire and given to the respondents. Primarily, Africa as a continent is aware of the huge benefits and opportunities presented by the 4IR, however, there are concerns about Africa's infrastructure constraints, particularly its shortfalls in transport infrastructure. This is a big challenge to the implementation and adoption readiness for the introduction of 4IR [46] No meaningful transition can be achieved if this big challenge is not addressed as 4IR is largely dependent on efficient transport infrastructure.

2.5. Research methodology

This study adopted the use of quantitative research method to assess readiness for adoption, awareness level and challenges confronting railway 4.0 technologies from a developing country perspective. Information from experts (Engineers, Architects, Quantity Surveyors and Builders) in the railway industry who are based in Lagos State, Nigeria was obtained. This process was guided with the use of structured questionnaire and the choice of quantitative research approach was premised on that fact questionnaire has advantage of reaching large audience easily, quickly, and easy to use [47]. Moreover, the nature of the study made numerical result more important compared to the depth of the research that is the superior argument for the adoption of the qualitative research method [48]. Information acquired from the evaluated literature was used to draft the questionnaire. Questionnaire design was partitioned into three components. The respondents' characteristics were asked in the first segment, their readiness for adoption and awareness in the second, and their opinions on the challenges of Railway 4.0 in the third segment. Using a five-point Likert scale, the respondents assessed the awareness of Railway 4.0, its adoption readiness, and its implementation challenges. This scale has frequently been utilised in numerous earlier investigations, including [37,49]. The study area selected for the research was Lagos State and this was

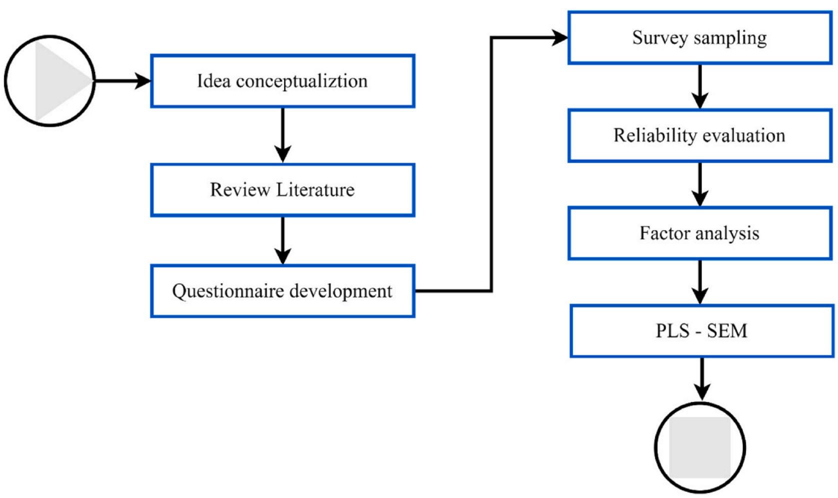


Fig. 1. Research methodological flow chart.

done for several reasons. First, Lagos State serves as the nation's commercial centre due to its rapid population growth and urbanization. It is Africa's most populous metropolis with at about 20 million residents covering an area of 3577 km^2. Lagos is equally the most populous state in Nigeria [50].

The questionnaire was administered via internet-mediated approach to railway construction professionals. This exercise took four months between January and April 2023 and each respondent spent at least 13 min on the average to complete the questionnaire. The ease of comparison and to gather a holistic opinion of the professionals in the built environment on the concept of Railway 4.0 necessitated the choice of experts in the railway construction sector. The sample size for the study for each sampled profession was conveniently drawn from railway construction professionals located in Lagos state. Convenience sampling was employed because it is easy to identify people who meet the requirements of a study and since everyone who participates is from the same region [51]. Out of the 169-questionnaire given to the respondents, 103 respondents which constitutes about 61 percent returned and filled the questionnaire correctly. This forms the total sample size that was used for the analysis and was adjudged adequate based on previous study by Ref. [52]. Prior to the data analysis employed for this study, validity and reliability check was done using Cronbach's alpha test to know whether data collected are reliable or otherwise. This is an important step towards ensuring the validity and reliability of the information gathered. As such, inferential and descriptive data analysis using explorative factor analysis and Structural equation modelling (SEM) were adopted for the study. The Statistical Package for Social Sciences (SPSS) Version 28 software and a Structural equation modelling software called SmartPLS4 were used for the analysis, respectively. The succeeding subsections give details on these statistical techniques. As contained in Table 2, 0.856, and 0.833 respectively are the figures obtained from the Cronbach's Alpha coefficient. These figures are above the minimum recommendation of 0.70 and therefore responses are considered reliable, and data gathered are adequate [53]. Fig. 1 below demonstrated the methodological flow for this research.

2.6. *Profile features of the respondents*

The profile background features of the respondents to questionnaire are contained in Table 1. The main profession sampled for data

Table 1
Profile background of the respondents from questionnaire.

Category	Classification	Frequency	Percentage
Gender	Male	58	56
	Female	45	44
	Total	103	100.0
Profession of respondents	Architects	20	19.41
	Construction Managers	15	14.56
	Quantity Surveyors	25	24.27
	Engineers	35	33.98
	Project Managers	8	7.76
	Total	103	100.0
Highest academic Qualification	OND	15	14.56
	HND	34	33.01
	B.Tech/B.sc	40	38.83
	M.Tech/M.sc/MBA	10	9.71
	PhD	4	3.88
	Total	103	100.0
Years of experience	1–5	10	9.71
	6–10	35	33.98
	11–15	30	29.13
	16–20	20	19.42
	Above 21	8	7.77
	Total	103	100.0
Department/Section in NRC	Architectural	19	18.45
	Civil/Engineering	33	32.04
	Quantity Surveying	23	22.33
	R&D	10	9.71
	Procurement	9	8.74
	Estate Services	9	8.74
	Total	103	100.0
Membership of Professional bodies	NIQS	28	27.18
	NIA	32	31.07
	NSE	33	32.04
	NIOB	8	7.77
	PMP	2	1.94
	Total	103	100.0
Type of membership	Graduate	25	24.27
	Probationer	24	23.30
	Corporate member	45	43.69
	Fellow	9	8.74
	Total	103	100.0

collection were Architects (19.41%), Construction Managers (14.56%), Quantity Surveyors (24.27%), Engineers (33.98%), and Project Managers (7.76%). Regarding work experience year, it can be deduced that 7.77% have worked for more than 21 years, 33.98% of respondents have worked between 6 and 10 years, while about 30% of the respondents have work experience of 13 years on the average. In terms of professional affiliation (association), majority (32.04%) belong to ~~are member of~~ the “Nigerian Society of Engineers (NSE)”, 27.18% belong to the” Nigerian Institute of Quantity Surveyors (NIQS)”, while 31.07% are Nigerian Institute of Architects (NIA) members. In terms of the academic profile of the respondents, 3.88% holds PhD degree, bachelor’s degree holders are 38.83% of the respondents, 9.71% are with master’s degree certificates and 33.01% holds higher National Diploma. It is sufficient to say that the respondents belong to their respective professional association and as such have the requisite knowledge and experience to provide the information required of them.

