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ASSESSING THE PERFORMANCE OF SUB-SAHARAN AFRICAN (SSA) RAILWAYS BASED ON AN INTEGRATED ENTROPY-MARCOS APPROACH

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Research paper

Abstract: *In this study, the performance of Sub-Saharan African railways systems (SSA) is assessed by using an integrated Entropy-MARCOS (Measurement Alternatives and Ranking according to COmpromise Solution) - based methodology. In the first phase, the Entropy method is employed to determine the weights of each sub-criterion of the decision model. This process identifies six main criteria, i.e., safety, security, internal business aspect, intermodal aspect, innovation, and learning aspect, and customer satisfaction which are further supplemented by 13 sub-criteria. In the second phase, the MARCOS method is used to rank the countries based on their railway performance assessment. Based on the results from the proposed method, a sensitivity analysis was carried out through a comparative analysis with seven other multi-criteria decision-making (MCDM) methods. The results of the study indicate that the most weighted sub-criterion is the labor productivity (internal business perspective criteria) followed by the terrorist incidence (security criteria) and the number of employees going through training/exposure sessions (innovation and learning perspective criteria). Moreover, it was revealed that Kenya is the best alternative in terms of its railway performance followed by Ethiopia, Cameroon, Nigeria, and Ghana. Based on the findings from this study, decision-makers can be assisted during the operative, designing, and planning investigations of the railway system through the consideration of these parameters as insert indicators. Also, the findings can help as a benchmark for the performance analysis of other railway systems in other African countries.*

Keywords: *Railways, Sub Saharan Africa, Performance, Entropy, MARCOS, Multi-criteria decision making*

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1. Introduction

In the present's severe rivalries between railway and road transportation modes in the major corridors of the African sub-region, a distinguished service distribution change into a regional trade demand. One of the pivotal constituents for modern railway corporations is performance appraisal and efficacy. This can reinforce reaching the organization's goals and analyze their achievement with identical leading policies marketing. To meet these excellent positions, a method should be elaborated by the railway corporation to create this evaluation in a beneficial approach.

Railway has lately undergone a universal renaissance via its network expansion and yearly traffic values. According to Bayane and Yanjun (2017) and Bouraima, Yang, and Qiu (2017), this improvement of railways is related to socio-economic and environmental advantages produced by the transport sector. Railway plays a considerable role through the assistance of economy and commerce of any country due to heavy traffic transportation of people and goods over long distances. A relative evaluation of air, road, and railway mode showed its potentiality in terms of cost, greenhouse gas, and carbon emission (Bouraima et al., 2020). In 2010, a coherent performance and demand development was universally reported in the railway system through a 40% rise in cargo and passenger traffic in comparison to an antecedent year. However, an opposite trend in the performance was noticed in Africa. While dynamic growth has been recorded in Asia, Europe, and America, Africa has seen a drop in passengers' services and freight transport.

Due to the recent powerful rise of the transport market worldwide, the contradictory trend in Sub Saharan Africa (SSA) revealed the crucial deficient railway system (Olievschi, 2013). In 2010, the Africa Union Commission has expressed the will to ameliorate the infrastructure condition through the infrastructure development program in the continent (Union, 2009). During this period, political leaders have expressed the connectivity ambition at both regional and continental levels (Commission, 2012). Nonetheless, this ambition has been rapidly impeded by several factors that affect railway development.

Several endogenous and exogenous factors restrict the competitiveness of African railway systems. While poor connectivity and interoperation of railways have seen to be the endogenous factors (Bouraima & Qiu, 2018; Bouraima & Yanjun, 2020), exogenous parameters are related to rivalry with road transport and the lack of policy related to transport (Bayane, Yanjun, & Bekhzad, 2020; Bouraima & Dominique, 2018; Bouraima, et al., 2020).

Literature available so far indicates the dramatic status of the railway sector in Sub-Saharan Africa (Bullock, 2009). A study by Mbangala Mapapa (2004) on the measurement of African railways productivity over 21 years indicated that the average efficiency is relatively low. As consequence, a need of improving the sector performance is imperative. Sabri, Colson, and Mbangala (2008) used data enveloped analysis (DEA) and Preference Ranking Organization METHod for Enrichment of Evaluations (PROMETHEE) II methods for the financial and technical performance analyses of five firms in North Africa. Sabri (2016) provided complimentary detailed information on the productivities of North African railways using a Malmquist quantity index. De Bod and Havenga (2010) highlighted the considerable cost depletion benefits feasible via the condensation of railway goods through prolonged distances, with related indications for profitability rise for rail operators. Olievschi (2013) suggested an extensive improvement method for the performance of the railway sector together with its governance modes. Wangai, Rohacs, and Boros (2020) introduced a harmonized interaction methodology including socio-economic needs, technical expansion, and rule for the development process of railway systems in low-income countries. Kutlar, Kabasakal, and Sarikaya (2013) measured the technical and allocative efficiencies scores of 31 railways companies using DEA and TOBIT analyses, respectively. Blumenfeld et al., (2019) proposed a technical strategy that captured the crucial capacity to be recommended to reach upcoming achievement in railway infrastructure in low-income countries while highlighting the necessity for arising technologies to be employed for appropriate solution.