2.7. Data analysis techniques

Factor Analysis and mean item score (MIS) were used to analyze the responses from the questionnaire. Validity and reliability evaluation check was the first analysis, proceeded by descriptive (Mean item score, and ranking) and exploratory factor analysis to extract the component factors.

Exploratory factor analysis (EFA) was conducted on the survey data to identify the underlying relationships between the variables and group them into coherent factors representing challenges to Railway 4.0 adoption. The EFA is a statistical approach used to uncover the fundamental structure of a set of assessed variables without imposing any preconceived structure on the outcome. It explores the data set to determine the nature of the constructs influencing the responses. Several steps were followed in conducting EFA, including assessing suitability of data, factor extraction, factor rotation, interpretation of the factors and naming of the factors.

Prior to this analysis, the Cronbach’s alpha coefficients was checked to determine the reliability and sufficiency of the data. According to Table 2 the challenges to the adoption of Railway 4.0. have corresponding Cronbach’s alpha coefficients of 0.856 and 0.833 respectively. Since the Cronbach’s alpha coefficients figure is more than 0.7, this suggests that the data provided is sufficient and the responses are reliable [53–55].

2.8. Partial least square structural equation modelling

Structural equation modelling was used in this study to investigate the interrelationships between two categories of variables, latent and observable variables, while taking measurement errors into account. SEM is an excellent tool for assessing the causal link between endogenous variables (also known as the structural model in SEM) and as such considered appropriate for this study to understand the relationship between latent and observed variable of this study [56,57]. The “Partial least squares structural equation modelling” (PLS-SEM) was utilised to analyze the survey data and test the hypothesized relationships in the conceptual model. PLS-SEM consist of two models namely measurement and structural model.

2.9. Measurement model

The measurement model was assessed by evaluating the indicator reliability, internal consistency reliability, convergent validity, and discriminant validity. Indicator reliability was examined through the outer loadings of the indicators on their respective constructs. Items with outer loadings above 0.7 were retained. Internal consistency reliability was tested using Composite Reliability (CR) and Cronbach’s alpha, with values above 0.7 considered acceptable. Convergent validity was assessed using the Average Variance Extracted (AVE), with values above 0.5 indicating adequate convergence.

Discriminant validity was checked using the Fornell-Larcker criterion where the square root of the AVE for each construct should exceed its highest correlation with any other construct. Cross-loadings were also examined to ensure each indicator’s outer loading on its associated construct was higher than its loadings on other constructs.

2.10. Structural model

The structural model was assessed by examining the path coefficients between the constructs and their statistical significance, as well as the coefficient of determination (R2) values. The path coefficients indicate the strengths of the relationships between the independent and dependent variables in the structural model. They are interpreted similarly to standardized beta coefficients in regression analysis. The coefficients range from -1 to $+1$, with higher absolute values indicating stronger relationships. The sign of the coefficient suggests whether the relationship is positive or negative.

Bootstrapping was performed to determine the significance of the path coefficients. This entails randomly sampling with

Table 2
Evaluation of reliability check for challenges, adoption readiness, and awareness of Railway 4.0

Adoption readiness & Awareness		Challenges	
Cronbach’s Alpha	Items No	Cronbach’s Alpha	Items No
0.856	27	0.833	40

replacement from the original dataset to create a bootstrap sample and estimate the PLS path model. This process is repeated many times, and the path coefficients for each resample are collected to construct a bootstrap distribution. If the confidence interval for a path coefficient does not include zero, it can be concluded that the relationship is statistically significant at that confidence level (usually 95%).

The R^2 value represents the proportion of variance in the endogenous constructs that is explained by the exogenous constructs linked to it in the model. It is a measure of the model's predictive accuracy for the endogenous constructs. R^2 values range from 0 to 1, with higher levels indicating greater predictive accuracy [2]. R^2 values of 0.25, 0.50, and 0.75 for endogenous constructs can be considered weak, moderate, and substantial respectively.

2.11. *Awareness of railway 4.0 technologies*

Table 3 outlines component of railway 4.0 technologies and it can be inferred that the overall level of awareness is moderate (MS = 3.72). Respondents level of awareness on 85% of all the components of railway 4.0 technologies revealed a mean score above average (that is MS ranges between 3.28 and 3.57). Building information modelling according to the respondents received higher awareness level than other components with (MS = 4.24). Internet of things (MS = 4.12), 3D printing (MS = 4.09), Blockchain (MS = 4.08), artificial intelligence (MS = 4.04), Machine learning (MS = 3.97), Big Data (MS = 3.85), and others also received high awareness level. The following components were comparatively rated as least and low in terms of awareness level. Cognitive Radio (MS = 3.28), Augmented Reality (AR) (MS = 3.33), Connected Machine (MS = 3.39), Segmentation Technique (MS = 3.49) and Cryptocurrency (MS = 3.50).

3. Results

3.1. *EFA to identify principal latent constructs*

EFA was employed to ascertain significant indicators and the primary latent constructs. ~~(EFA)~~ is described as a complex, multi-step process that has found wide application in social science and construction domains [58,59]. It is a statistical technique used for data analysis usually for either factor reduction and extraction or vice versa. Factor analysis aims at revealing any latest variable that made the manifest variable correlate or covary [60] As for sample size to be used for EFA, even though a relatively sample sizes for EFA is an error-prone procedure, EFA by design is still the most appropriate for use in exploring a data set and it is considered one of the most suitable tools to ascertain the link between measured items and the underlying constructs [60,61]. As such, EFA technique was utilised for this study, because it was psychometrically sound and scientifically easier to use.

To see if there was a systematic relationship between the variables and to see if the data collected were appropriate for factor analysis, Bartlett's test of sphericity and Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy were tested (see Table 4). When the

Table 3
Cognizance level of Railway 4.0 Technologies by the respondents.

Components of Railway 4.0 Technologies	Mean	Std	Rank
Building Information Modelling (BIM)	4.24	1.150	1
Internet of Things (IoT)	4.12	0.921	2
3D printing	4.09	1.058	3
Block Chain	4.08	1.058	4
Artificial Intelligence (AI)	4.04	1.154	5
Machine Learning	3.97	1.133	6
Big Data	3.85	1.200	7
Modelling and Simulation	3.84	1.064	8
Cybersecurity/Cyber technology	3.76	1.133	9
Digital twins	3.75	1.226	10
5G	3.74	1.180	11
Drone and Robotic	3.70	1.162	12
Cloud or Edge Computing.	3.69	1.138	13
Virtual Reality (VR)	3.69	1.112	14
Smart Decision Support Systems (SDSS)	3.68	1.293	15
Computer Vision	3.67	1.309	16
Gamification	3.65	1.152	17
Quantum Computing	3.63	1.171	18
Radio frequency identification RFID	3.57	1.311	19
Extended reality	3.57	1.226	20
Computer Vision and	3.57	1.072	21
Cryptocurrency	3.50	1.244	22
Smart Sensors	3.49	1.212	23
Segmentation Techniques	3.44	1.304	24
Connected Machines	3.39	1.246	25
Augmented Reality (AR)	3.33	1.149	26
Cognitive Radio	3.28	1.339	27

Table 4
KMO and Bartlett's test.