Among these studies (Blumenfeld et al., 2019; Bullock, 2009; Mbangala Mapapa, 2004; Sabri, 2016; Sabri et al., 2008; Wangai et al., 2020), none of them have examined the key performance indicators (KPI's) of SSA's railways. Moreover, none of them have applied the MCDM method for the performance assessment of Sub-Saharan African railways. This paper proposed an integrated Entropy-MARCOS approach for the assessment of SSA's railways. The criteria and alternatives associated with the KPI's of railways are defined. A questionnaire survey was prepared for data collection and assigned to the railway experts from different countries. All experts hold senior positions with associated working experience and most of them had practiced in the field for 15 years at least. They all belong to the railway corporation in their respective countries: Cameroon Railway Corporation (CAMRAIL), Ethiopian Railway Corporation (ERC), Ghana Railway Corporation (GRC), Nigeria Railway Corporation (NRC), and Kenya Railway Corporation (KRC). The survey of experts is carried out in the study so that necessary data will be collected to determine relative criteria weight using the entropy method. The measurement and ranking of alternatives are assessed through the MARCOS method.

Through the proposed model in this study, various objectives are elucidated: 1) Review of the existing methodologies for the evaluation of different areas of the railway transport; 2) Enhancing the methodology for railway performance assessment and determining criteria weights and alternatives ranks through the development of the original multi-criteria entropy-MARCOS model; 3) Proposal of new methodology for the railway performance assessment; and (4) Cross over the existing gap for the railway performance evaluation approach in Sub-Saharan Africa.

The remaining sections of the paper are as follows. Section 2 includes the review of similar research topics in which are applied the models for the analysis of railway transport. Section 3 deals with the materials and methods. In section 4, the results and the discussion of the entropy-MARCOS methods are provided. Section 5 presented and discussed a comparative analysis of the proposed method with others MCDM methods. Section 6 ends with the conclusion along with the benefit of the research and the guidance for upcoming research.

2. Literature review

The analytical hierarchy process (AHP) introduced by Saaty (1990), is the most frequently applied MCDM approach in transport sector problems (Yannis et al., 2020). Vesković et al., (2016) used the fuzzy AHP approach to examine the operation of railways. Vesković et al., (2018) evaluate the management of railway through the combination of the Delphi- SWARA - MABAC approaches. The performance of goods transport in the railway sector is measured by Blagojević et al., (2020) through the usage of fuzzy-AHP-DEA approaches. Simić, Soušek, and Jovčić (2020) assessed the risk related to the railway infrastructure through the application fuzzy MCDM picture. Blagojević et al., (2021) examined the safety degree of the railway crossings with a new hybrid fuzzy MCDM approach so that durable traffic management can be reached. A new hybrid SAW (Simple Additive Weighting) - RN (rough numbers) method introduced by Stević et al., (2017) was used to choose wagons for the internal logistic transport enterprise. A choice of suitable alternative for the passenger rail operators business was done by Vesković et al. (2020) through a new hybrid fuzzy PIPRECIA (Pivot Pairwise Relative Criteria Importance Assessment)- fuzzy -EDAS approach. Blagojević et al., (2020) assessed the safety of railway traffic using a new integrated fuzzy PIPRECIA-entropy-DEA.

Not much structural performance has been achieved in most of SSA's countries' railways, especially in recent times. Nonetheless, new investments and developments have been noticed on the rail and some actions are taken in place to rejuvenate the railway system in most of SSA's countries. A renaissance has been felt in the railway system through the development of new lines and modernization and rehabilitation of old lines. As consequence, performance criteria are very important to measure and manage the railway sub-sector. The performance indicators for the railway system have been elucidated by Onatere, Nwagboso, and Georgakis (2014) in Nigeria. However, no research has been conducted regarding a comparative analysis of these performance indicators between countries from different regions of Sub-Saharan Africa. As consequence, this research is new and different from previous studies related to African railway performance since it takes into account countries from West Africa (Ghana and Nigeria), East Africa (Ethiopia and Kenya), and Central Africa (Cameroon).

3. Materials and methods

Section 3 is divided into two sub-sections. The first sub-section presents the materials which are the case study, where thirteen parameters are used to assess the railway performance of five selected SSA countries. The second sub-section deals with the presentation of the models used and the entropy-MARCOS algorithm is shown

3.1 Materials (case study)

Section 3.1 includes the background of the railway system in the selected countries (section 3.1.1), the definition of key performance indicators (section 3.1.2), and the formation of the multi-criteria model (section 3.1.3).

3.1.1. Overview of the railway in selected countries

In this study, five countries have been selected for the performance analysis based on the recent construction of new lines and maintenance and rehabilitation of existing networks. They comprise Ghana and Nigeria in West Africa, Ethiopia and Kenya in East Africa, and Cameroon in Central Africa, as can be seen in Figure 1.

The construction of the existing railway in Cameroon dates back to the 1900s. Being single track, it consists of the metric gauge with wood and iron sleepers. The Cameroonian railway network may be categorized into three routes: TRANSCAM I line (also referred to as the Central railway line), connecting Douala to Yaoundé, is CAMRAIL's central line; TRANSCAM II line (also referred to as the Northern line) connecting Yaoundé to Ngaoundere; and the Western line running between Douala and Kumba (Douala-Mbanga-Nkongsamba line, Mbanga~Kumba line). The total length of the railways is 1, 270km (Figure 2-a). Although the country has the most important and heaviest railway structures among countries of the sub-region, it is less extensive and operational in only part of the country. The only line that is functional provides a durable communication link between the north and south of the country, whereas it is still not operating at the international level. As consequence, the Cameroonian government commissioned the National Railway Master Plan in Cameroon Project in 2009 intending to construct 6000 km of lines categorized into short (S), mid (M), and long (L) term; with double track and standard gauge and in the same time develop urban railway for Yaoundé and Douala.