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.797
Bartlett's Test of Sphericity	Approx. Chi-Square	5452.22
	df	328
	Sig.	0.000

Significance level or value or P value.

p (Sig.) significant threshold is less than 0.05, it is considered that the variables have a systematic connection. Additionally, Refs. [62, 63] posit that for the variables to be considered adequate the sampling adequacy value of above 0.50 is recommended for the KMO. Accordingly, values for "KMO should be at least 0.5 (just acceptable), between 0.7 and 0.8 are Acceptable, and ≥0.9 are Excellent" [62]. Bartlett's test of sphericity for the Railway 4.0 challenges, as reported in Table 7, the appropriateness of factor analysis adopted in this study was confirmed. Data are considered credible when the computed values of Cronbach's are greater than 0.5 and when

Table 5
Rotated component matrix of challenges to railway 4.0

Variables	Component											
	1	2	3	4	5	6	7	8	9	10	11	12
Complexity.	0.748											
Identifying and incorporating technologies	0.736											
Effective management of a system approach to transformational change	0.724											
Customer Buy-in	0.720											
Reliability and Availability	0.700											
Staff Buy-in	0.664											
Compatibility and Interoperability	0.648											
Relative Advantage	0.620											
Absence of performance standards for employees		0.887										
Cybersecurity		0.871										
Unwillingness to investing in research and development programs		0.573										
Legal and contractual issues		0.554										
Obsolescence Management			0.815									
Lack of digital strategy alongside resource scarcity			0.809									
Railway construction professionals' low technical capability			0.595									
Management is not willing to support for I4.0 transition				0.814								
Shocking rates of accident in the construction industry				−0.720								
Top Management Support and Championship				0.611								
Industry Cluster				−0.513								
Financing and security					0.762							
Cost of Railway 4.0 transition					0.741							
Market Uncertainty					0.653							
Supply Chain Sustainability						0.904						
Lack of standards and poor data security:						0.894						
Data protection and cybersecurity							0.805					
Poor planning and programming practices							0.799					
Nature of the construction industry is broken and cautious							0.671					
Benefits and gains in terms of labour and workforce not certain								0.837				
Poor knowledge management								0.774				
Shortfalls in transport infrastructure									0.688			
Market Transparency for the technology									0.622			
Security Concerns									0.577			
Organizational Structure										0.865		
Lack of skilled labour											−0.648	
Resistance to change											0.630	
Lack of standardization											0.586	
Lack of training and resources												0.691

consistency considered in such analysis [64].

After determining that the data were appropriate, a factor analysis was carried out using EFA and the extraction method varimax rotation. Using the cut-off point of 0.50 as the factor loading, twelve components with eigen values of >1 were identified as presented in Table 5 (rotated factor loadings) for the identified twelve factors [65]. Retaining all indicators with an eigenvalue greater than 1 is the usual criteria SPSS employs popularly known as Kaiser criterion [66].

The first factor has eight indicators loaded onto it, which capture the challenges of railway 4.0. The indicators include: (a) complexity; (b) identifying and incorporating technologies; (c) effective management of a system approach to transformational change; (d) customer Buy-in; (e) reliability and availability; (f) staff Buy-in; (g) compatibility and Interoperability and; (h) relative advantage. The second factor captures legal and policy regulation and accompanied by four indicators: (a) legal and contractual concerns; (b) lack of employee performance requirements; (c) cybersecurity risks and (d) reluctance to fund development and research (D&R) programs.

The third factor is Lack of technical know-how and investment in R&D, which is captured by three indicators: (a) absence of digital strategy combined with resource scarcity; (b) the management of obsolescence and (c) the lack of technical expertise of railroad construction specialists. Unwillingness by the management to support I4.0 transition is the fourth factor and has four indicators. The indicators include: (a) The absence of support from the management towards transition to I4.0; (b) worrying rates of accident in the construction sector; (c) the best management support and championship and (d) industry cluster.

The fifth factor captures finance and market security and accompanied by three indicators: (a) market uncertainty; (b) cost of the transition to railway 4.0 and (c) financing and security. Lack of standardization is the sixth factor and has two indicators. The indicators include: (a) lack of standards and sustainable supply chain and (b) inadequate data security. The seventh factor is conservative and fragmented nature of the construction industry and is accompanied by three indicators. (a) Data protection and cybersecurity; (b)

Table 6
The result of convergent validity or Construct reliability and validity tests.

Construct		Outer loading				
	Item	Initial	Modified	Cronbach's alpha	Composite reliability	AVE
Reliability and Availability	RCH35	0.789	0.789	0.841	0.880	0.514
	RCH34	0.613	0.615			
	RCH33	0.644	0.646			
	RCH36	0.709	0.709			
	RCH37	0.697	0.697			
	RCH31	0.771	0.770			
	RCH30	0.776	0.774			
Legal and policy Regulation	RCH19	0.902	0.901	0.812	0.878	0.645
	RCH38	0.879	0.878			
	RCH16	0.694	0.693			
	RCH15	0.716	0.718			
Lack of technical know-how	RCH26	0.600	0.595	0.700	0.822	0.548
	RCH39	0.851	0.853			
	RCH20	0.905	0.906			
	RCH18	0.535	0.539			
Lack of mngt support for I4.0 transition	RCH5	0.277	**Deleted***	0.737	0.837	0.721
	RCH13	−0.090	**Deleted***			
	RCH27	0.764	0.760			
	RCH28	0.909	0.930			
Finance and Market Security	RCH3	0.676	0.698	0.703	0.780	0.515
	RCH2	−0.118	**Deleted***			
	RCH29	0.756	0.737			
Lack of standardization	RCH40	0.956	0.955	0.930	0.965	0.933
	RCH21	0.976	0.976			
Fragmented and conservative nature CI	RCH8	0.707	0.870	0.708	0.825	0.613
	RCH12	0.894	0.895			
	RCH10	0.743	0.744			
Uncertainties in benefits and gains	RCH9	0.648	0.640	0.777	0.827	0.576
	RCH11	0.856	0.861			
Shortfalls in transport infrastructure	RCH1	−0.302	**Deleted***	0.704	0.775	0.642
	RCH24	0.624	0.625			
	RCH23	0.936	0.946			
Resistance to change	RCH25	0.988	0.989	0.977	0.989	0.978
	RCH6	0.048	**Deleted***			
	RCH4	0.160	**Deleted***			
	RCH7	0.984	0.988			
Lack of training and resources	RCH14	0.572	0.634	0.729	0.792	0.562
	RCH17	0.744	0.808			
	RCH19	0.770	0.796			
	RCH22	0.487	**Deleted***			

AVE = Average Variance Extracted Deleted* = Deleted items.

Table 7
List of abbreviation used.

Meaning	Abbreviation
Finance and market security	FAMS
Fragmented and conservative nature of the construction industry	FCNC
Lack of management support for I4.0 transition	LMST
Lack of standardization	LASD
Lack of technical know-how	LTKN
Lack of training and resources	LTAR
Legal and policy regulation	LEPR
Reliability and availability	REVA
Resistance to change	RETC
Shortfalls in transport infrastructure	SITI
Uncertainties in benefits and gains	UIBG
Awareness and readiness	AR
Railway 4.0 Challenges	RCH
Measurement Item Code	MIC

poor planning and programming practices and (c) fragmented and conservative nature of the construction industry.

The eighth factor is uncertainties in benefits and gains and returned two indicators. (a) Uncertainties in benefits and gains in terms of labour and workforce and (b) poor knowledge management. Shortfall in transport infrastructure is the nineth factor and returned three indicators. The indicators include: (a) security issues; (b) market transparency for technology and (c) shortfalls in the transportation infrastructure. Organizational Structure, data protection and cybersecurity is the tenth component and has one indicator. While resistance to change is number eleven factor and returned three indicators. The indicators include: (a) lack of standardization; (b) lack of skilled labour and (c) resistance to change. The twelfth factor is loaded by one indicator, which is Lack of training and resources. The indicator is lack of resources and training.

3.2. *Analysis of structural relationships of latent constructs*

The twelve principal constructs of challenges of railway 4.0 technologies from the EFA was subjected to further analysis to determine the association between them and their influence on the overall awareness and readiness for adoption. SEM was employed to establish the direct/indirect relationships between the constructs, including challenges of railway 4.0 and the overall influence on the awareness and readiness for adoption in a developing economy. With regards to the research questions (see introduction section), one hypothesis was meant to be verified in this study. The null hypothesis states that (H0) Challenges to railway 4.0 technologies has no significant effect on the awareness and readiness for adoption. While the alternative hypothesis states that (H1) challenges to railway 4.0 technologies has significant effect on the awareness and readiness for adoption.

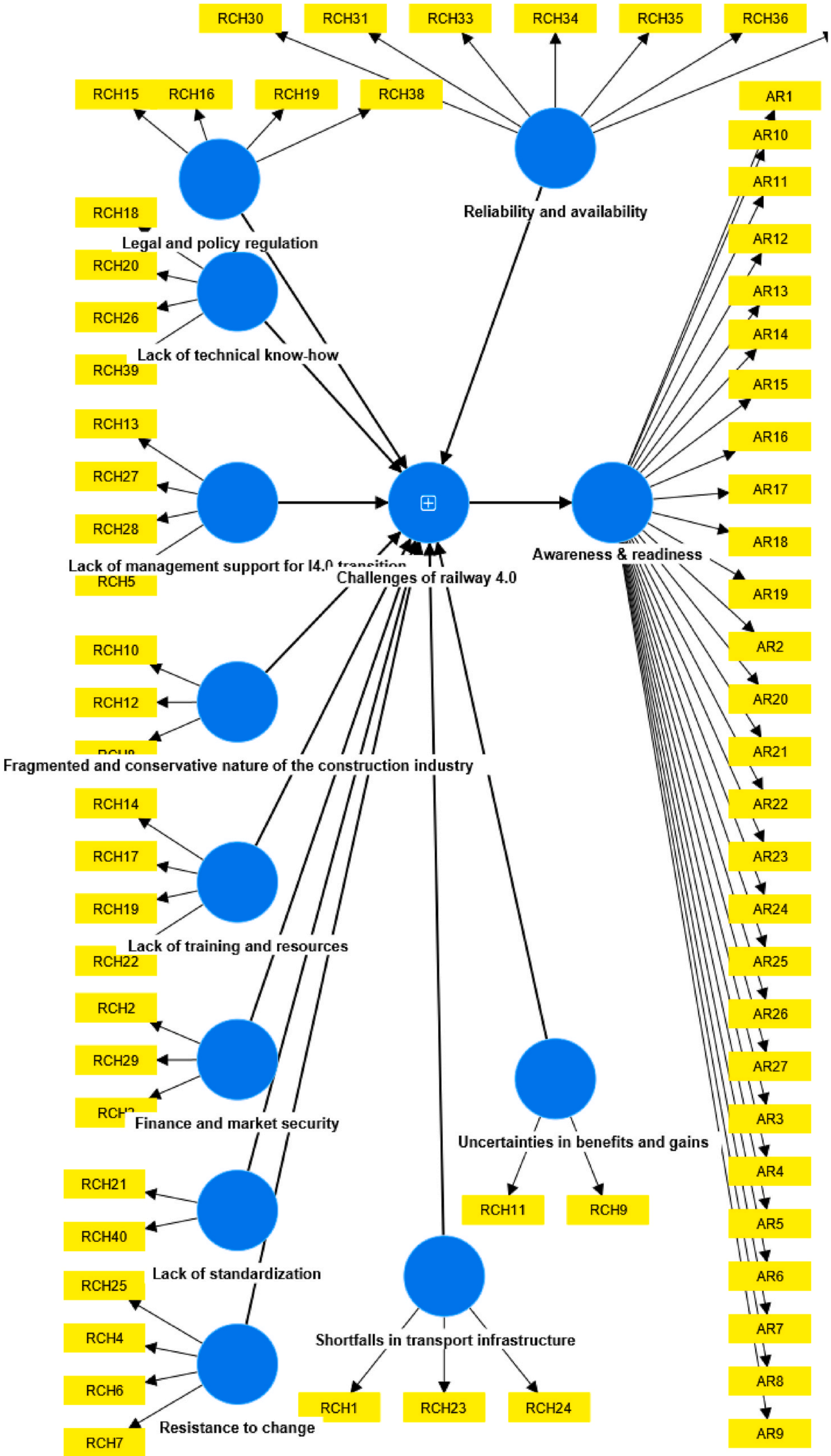
PLS-SEM is used in SEM to investigate the incremental impact of treatments of actions on sets of outcomes. Therefore, it approaches variables relationship in SEM using causal-predictive techniques [54]. SEM main aim is to offer explanation and validation for causal theoretical model and test the relationship between variables [49] and as such, this work benefitted from the robustness of SEM analysis. SEM examines the direct and indirect effects of hypothesized causal association, which is one of its defining features that differentiate it from other modelling techniques [67]. There are two steps of validation exercise in SEM analysis: The first validation process is that measured indicators that indicate relevant constructs in the measurement model are confirmed by carrying out (CFA) confirmatory factor analysis on them. The second validation process is where the structural model is formed or created, and path analysis is used to evaluate the research hypothesis [61]. Covariance and component-based techniques are the two methodologies available in SEM.

According to Ref. [54], the component-based technique (PLS-SEM) is mostly preferred by researchers because it offers a stronger statistical tool for evaluating numerous factors and reinvested in investigational variances, and also give a better predictive result than the covariance-based approach (CB-SEM). Hence, PLS-SEM was used in this study. The two principal components of SEM are(i) measurement model-this covers the effects of latent constructs, and (ii) Structural model-this shows the relationships between endogenous and exogenous variables. The relationship between the hypothesized variables is usually linear in nature. The Significant indicators were identified from the EFA and they formed the measurement model for this study. The Conceptual model obtained and the estimating SEM that covered the hypothesis are shown in Fig. 2.