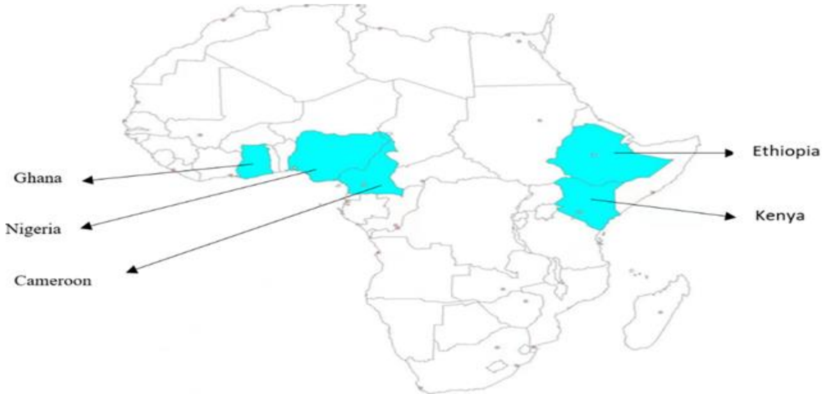


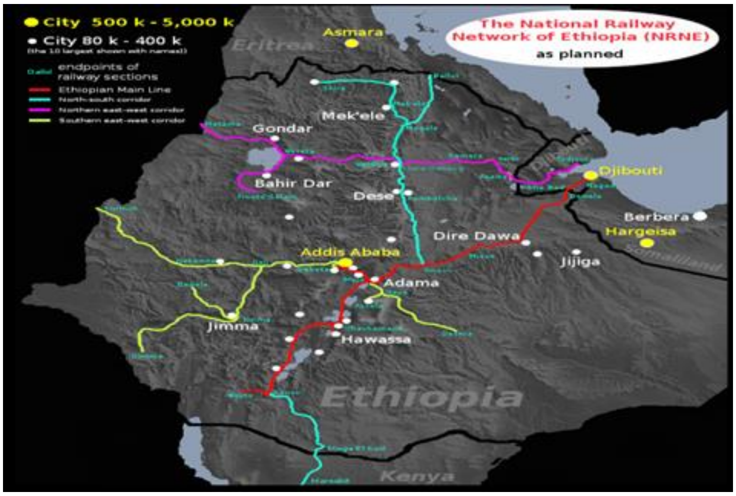
Figure 1. Countries of Sub-Saharan African contemplated in the study

The first railway line built in Ethiopia dates back to 1917 and links Ethiopia to Djibouti (Figure 2-b). It is a 784km metric gauge railway of which 475 km are destroyed and abandoned due to poor maintenance. The national railway network of Ethiopia (NRNE) is in charge of the management and operation of the railway. In recent years, the national railway has been modernized through the completion of the Addis Ababa–Djibouti electrified standard gauge railway and the ongoing construction of the Awash–Weldiya and Weldiya–Mekelle lines. Additionally, there is an urban light rail system in the capital which started operation in 2015 and represents the first light rail and rapid transit in the eastern and sub-Saharan Africa region. The existing 947 km Ghanaian railway network (Figure 2 c) comprises three lines: the eastern line (Kumasi –Accra: 303.9 km), the western line (Kumasi to Sekondi-Takoradi: 266.8 km), and the Central line (eastern-western). Most of the existing lines are single track, except a 32 km double-track line from Takoradi to Manso.

The Kenyan narrow-gauge railway (NGR) still plays a crucial role in the country's transport and logistics. Its construction began in the year 1896 under British rule. The mainline is composed of the 530.3km Mombasa-Nairobi section and the 551.88km Nairobi- Nakuru-Malaba, at Kenya's border with Uganda (Figure 2-d). This line is operational mostly for freight with a speed range of 20km/h to 30km/h from the Mombasa to Malaba border. The Kenya Vision 2030 which is the country's future development blueprint puts forward expansion and development of the railway system as one of the key flagship projects. The Kenya Government identified the Northern corridor and the LAPSSET corridor for the development of the modern Standard Gauge Railway (SGR). The Northern corridor is made up of; Mombasa-Nairobi, Nairobi-Naivasha, Naivasha–Narok–Bomet–Nyamira–Kisumu, and Kisumu–Yala–Mumias–Malaba. The Lamu Port South Sudan Ethiopia Transport (LAPSSET) corridor is a regional project intended to create seamless connectivity between Kenya and her neighbors Ethiopia and South Sudan.

The construction of Nigeria's existing railway network began in 1898 under British colonial power. This includes a 3,505 km old narrow-gauge single track running through three main north-south branch lines that run diagonally through the country (Figure 2-e). These lines initially played a significant economic role. To develop and refurbish the railway network, as mentioned in the 25-year strategic plan, all the existing 3505-km network of the narrow-gauge track will be converted for commercial freight and new standard-gauge lines will be built for passenger traffic that will link the economic centers and all the main states. This explains the construction of two main standard gauge railway (SGR) Greenfield projects that have been backed by Chinese funding: the new 2,733 km Lagos-Kano SGR line project is the first one substituting the colonial track, and split into four portions: Lagos-Ibadan, Ibadan-Kaduna, Kaduna-Kano, and Abuja-Kaduna and the new coastal railway line linking Lagos to Calabar through Port Harcourt and Warri.

(a)


City 500 k - 5,000 k
City 80 k - 400 k
endpoints of railway sections
The National Railway Network of Ethiopia (NRNE)
as planned
Eritrea
Asmara
Mek'ele
Gondar
Bahir Dar
Dese
Djibouti
Berbera
Hargeisa
Dire Dawa
Jijiga
Addis Ababa
Adama
Jimma
Hawassa
Ethiopia
Kenya

(b)


BURKINA FASO
BENIN
TOGO
COTE D'IVOIRE
GULF OF GUINEA
LEGEND

(c)


Ethiopia
Uganda
Kenya
Somalia
Nairobi
Mombasa
INDIAN OCEAN
United Republic of Tanzania

(d)

(e)

Figure 2. Railway networks of different countries (a) Cameroon, (b) Ethiopia, (c) Ghana, (d) Kenya, (e) Nigeria.

3.1.2. Defining key performance indicators

Different actions were employed to examine and trace an organization’s development upon its objective. According to Henning, Essakali, and Oh (2011), the quality of an organization's performance is quantified through KPIs. The choice and operation of adequate KPIs might be completely difficult, particularly when handling an organization like the railway sector in Sub-Saharan Africa. For this purpose of evaluating Sub-Saharan African railway performance, thirteen indexes were applied, as shown in Figure 3. In this study, we follow the indexes based on the literature reviews related to KPIs (Onatere et al., 2014) as follows: safety, security, internal business aspect, intermodal aspect, innovation, and learning aspect, and customer satisfaction.

Safety is related to the preservation of property and life through the advanced technology, rule, and management of all kinds of the railway sector. Some railway accidents have been noticed in some of the sub-Saharan African countries because of the poor safety measures. There is the occurrence of the death of some individuals because of the disposition of wares by traders along rail lines and carelessness of people when traversing lines. Also, the congested state of trains with people on the rooftop causes deaths of people who fall from trains. The KPIs for the safety criteria are shown in Figure 3.

Security is a component of safety, from the substantial preservation of infrastructure to techniques that protect the information network. Appropriate security actions are very important in the country where there is the occurrence of terrorist attacks and the presence of hard drugs and hemp used by people during the train journey. The KPIs for the security criteria are shown in Figure 3.

Internal business viewpoint is an ameliorated inner performance of the railway transport which is important for the customer satisfaction requirements. As consequence, the evaluation of whether the inner performance directed the necessity or prediction of the client is pivotal. The KPIs for the internal business viewpoint are shown in Figure 3.

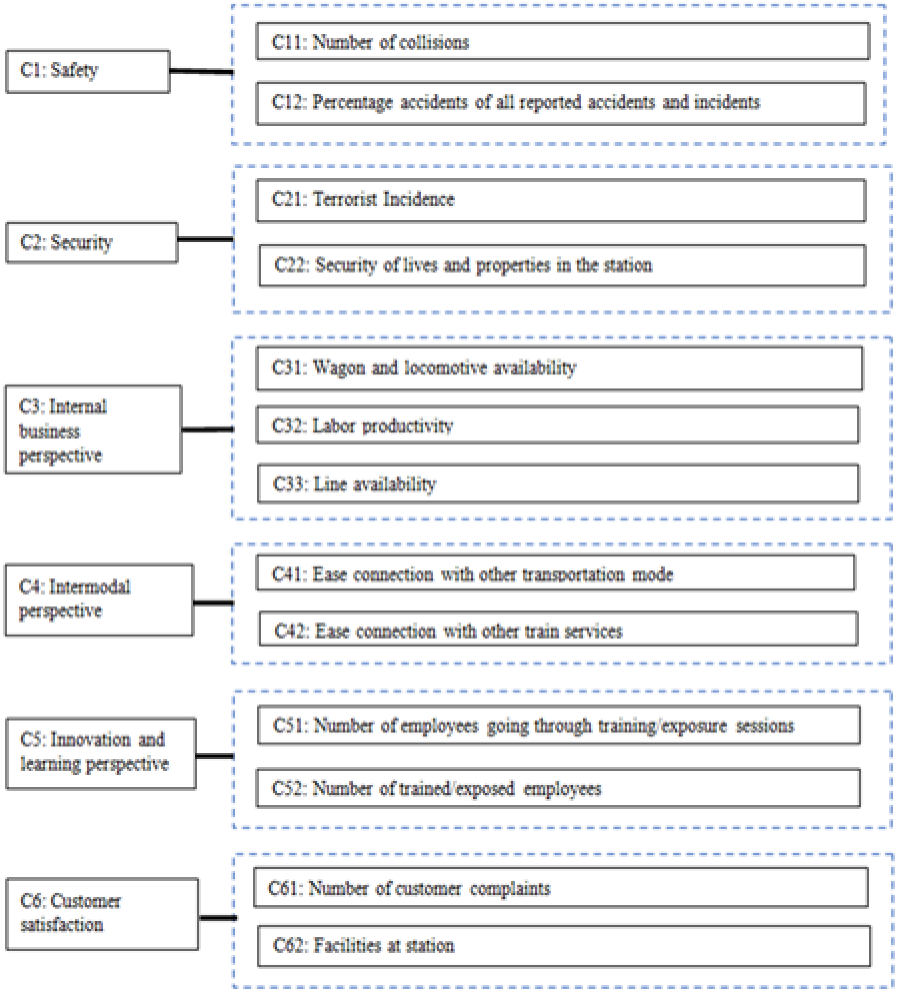


Figure 3. Performance indicators for railway system measurement

Intermodality is the involvement of diverse transportation modes for travel. As consequence, the construction of stations of different types of public transport modes such as rail, airport, and bus should be close to each other. By preference, they should just step away, which makes it convenient for the traveler to link with other transport means. The KPIs for intermodal perspective are shown in Figure 3.