4. Model analysis and results

4.1. *Measurement models*

To assess the measurement model, the convergent and discriminant validities are needed [49]. The Cronbach's alpha, outer loading, average variance extracted (AVE) and composite reliability; are what constitute the convergent validity assessment. While the Cross-loading criterion and Fornell and Larker's criterion; constitutes the discriminant validity assessment. As stated earlier, the indicators from the EFA were used to estimate the measurement models for the challenges to railway 4.0 technologies. The final model stemmed from the validity tests, and contains only significant indicators which met behavioural and statistical relevance were retained



(caption on next page)

Fig. 2. Conceptual model of PLS-SEM

in the SEM. This section presents a discussion of the outcome of the component's model measurement.

4.2. Evaluation of measurement models

Table 6 present the outcome of the measurement model of the challenges of railway 4.0 and awareness and readiness. Items with factor loading <0.50 were removed and the analysis redone. This process continued until accurate and dependable measurement model was obtained. Because the constructions cause the items—that is, the arrows in Fig. 2 point from the constructs to the measurement items—this study solely uses reflective measurement items. According to Ref. [54], reflective measuring items are highly linked, interchangeable, and some may be removed without altering the construct's meaning. Reference [68] also strongly suggested that variables with low loadings have little or no significant explanatory power and should be removed so that they do not distort the estimation of other measurement items. The cross-loading criteria and Fornell Larcker's criterion as indicated in Table 8 are two ways to determining discriminant validity. To begin [69], criteria were employed to investigate the link and association between the concept and the square root of AVE. The criteria guiding the use of Fornell Larcker's is that the construct's AVE square root must be greater than the association involving the other constructs [70]. The model's discriminant validity is confirmed by the results obtained (see Table 6).

Second, the cross-loading criterion is utilised to determine that the loading value of each indicator, together with its construct, must be larger than the loading value of the other construct on the same row. The findings of cross loadings to assess the discriminant validity of indicators are shown in Table 9, and it revealed that the degree of unidimensionality of each construct is high.

4.3. Evaluation of structural models (path analysis)

The outcome of the bootstrapping of the railway 4.0 challenges and awareness and readiness model is shown in Table 10. With a t-value >1.96, the path link finance and market security challenges of railway 4.0 is statistically significant at 5% level of significance, thus, supports a direct relationship. The regression weights is represented by the path coefficient [71], and the higher path coefficient, the greater the influence of the independent variables on the dependent variables [72]. The interpretation of the influence of the path coefficient are categorised into three; (i) 0.10–0.30 = week influence, (ii) 0.30–0.50 = moderate influence, and (iii) 0.50–1.00 = strong influence [73]. In this study, the relationship of reliability and availability and challenges of railway 4.0, has a strong influence on the model, had a path coefficient of 0.577, indicating a strong influence. It is worthy of note that the construct (FCNC → Challenges of Railway 4.0) is not significant as its p-value is greater than 0.05. This means that the construct is not found significant to have effect on the awareness. In contrast, even though the path coefficient values are low for all the remaining relationship (FAMS, LMST, LASD, LTKN, LTAR, LEPR, RETC, SITI and UIBG), the *t*-values are above 2.58 which means all the relationships are statistically significant at 0.01 [56]. These results show that the influence of most of the identified challenges of railway 4.0 technology on awareness and readiness are statistically significant. Importantly, the path coefficient (β) between challenges construct and that of the awareness and readiness construct is 0.852 and statistically significant (p value = 0.000 and t value = 27.90), confirming the alternative hypothesis proposed in this study. This result indicates that the identified challenges have a strong positive influence on awareness and readiness, as evidenced by the high coefficient value. The highly significant p-value <0.001 suggests there is a less than 0.1% probability that this strong positive relationship occurred by chance.

The large t-value of 27.90 further validates that the challenges construct has a statistically significant effect on awareness and readiness. Overall, this provides clear empirical evidence that the latent constructs representing the Railway 4.0 adoption challenges are important antecedents that strongly predict the level of awareness and readiness among railway professionals in the context studied. Addressing these challenges can thus potentially play a major role in improving awareness and readiness for adopting Railway 4.0 technologies in the developing economy.

The coefficient of determination ($R2$) of the dependent variable as indicated-in Table 11, was 0.726 and independent variable

Table 8
Correlation of latent variables and discriminant validity (Fornell-Larcker criterion).

Construct	FAMS	FCNC	LMST	LASD	LTKN	LTAR	LEPR	REVA	RETC	SITI	UIBG
FAMS	**0.962**										
FCNC	0.410	**0.840**									
LMST	0.466	0.538	**0.738**								
LASD	0.281	0.530	0.479	**0.783**							
LTKN	0.233	0.367	0.174	−0.023	**0.715**						
LTAR	0.374	0.634	0.250	0.002	0.433	**0.966**					
LEPR	0.210	0.521	0.246	0.240	0.284	0.194	**0.581**				
REVA	0.270	0.539	0.240	0.188	0.220	0.099	0.534	**0.780**			
RETC	0.852	0.610	0.409	0.059	0.265	0.263	0.31	0.146	**0.803**		
SITI	0.184	0.469	0.718	0.062	0.529	0.209	0.353	0.254	0.230	**0.717**	
UIBG	0.276	0.481	0.371	0.195	0.271	0.120	0.226	0.305	0.266	0.279	**0.989**

NB: The diagonal bold values are the square root of the Average AVE of the construct, while other represent the correlation values.

Table 9
Testing the indicator's discriminant validity through cross loading.