Innovation and learning perspective is considered as the design and application of the business management initiatives emphasized by the company that foster increased innovation and learning among the workforce. The sector in most Africans has endured deterioration with regards to high profile personnel. The KPIs for innovation and learning criteria are shown in Figure 3.

Customers' satisfaction has mostly been ignored in the existing African rail transport system due to poor facilities. The satisfaction of commuters should become a preference and vital for sustainable railway development since under normal cases, transport services are required by commuters. As consequence, in the case of dissatisfaction, they will refer to other modes of transport. The KPIs for customer satisfaction are shown in Figure 3.

Among these criteria, the number of collisions, the recorded accidents and incidents, the terrorist incidence, and the number of customer complaints are criteria of underestimate type and are included in the cost group. Meanwhile, others are criteria of interest type, i.e. they need to be enhanced.

3.1.3. Forming a multi-criteria model

Based on criteria associated with the KPIs, experts from different countries have evaluated each criterion based on the linguistic scale (Table 1) to make a decision matrix (Table 2).

Table 1. Linguistic scale for the evaluation of alternatives depending on the type of criteria

Criteria	scale
1	Very poor-VP
2	Poor -P
3	Medium poor-MF
4	Fair -F
5	Medium good -MG
6	Good-G
7	Very good-VG

Table 2. Decision matrix

	A1	A2	A3	A4	A5
	CAM	NIG	GHA	ETH	KEN
C11	3	3	3	2	2
C12	3	3	2	2	2
C21	3	3	2	2	1
C22	4	4	5	6	6
C31	4	4	2	5	5
C32	4	4	2	6	5
C33	2	2	3	4	5
C41	2	2	2	2	4
C42	2	2	4	3	4
C51	4	4	2	6	5
C52	4	4	3	5	5
C61	4	4	4	4	4
C62	4	4	3	5	4

Note: CAM (Cameroon), NIG (Nigeria), GHA (Ghana), ETH (Ethiopia), KEN (Kenya)

3.2. Methods

The entropy- MARCOS model is implemented in two steps. In the first step, the determination of criteria weights is done using the entropy model (Shannon, 1948) right after their evaluation by experts. In the second step, these weight coefficients are employed to rank alternatives through the MARCOS model. In the following sections (sections 3.2.1 and 3.2.2), the steps of the entropy and MARCOS model are presented.

3.2.1. Entropy method

The entropy method, originally obtained from thermodynamics (Clausius, 1865), and employed to examine the irremediable situation of a procedure (Mon, Cheng, & Lin, 1994), is a means of ambiguity in information produced regarding the hypothesis of the probability. The entropy theory is firstly initiated by Shannon (1948) as a concept to determine weights in an objective manner(Zou, Yi, & Sun, 2006). It includes successive steps:

At first, the initial matrix is normalized through Equation (1).

$$r_{ij} = x_{ij} / \sum_{i=1}^{m} x_{ij} \quad (1)$$

Where r_{ij} stands for normalized values and x_{ij} represents primary decision-making matrix values.

Secondly, equation (2) is employed to compute the entropy measure e_j

$$e_j = -\frac{1}{\ln(m)} \sum_{i=1}^{m} r_{ij} \ln(n_{ij}) \quad (2)$$

Where *m* stands for the number of alternatives.

Thirdly, equation (3) is used to compute the criterion weight w_j

$$w_j = (1 - e_j) / \sum_{j=1}^{n} (1 - e_j) \quad (3)$$

where n stands for criteria quantity

3.2.2. MARCOS method

The MARCOS method depends on the interaction between ideal and anti-ideal options and alternatives. Regarding the established correlations, the beneficial functions of options are settled and the compromise classification is produced according to both options. The beneficial function is the location of an alternative concerning both options. The best option is the one that is the nearest to ideal and concomitantly the anti-ideal mentioning point. The MARCOS method is performed through the following steps (Đalić et al., 2020; Mitrović Simić et al., 2020; Puška, Stević, & Stojanović, 2021; Stanković et al., 2020; Stević & Brković, 2020; Puška, & Chatterjee, 2020; Stević, Tanackov, & Subotić, 2020):

Step 1: Initial decision-making matrix creation through the evaluation by experts.

Step 2: Extended initial matrix modeling through the setting of the ideal (AI) and anti-ideal (AAI) solution.

$$X = \begin{matrix} & C_1 & C_2 & \dots & C_n \\ AAI & x_{aa1} & x_{aa2} & \dots & x_{aan} \\ A_1 & x_{11} & x_{12} & \dots & x_{1n} \\ A_2 & x_{21} & x_{22} & \dots & x_{2n} \\ \dots & \dots & \dots & \dots & \dots \\ A_m & x_{m1} & x_{22} & \dots & x_{mn} \\ AI & x_{ai1} & x_{ai2} & \dots & x_{ain} \end{matrix} \quad (4)$$

The anti-ideal solution (AAI) is the least effective option while the ideal solution (AI) represents the best option. Regarding the criteria aspect, equations (2) and (3) are respectively applied to determine the AAI and AI:

$$AAI = \min_i x_{ij} \quad if \;\; j \in B \quad and \quad \max_i x_{ij} \quad if \;\; j \in C \quad (5)$$

$$AI = \max_i x_{ij} \quad if \;\; j \in B \quad and \quad \min_i x_{ij} \quad if \; j \in C \quad (6)$$

where there is benefit group criteria (B) and cost group criteria (C)

Step 3: Extended initial matrix normalization (X). In this step, equations (7) and (8) are used to get the components of the normalized matrix: N= $[n_{ij}]_{m\times n}$

$$n_{ij} = \frac{x_{ai}}{x_{ij}} \text{ if j} \in \text{C} \quad (7)$$

$$n_{ij} = \frac{x_{ij}}{x_{ai}} \text{ if j} \in \text{B} \quad (8)$$

where x_{ij} and x_{ai} are the components of the matrix *X*

Step 4: Weighted matrix V= $[v_{ij}]_{m\times n}$calculation through equation (9) multiplying the normalized matrix *N* with the weight coefficients of the criterion w_j

$$v_{ij} = n_{ij} \times w_j \quad (9)$$

Step 5: Computation of utility degree Ki, using equations (10) and (11) concerning the anti-ideal and ideal options.

$$K_i^- = \frac{S_i}{S_{aai}} \quad (10)$$

$$K_i^+ = \frac{S_i}{S_{ai}} \quad (11)$$

where S_i (i=1, 2,..., *m*) stands for the aggregates of the components of the weighted matrix *V*, and calculation through equation (12)

$$S_i = \sum_{i=1}^{n} v_{ij} \quad (12)$$

Step 6: Use equation (13) to compute the utility function of alternatives f (Ki). The utility function is the arrangement of the detected option concerning both solutions.

$$f\ (K_i) = \frac{K_i^+ + K_i^-}{1 + \frac{1-f(K_i^+)}{f(K_i^+)} + \frac{1-f(K_i^-)}{f(K_i^-)}}; \quad (13)$$

where $f(K_i^-)$, the utility function (anti-ideal solution, see equation 14) and $f(K_i^+)$, the utility function (ideal solution, see equation 15)

$$f(K_i^-) = \frac{K_i^+}{K_i^+ + K_i^-} \tag{14}$$

$$f(K_i^+) = \frac{K_i^-}{K_i^+ + K_i^-} \tag{15}$$

Step 7: Classification of the alternatives according to the utility function results. Alternative with greater utility function value is advisable.

4. Results and discussion

4.1 Entropy method

The entropy method is used for the determination of weights for each criterion. At first, equation (1) is employed to normalize the decision matrix (Table 3) for profitable and non-profitable criteria, respectively. Then, the determination of entropy measures of each criterion is made. Next, equations (2) and (3) are used for the weight calculation (Table 4). The results from Table 4 showed that labor productivity (internal business perspective) is the most significant criterion with a higher value (0.138). This is understandable because most considerable growth in resources is predicted from it. This is succeeded by the terrorist incidence (security) which is a non-profitable criterion at a value of 0.133. The quantity of employees that are exposed to the training (innovative and learning viewpoint) which is of beneficial type comes in the third position with a value of 0.114. The other criteria are classified as follows: C31 (benefit type) > C41 (benefit type) > C42 (benefit type) > C33 (benefit type) > C52 (benefit type) > C12 (cost type) > C11 (cost type) > C62 (benefit type) > C22 (benefit type) > C61 (cost type).

Table 3. Normalized matrix

	A1	A2	A3	A4	A5
C11	0.231	0.231	0.231	0.154	0.154
C12	0.250	0.250	0.167	0.167	0.167
C21	0.273	0.273	0.182	0.182	0.091
C22	0.160	0.160	0.200	0.240	0.240
C31	0.158	0.211	0.105	0.263	0.263
C32	0.150	0.200	0.100	0.300	0.250
C33	0.176	0.118	0.176	0.235	0.294
C41	0.167	0.167	0.167	0.167	0.333
C42	0.133	0.133	0.267	0.200	0.267
C51	0.227	0.182	0.091	0.273	0.227
C52	0.261	0.174	0.130	0.217	0.217
C61	0.238	0.190	0.190	0.190	0.190
C62	0.238	0.190	0.143	0.238	0.190

Table 4 Entropy values and entropy weights

	Entropy value	Entropy weight
C11	0.989	0.039
C12	0.987	0.043
C21	0.961	0.133
C22	0.990	0.034
C31	0.969	0.107
C32	0.960	0.138
C33	0.972	0.095
C41	0.970	0.103
C42	0.972	0.096
C51	0.967	0.114
C52	0.984	0.054
C61	0.997	0.009
C62	0.990	0.035

4.2. MARCOS method

Table 5 shows the extended initial matrix based on step 2 of the MARCOS approach through equations (4)– (6). The rate of collisions (C11), the terrorist incidence (C21), and the number of customer complaints (C61) are of a non-profitable type and using equation (5), the anti-ideal solution (AAI) has been calculated and represents the maximum attribute, with a value of 3 for C11, C12, and C21, and a value of 5 for C61.