MIC	FAMS	FCNC	LMST	LASD	LTKN	LTAR	LEPR	REVA	RETC	SITI	UIBG
AR1	0.351	0.128	0.249	0.162	0.397	0.231	0.275	**0.736**	0.303	0.282	0.435
AR10	0.124	0.061	0.077	0.134	0.182	0.045	0.135	**0.453**	0.034	−0.047	0.199
AR11	0.369	0.044	0.252	0.232	0.376	0.226	0.234	**0.758**	0.315	0.267	0.430
AR12	0.199	0.084	0.102	0.142	0.198	0.081	0.108	**0.643**	0.027	0.018	0.258
AR17	0.362	0.158	0.225	0.175	0.414	0.222	0.231	**0.774**	0.280	0.316	0.433
AR2	0.254	−0.017	0.144	0.312	0.275	0.057	0.108	**0.770**	0.158	0.218	0.364
AR20	0.301	0.052	0.197	0.134	0.252	0.150	0.180	**0.772**	0.051	0.193	0.389
AR21	0.121	−0.086	0.100	0.223	0.198	0.093	0.166	**0.646**	−0.169	0.183	0.216
AR22	0.443	0.049	0.114	0.127	0.018	0.014	0.077	**0.615**	−0.013	0.116	0.280
AR23	0.366	0.027	0.225	0.137	0.223	0.124	0.181	**0.789**	0.075	0.207	0.392
AR24	0.289	0.115	0.299	0.147	0.182	0.139	0.176	**0.709**	0.120	0.244	0.394
AR25	0.209	0.012	0.200	0.199	0.152	0.035	0.098	**0.697**	0.078	0.061	0.237
AR26	0.244	−0.021	0.221	0.271	0.344	0.099	0.175	**0.722**	0.149	0.174	0.395
AR5	0.350	0.045	0.224	0.122	0.232	0.167	0.253	**0.723**	0.097	0.181	0.443
AR8	0.309	0.125	0.261	0.169	0.492	0.402	0.378	**0.707**	0.194	0.320	0.560
AR9	0.361	−0.056	0.264	0.124	0.207	0.147	0.215	**0.729**	0.103	0.180	0.378
RCH1	−0.175	0.067	−0.016	−0.051	**0.109**	0.004	0.011	−0.052	−0.211	−0.187	0.104
RCH10	0.087	**0.744**	0.053	−0.053	−0.034	0.138	0.062	0.064	0.040	0.069	−0.017
RCH11	0.302	0.055	0.201	0.043	0.252	0.203	0.230	0.485	0.246	0.293	**0.861**
RCH12	0.075	**0.895**	0.072	−0.007	0.040	0.215	0.221	0.052	0.082	0.206	0.079
RCH13	−0.158	−0.043	−0.028	−0.093	0.113	−0.156	−0.063	0.048	−0.142	−0.186	0.046
RCH14	0.039	0.123	0.051	0.179	0.308	**0.634**	0.359	−0.007	0.091	0.181	0.175
RCH15	0.208	0.132	0.120	0.009	0.297	0.477	**0.718**	0.209	0.175	0.322	0.243
RCH16	0.140	0.008	0.103	−0.050	0.458	0.478	**0.693**	0.110	0.185	0.254	0.148
RCH17	0.240	0.149	0.330	0.165	0.496	**0.808**	0.415	0.152	0.257	0.302	0.243
RCH18	0.120	−0.017	0.272	0.075	0.539	0.238	0.154	0.180	0.178	0.015	0.625
RCH19	0.211	0.250	0.187	0.119	0.465	**0.796**	0.901	0.129	0.184	0.194	0.228
RCH2	−0.155	−0.214	−0.047	0.077	0.115	−0.034	0.062	0.096	−0.258	0.050	0.071
RCH20	0.209	0.010	0.330	0.108	**0.906**	0.460	0.438	0.288	0.316	0.171	0.376
RCH21	0.178	−0.037	0.267	0.976	0.143	0.197	0.108	0.299	0.197	0.150	0.138
RCH22	0.230	0.055	0.001	0.272	0.149	0.153	0.211	0.237	0.205	**0.315**	0.199
RCH23	0.342	0.172	0.278	0.073	0.289	0.290	0.256	0.313	0.281	**0.946**	0.251
RCH24	0.252	0.153	0.116	0.171	−0.038	0.186	0.155	0.055	0.199	**0.625**	0.115
RCH25	0.735	0.072	0.535	0.204	0.349	0.237	0.204	0.145	**0.989**	0.313	0.294
RCH26	0.262	0.013	0.464	0.136	**0.595**	0.561	0.488	0.240	0.265	0.278	0.153
RCH27	0.347	0.004	**0.760**	0.217	0.266	0.259	0.097	0.066	0.483	0.258	0.195
RCH28	0.455	0.071	**0.930**	0.250	0.439	0.240	0.244	0.324	0.446	0.223	0.299
RCH29	0.737	0.051	0.519	0.189	0.361	0.260	0.240	0.111	**0.989**	0.285	0.272
RCH3	**0.698**	0.071	0.158	0.057	−0.013	0.089	0.101	0.488	0.044	0.247	0.155
RCH30	0.362	0.158	0.225	0.175	0.414	0.222	0.231	**0.774**	0.280	0.316	0.433

NB: Variables with loadings >0.50 within a construct are the bold values.

Table 10
Path analysis for second-order models test using bootstrapping for foundational construct.

Direct relationship	Path coefficient (β)	Standard Deviation (STD)	T statistics	ρ values	VIF
FAMS → Challenges of Railway 4.0	0.095	0.023	4.159	0.000	3.154
FCNC → Challenges of Railway 4.0	0.018	0.028	0.631	0.528[a]	1.135
LMST → Challenges of Railway 4.0	0.073	0.026	2.871	0.004	1.659
LASD → Challenges of Railway 4.0	0.088	0.036	2.469	0.014	1.244
LTKN → Challenges of Railway 4.0	0.156	0.039	4.045	0.000	2.233
LTAR → Challenges of Railway 4.0	0.090	0.032	2.781	0.005	3.269
LEPR → Challenges of Railway 4.0	0.135	0.039	3.469	0.001	2.726
REVA → Challenges of Railway 4.0	0.577	0.073	7.930	0.000	1.977
RETC → Challenges of Railway 4.0	0.098	0.044	2.214	0.027	3.085
SITI → Challenges of Railway 4.0	0.095	0.027	3.468	0.001	1.289
UIBG → Challenges of Railway 4.0	0.109	0.023	4.774	0.000	1.598
Challenges of Railway 4.0 → AR	0.852	0.031	27.900	0.000	1.000

[a] = construct is not significant (p-value < 0.05).

0.995, respectively moderating an acceptable level of predictive accuracy and model quality [54].

5. Hypothesis testing

SmartPLS4 software was utilised to test the study's hypothesis the causal relationship among the assessed items. This followed the

Table 11
The coefficient of determination (R^2).

Endogenous Construct	R^2	Adjusted R^2	Explained Size
Barriers	0.726	0.723	Large
Drivers	0.995	0.995	large

approach of [74,57]. The SEM analysis presented in Fig. 2 indicates that results show that the influence of most of the identified challenges of railway 4.0 technology on awareness and readiness are statistically significant. Importantly, the path coefficient (β) between challenges construct and that of the awareness and readiness construct is 0.852 and statistically significant (p value = 0.000 and t value = 27.90), confirming the alternative hypothesis proposed in this study. This result indicates that the identified challenges have a strong positive influence on awareness and readiness, as evidenced by the high coefficient value (Fig. 2 and Table 10). Table 12 shows the hypothesis and result.

6. Discussion

This study adopted SEM to establish the relationships (direct/indirect) that exist between the EFA construct and their influence on overall awareness and readiness to adopt railway 4.0. It also covered the challenges of railway 4.0 and the overall influence on the awareness and readiness for adoption in a developing economy. The PLS-SEM results are discussed in this section. Generally, with the exclusion of Fragmented and conservative nature of the construction industry construct, all the challenges to railway 4.0 are statistically significant at p-value of 0.05 and have influence on the awareness and adoption readiness.

6.1. *Reliability and availability*

From the PLS-SEM results, reliability and availability ranked first with a path coefficient score (value) of 0.577. This is a system performance issue, and in today's digitally connected world, users want business applications and services to function all the time with ease and in real time. However, unavoidable errors and the impracticality to control the technology that support digital services, impact the expectations of users. This is a great challenge even in railway 4.0 technologies. The reliability and availability is a serious challenges to railway 4.0 technology adoption. Reliability is a measure of the likelihood that a system will fulfil set performance requirements when executing its intended function over a certain time span. Availability, on the other hand, is a percentage of the time that an IT service or component is operational [75]. Railway construction and project are complex in nature and transition towards the digitalization comes with its attendance complexity. Reference [5] submit that rail transportation especially mega rail is complex and full of risks. Complexity results in poor project performance [76]. This suggests that the complex nature of digital technology might pose serious challenges to the adoption and implementation of Railway 4.0 technology. In railway infrastructure just like any other infrastructure projects, is loaded with a lot of complexity from design to operation due to the level of risk involved and its large-scale nature. For instance, uncertainty in project scope and budget, delivery selection together with technological advances, environmental issues and globalization, economic liberalization, technological advances all these resulted in the growing complexity of infrastructure projects [77,78].