Table 5. Extended initial decision matrix

Criteria	AAI	A1	A2	A3	A4	A5	AI
C11	3	3	3	3	2	2	2
C12	3	3	3	2	2	2	2
C21	3	3	3	2	2	1	2
C22	4	4	4	5	6	6	6
C31	2	3	4	2	5	5	5
C32	2	3	4	2	6	6	6
C33	2	3	2	3	4	5	4
C41	2	2	2	2	2	4	2
C42	2	2	2	4	3	4	3
C51	2	5	4	2	6	6	6
C52	3	6	4	3	5	6	5
C61	5	5	4	4	4	4	4
C62	3	5	4	3	5	5	5

For the security of human being and belongings in the station (C22), the wagon and locomotive availability (C31), the labor productivity (C32), the line availability (C33), the ease of connection with another transportation mode (C41), the ease connection with other train services (C42), the number of employees for training/exposure sessions (C51), quantity of trained/exposed employees (C52), and the facilities at station (C62), 4, 2, and 3 are the lowest values for (C22); (C31, C32, C33, C41, C42, C51); and (C52, C62) respectively and are involved in the AAI solution. The determination of values comprised of the ideal solution (AI) is made using equation (6). The values of 2, 1, and 4 are the smallest ones for (C11, C12), (C21), and (C61), whereas 6, 5, and 4 are the highest ones for (C22, C32, C51, C52), (C31, C33, C62), and (C41, C42), respectively for non-beneficial type (cost). Following the extension of the initial matrix, equation (7) is used for the normalization of non-profitable type while equation (8) is applied in the case of the profitable type. Table 6 illustrated the normalization of the decision matrix.

$n_{ij} = \frac{x_{ai}}{x_{ij}}$ if j ∈ C ↔ n_{111} =2/3=0.667, for non-beneficial type

$n_{ij} = \frac{x_{ij}}{x_{ai}}$ if j ∈ B ↔ n_{442} =3/4=0.750, for benefit type

Table 6. Normalized decision matrix

	AAI	A1	A2	A3	A4	A5	AI
C11	0.667	0.667	0.667	0.667	1.000	1.000	1.000
C12	0.667	0.667	0.667	1.000	1.000	1.000	1.000
C21	0.333	0.333	0.333	0.500	0.500	1.000	1.000
C22	0.667	0.667	0.667	0.833	1.000	1.000	1.000
C31	0.400	0.600	0.800	0.400	1.000	1.000	1.000
C32	0.333	0.500	0.667	0.333	1.000	0.833	1.000
C33	0.400	0.600	0.400	0.600	0.800	1.000	1.000
C41	0.500	0.500	0.500	0.500	0.500	1.000	1.000
C42	0.500	0.500	0.500	1.000	0.750	1.000	1.000
C51	0.333	0.833	0.667	0.333	1.000	0.833	1.000
C52	0.500	1.000	0.667	0.500	0.833	0.833	1.000
C61	0.800	0.800	1.000	1.000	1.000	1.000	1.000
C62	0.600	1.000	0.800	0.600	1.000	0.800	1.000

The weight normalized matrix is then computed through the multiplication of the precedent normalized matrix by the alternatives/ criteria values acquired in the entropy approach. Table 7 indicates the normalized weighted matrix.

Table 7. Weight normalized decision matrix

	AAI	A1	A2	A3	A4	A5	AI
C11	0.026	0.026	0.026	0.026	0.039	0.039	0.039
C12	0.029	0.029	0.029	0.043	0.043	0.043	0.043
C21	0.044	0.044	0.044	0.067	0.067	0.133	0.133
C22	0.023	0.023	0.023	0.028	0.034	0.034	0.034
C31	0.043	0.064	0.085	0.043	0.107	0.107	0.107
C32	0.046	0.069	0.092	0.046	0.138	0.115	0.138
C33	0.038	0.057	0.038	0.057	0.076	0.095	0.045
C41	0.052	0.052	0.052	0.052	0.052	0.103	0.103
C42	0.048	0.048	0.048	0.096	0.072	0.096	0.096
C51	0.038	0.095	0.076	0.038	0.114	0.095	0.114
C52	0.027	0.054	0.036	0.027	0.045	0.045	0.054
C61	0.007	0.007	0.009	0.009	0.009	0.009	0.009
C62	0.021	0.035	0.028	0.021	0.035	0.028	0.035

Through the MARCOS approach, the final results have been obtained in Table 8 with the application of equations from (10) to (15). The summarization of all values for the alternatives (by rows) is shown below through equation (12).