6.2. *Lack of technical know-how and investment in R&D*

In comparison to other organizations, the construction sector often has little investment in R&D budgets. According to the results, Lack of technical know-how ranked second with a path coefficient value of 0.156. The comparatively low rate of technological adoption has several causes. Reference [79] itemized a few potential causes for the slow uptake of new technologies, including challenges with low R&D spending, finances, technology, ethical concerns, and health. Investment in R&D should be given high importance by any organization that wants to adopt new technologies because it is the foundation of innovation and new technologies. Research and development produce the knowledge that gives rise to new technologies and discoveries [80,81].

6.3. *Legal and policy regulation*

According to the results, legal and policy regulation ranked third with a path coefficient value of 0.135. Legal and contractual issues arise in almost all construction projects, which will have an impact on their success [25]. Legal and contractual issues are frequently

Table 12
Hypothesis and results.

Hypothesis	Results
H0	Reject
H1	Accept

the root of poor digitalization and new technology adoption [82–84]. Another obstacle to the shift to industry 4.0 is the legal and policy environment in which the Railway project is implemented. Before they are put into practice, government laws or policies must be taken into account by railroad professionals.

6.4. Uncertainties in benefits and gains

Ignorance is a disease, and nobody wants to be associated with it. When firms or organizations are not adequately informed about the gains and benefits in adopting new innovation and technologies, they might not invest into it. Ignorance about the benefits in the adoption of I4.0 according to Ref. [85], is a serious problem to the construction industry and other industries. When certain gains and benefits that would be derived from adopting Railway 4.0 technology are not clearly stated or explicitly determined, it poses serious challenge to the transition to digital space. Uncertainties in benefits and gains according the PLS-SEM results ranked fourth with 0.109 value of path coefficient. Most firms or railway construction professionals will not be willing to invest in new technologies when they do not understand the benefits and gain that would be derived from it [25]. Extant literature supports this by saying that companies, either large or small, might not be willing to commit their resources to new technologies unless they have knowledge about potential benefits and gain from such investment [82].

6.5. Resistance to change

Resistance to change is another serious challenge confronting the adoption of I4.0 in any organization. This according to results ranked fifth with path coefficient of 0.095. Companies and firms are used to doing business following existing procedures and principles and as such a not accustomed to change. Previous studies have reported on resistance to change as a critical hindrance to technology adoption such as Automating and digitalization of construction process and projects, BIM tools, railway signalling and communication digitalization among others [86]. Reference [87] noted in Swedish construction industry, that reluctant and hesitant by the companies toward adopting the change brought by the technology was because of resistance to change that existed. Reference [88] submitted in the Hong Kong construction industry, that construction stakeholders argued resistance to change in terms of lack of proper standards and BIM adoption. This might be because of the wrong perception of companies as regards I4.0 transformation as challenging, they might also consider implementation cost too high, and as a serious burden for creating an environment open to innovations and change.

6.6. Shortfalls in transport infrastructure

The result from PLS-SEM ranked shortfalls in transport infrastructure sixth with path coefficient of 0.095. It is impossible to overstate the value of infrastructure services. Infrastructure service accessibility has a big impact on how regions and nations grow [89]. The quantity and quality of infrastructure have a direct impact on the productivity and expansion of businesses, while inadequate infrastructure investments increase inequality between regions and nations [90]. Since any sort of development is impossible without proper infrastructure, the effect of infrastructure investments on a country's development is a crucial topic [90]. However, there is a severe lack of this crucial development facilitator, which puts the pursuit of development in grave danger. Infrastructure is currently unquestionably one of the most difficult obstacles standing in the way of the nation's efforts to achieve sustainable economic and social growth. Infrastructure that is inadequate or dilapidated is an issue since it hinders growth and the shift to digitalization [89]. Even in the UK, research reveals that there is a shortage in current infrastructure investment by the UK government. There has been an evident, long-term Transitioning to railway 4.00 could be a fantasy without appropriate infrastructure provision [91]. The lack of infrastructure was mentioned by Ref. [46] as a challenge to adopting railway 4.0.

6.7. Finance and market security

The result from PLS-SEM also ranked Finance and market Security sixth with path coefficient of 0.095. The significance of financial resources to the success of the railway 4.0 project cannot be overstated, just like any other capital project. The adoption of Railway 4.0 Technology will be capital expensive and call for significant financial resources. The correct technology must be purchased and implemented with sufficient financing. The necessary resources must be committed to upgrade, train, and build capacity for the intended transition as part of the system's ongoing improvement [92].

6.8. Lack of training and resources (lack of labor force)

Crucial component for a successful process improvement and technology transformation is a skilled labor force because its absence typically results in insufficient training and motivation [25]. The result of the SEM ranked lack of training and resources seventh with path coefficient of 0.090. This is said to be a significant obstacle to the adoption of Railway 4.0 in the construction sector. Reference [93] argued that when there is a labor shortage, a company is more likely to experience low productivity, and [94] contended that a lack of labor force causes construction and project managers to raise concerns about whether the available labor force is qualified and prepared to adopt new technologies. Poor performance and reluctance to embrace change brought on by new, innovative technology are side effects of a skilled labor force scarcity. Any organization without internally trained individuals to carry out the intended transformation has an impossible task or impossible dream of starting a successful technology transformation. According to Ref. [95], implementing Railway 4.0 is expected to solve various issues in the sector related to labour, material, and lengthy set-up periods.

6.9. Lack of standardization

The result of the SEM ranked lack of standardization eighth with path coefficient of 0.088. Studies [96–98] have identified a lack of standardization as a hindrance to the implementation of railway 4.0 and construction projects. One of the primary arguments made against standardization is the construction project's temporary nature. Reference [96] submit that in the Yemeni construction sector, Lack of uniformity was identified as a barrier to the adoption of BIM. According to Ref. [98], the Chinese construction industry has not successfully embraced engineering construction standards due to a shortage of standardization talent. Reference [97] argued that temporary/transitory organizations experience problems with a lack of information sharing and process standardization. This construction businesses' effort to standardize processes and procedures has had a negative impact on their desire to implement railway 4.0. and as such, lack of standardization is considered as an important challenge for the railway 4.0 adoption. For a workflow and production environment to be successful, standardization is essential [99].

6.10. Lack of management to support I4.0 transition

Lack of management support according to the result of the PLS-SEM was ranked nineth with 0.073 as the path coefficient value. Successful transition from the traditional approach to Industry 4.0 would require the support from the management of an organization. When this is missing, it poses a great challenge to the adoption of railway 4.0 technology. The absence of support from the management towards transition to I4.0, worrying rates of accident in the construction sector, the best management support and championship, and the industry cluster are some of these causes. If there is no management support for the transition, new technology might not see the light of the day.

6.11. Conventional and fragmented nature of the construction industry

Major obstacles to the adoption of Railway 4.0 include construction projects' fragmentation and project-based nature. The construction sector is typically perceived as being hesitant to adopt new technology and advances due to its conservative and fragmented character. Whether construction firms would ever be prepared and likely going to adjust their focus toward becoming more technical organizations adopting the cutting-edge solutions driven by industry 4.0 would be a matter for consideration [25]. According to a study by Ref. [100] on the important issues facing Malaysian construction projects, the fragmented character of these projects is to blame for people's resistance to adopting creative ideas, poor project performance, and low productivity. It is worthy of note that this construct (colored text in the table) fragmented and conservative nature of the construction industry according to results, indicate that the construct is not significant as its p-value is greater than 0.05. This suggests that the construct is not found significant to have effect on the awareness.

7. Conclusions

Digital technology or industry 4.0 technologies are widely used nowadays in many industrialised nations because of their numerous advantages and sustainability. However, its application is hardly ever seen in developing nations. The Nigerian railway construction industry is the subject of this study because there is little existing research in this field and little use of industry 4.0 in the rail sector. The main goal of this study is to evaluate how well-known, ready for implementation, and challenges of Railway 4.0 technologies are in Nigeria because addressing these issues is essential to the implementation's success. A thorough analysis of the literature revealed 40 barriers to the adoption of Railway 4.0. The mean score result showed that the adoption readiness of Railway 4.0 technologies is low and the awareness level of Railway 4.0 is modest. To verify the relationships between challenges to railway 4.0 technology and awareness and adoption readiness for railway 4.0 technologies, a PLS-SEM technique was implemented. Based on the findings of the path analysis, the primary categorised challenges (i.e. constructs) can be ranked in descending order as follows: reliability and availability, lack of technical know-how and investment in R&D, legal and policy regulation, uncertainties in benefits and gains, resistance to change, shortfalls in transport infrastructure, finance and market security, lack of training and resources (lack of labor force), lack of standardization, lack of management to support I4.0 transition.

The path coefficient β value, which indicates a significant and substantial correlation between challenges and awareness and adoption readiness, validates the hypothesis that challenges of railway 4.0 technology has a significant influence on the awareness and adoption readiness. The p value is less than 0.05 and path coefficient (β) is 0.852.

In a general context, this study suggests that the complexity of railway 4.0 technology may be managed by ensuring clear communication and understanding from the beginning of the project design stage until its completion. Efficient communication and accurate information regarding the shift to the digital age are crucial for managing the complexities of railway 4.0. To address the deficiencies in transportation infrastructure, it is necessary to allocate additional resources towards the development of both digital and physical transportation infrastructure. The government can promote the adoption of digital technology by implementing effective legal policies and regulations. Establishing and providing incentives to promote buy-in, public awareness, and sensitization, among other strategies. Furthermore, the shift towards the era of new technologies necessitates the need for retraining and capacity building in order to keep up with the needs of this transformation. The advancement of technology is propelled by knowledge, and railway experts must acquire new knowledge in order to stay abreast of the latest technological developments and effectively implement them.

Implementing these recommendations will significantly enhance understanding regarding the significance of applying digital technology in the railway business and the issues it entails. This will offer railway experts and government officials valuable benchmarks to make well-informed decisions regarding the transition to railway 4.0.

In the context of Nigeria, the aforementioned recommendations are also relevant, especially in addressing deficiencies in transportation infrastructure. Nigeria, similar to other emerging nations, faces a deficiency in terms of transport infrastructure. Consequently, it is projected that the Nigerian government will allocate more resources towards the development of both digital and transport infrastructure. In addition, the government can promote the adoption of digital technology through effective legal policy and law. Measures that promote a smoother shift from conventional methods to the digital age. Furthermore, the shift towards the era of new technologies necessitates the need for re-training and capacity development in order to keep up with the needs of this transformation. Given these circumstances, Nigerian railway experts would need to acquire fresh expertise in order to stay abreast of cutting-edge technology and effectively use it.

In terms of practise and knowledge, substantial contributions have been made to this study. However, its constraints open up a number of possibilities for further investigation. The research questionnaire was only given to railway construction professionals in Lagos, Lagos State in Nigeria, therefore the study's geographic reach is constrained in the first place. Future research should, rather than focusing solely on Lagos, include a wider and more varied cross-section of Nigerian railway construction specialists. Second, the study's measurement of the Railway 4.0 technologies is limited, and it is advised that future research expand its scope to include further technologies.

7.1. Theoretical, practical and policy implications

This study makes important theoretical contributions to the understudied area of Railway 4.0 adoption in developing economies. The identification and empirical validation of the key challenges influencing awareness and readiness provides categorization of the challenges from a theoretical lens. The conceptual model put forth provides a theoretical framework for explaining how the challenges of adopting Railway 4.0 technologies impact the awareness and readiness levels. The model was rigorously tested using structural equation modelling, contributing to theory building and testing for Railway 4.0 adoption. The findings offer theoretical insights into customizing the implementation strategies and policies based on developing countries' specific challenges. This can inform theoretical models on technology adoption by contextualizing the challenges. Moreover, the research fills an important knowledge gap regarding Railway 4.0 adoption in emerging economies like Nigeria which have received less scholarly attention.

7.2. Implications of our findings for practice and policy

The implication of our findings in terms of practice and policy, is that findings of this study can assist policy makers in formulating targeted policies and initiatives to address the priority challenges identified by the study as hindering Railway 4.0 adoption. Railway organizations can leverage the insights to adapt their technology implementation plans based on the prevailing challenges in their context. The low adoption readiness suggests the need for dedicated awareness campaigns and training programs among railway professionals to build knowledge and capabilities regarding Railway 4.0. Infrastructure improvement and clear communication of the benefits were highlighted as ways to potentially accelerate adoption. The study provides a valuable benchmark for practically assessing and comparing Nigeria's standing in terms of adopting Railway 4.0 technologies.

Data availability

Sharing research data helps other researchers evaluate your findings, build on your work and to increase trust in your article. We encourage all our authors to make as much of their data publicly available as reasonably possible. Please note that your response to the following questions regarding the public data availability and the reasons for potentially not making data available will be available alongside your article upon publication.

Has data associated with your study been deposited into a publicly available repository?

Response: No

Please select why. Please note that this statement will be available alongside your article upon publication. as follow-up to **Data Availability**

Sharing research data helps other researchers evaluate your findings, build on your work and to increase trust in your article. We encourage all our authors to make as much of their data publicly available as reasonably possible. Please note that your response to the following questions regarding the public data availability and the reasons for potentially not making data available will be available alongside your article upon publication.

Has data associated with your study been deposited into a publicly available repository.

Response: Data will be made available on request.

CRediT authorship contribution statement

Imoleayo A. Awodele: Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Modupe C. Mewomo:** Supervision, Conceptualization. **Angel M. Gento Municio:** Writing – original draft, Supervision. **Albert P.C. Chan:** Supervision. **Amos Darko:** Writing – review & editing, Supervision, Methodology. **Ridwan Taiwo:** Methodology, Formal analysis, Conceptualization. **Nathaniel A. Olatunde:** Writing – original draft, Data curation, Conceptualization. **Emmanuel C. Eze:** Writing – review & editing, Formal analysis, Conceptualization. **Oluwaseyi A. Awodele:** Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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