S_{AAI}=0.026+0.029+0.044+0.023+0.043+0.046+0.038+0.052+0.048+0.038+0.026+0.007+0.021=0.441

At the same time, the values for the remained alternatives are procured. The calculation of the utility of degree concerning the anti-ideal solution is done through equation (10). An illustration calculation is shown bellows.

$$K_1^- = \frac{0.602}{0.441} = 1.365$$

Meanwhile, the utility degrees concerning the ideal solution are acquired by applying equation (11), e.g.:

$$K_1^+ = \frac{0.601}{1} = 0.602$$

Equation (14) is used to set the utility function regarding the anti-ideal solution as follows:

$$f(K_i^-) = \frac{K_i^+}{K_i^+ + K_i^-} = \frac{0.602}{0.602 + 1.365} = 0.306$$

At the same time, equation (15) is used for the utility function regarding the ideal solution as follows:

$$f(K_i^+) = \frac{K_i^-}{K_i^+ + K_i^-} = \frac{1.365}{0.602 + 1.365} = 0.694$$

At last, equation (13) is used to get the utility function of Alternative A1:

$$f\ (K_i) = \frac{K_i^+ + K_i^-}{1 + \frac{1 - f(K_i^+)}{f(K_i^+)} + \frac{1 - f(K_i^-)}{f(K_i^-)}} = \frac{0.602 + 1.365}{1 + \frac{1 - 0.694}{0.694} + \frac{1 - 0.306}{0.306}} = \frac{1.967}{1 + 0.442 + 2.268} = \frac{1.967}{3.709} = 0.531$$

The remained values that appeared in the final results are got identically as elucidated in Table 8.

Based on the results of the new integrated method, the performance evaluation showed that the alternative with code 5 (Kenya) has the best performance followed by alternatives under codes 4 and 1 (Ethiopia and Cameroon) in the classification, respectively. A look in the classification showed that no much difference exists between the third and fourth positions and a variation in the classification can be predicted for future evaluation based on expert judgment. Although the railway system in Nigeria is being rejuvenated through the construction of new standard gauge railway lines, its railway performance is lower in comparison to Cameroon.

This can be explained by the fact that there are security challenges, poor facilities at a station in the old railway networks, and a higher rate of commuter complaints.

Table 8 Finding of the MARCOS approach.

	S_i	K_{i-}	K_{i+}	f_{K-}	f_{K+}	f_{Ki}	Rank
AAI	0.441	1.000					
A1	0.602	1.365	0.602	0.306	0.694	0.531	3
A2	0.586	1.327	0.586	0.306	0.694	0.516	4
A3	0.553	1.252	0.553	0.306	0.694	0.487	5
A4	0.830	1.880	0.830	0.306	0.694	0.731	2
A5	0.942	2.135	0.942	0.306	0.694	0.830	1
AI	1.000		1.000				

5. Sensitivity analysis

A comparative evaluation is carried with other seven methods: EDAS – evaluation based on distance from average solution (Keshavarz Ghorabaee et al., 2015), SAW – Simple Additive Weighting method (Kishore et al., 2020, Durmić et al. 2020), ARAS – additive ratio assessment (Zavadskas & Turskis, 2010), CoCoSo - Combined Compromise Solution (Yazdani et al., 2019), MABAC – Multi-Attributive Border Approximation area Comparison (Pamučar & Ćirović, 2015, Pamučar et al. 2021), TOPSIS – Technique for Order of Preference by Similarity to Ideal Solution (Anthony et al., 2019), and WASPAS – weighted aggregated sum product assessment (Zavadskas et al., 2012).

The results of this comparative analysis are shown in Figure 4. As can be seen from it, there were certain changes in the ranks, which is a consequence of a diverse normalization approach in applying other approaches. As consequence, one of the sources of variations in the rankings is emulated in a very small variation in the values of some alternative solutions obtained in the initial model. A look at Figure 5 indicates that the greatest alternative does not vary from its initial position whichever method is applied. As consequence, the fifth alternative keeps its first place. The second place is assigned to the fourth alternative for all the methods, with exception of TOPSIS, where it takes the fourth place. There is no variation in position for all the alternatives when using the MARCOS, WASPAS, ARAS, EDAS, and SAW approaches. However, when using MABAC and the five antecedent methods, there is only one variation in the classification where A2 and A3 replace their positions occupying the fifth and the fourth place, respectively.

When applying the MARCOS and CoCoSo methods for a comparative analysis for the classification, some moderate variations are noticed whereas in the case of the TOPSIS method, the variation in the classification is a little bit more.

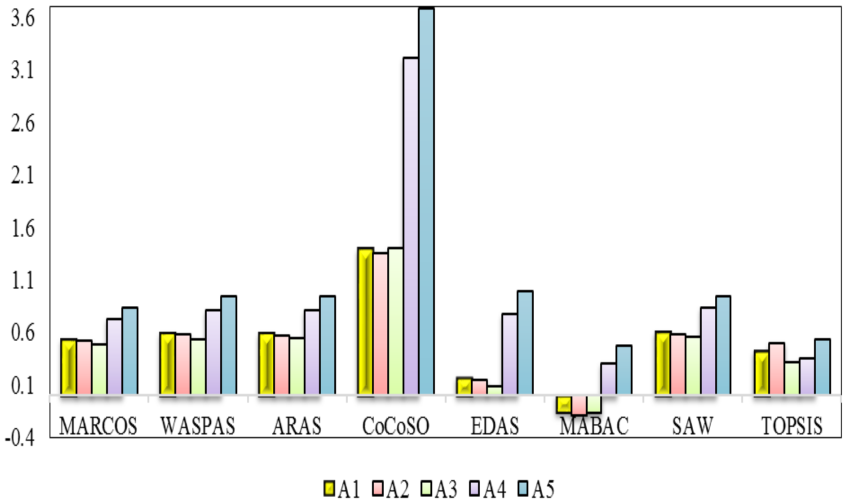


Figure 4. Values of alternatives through a comparative analysis

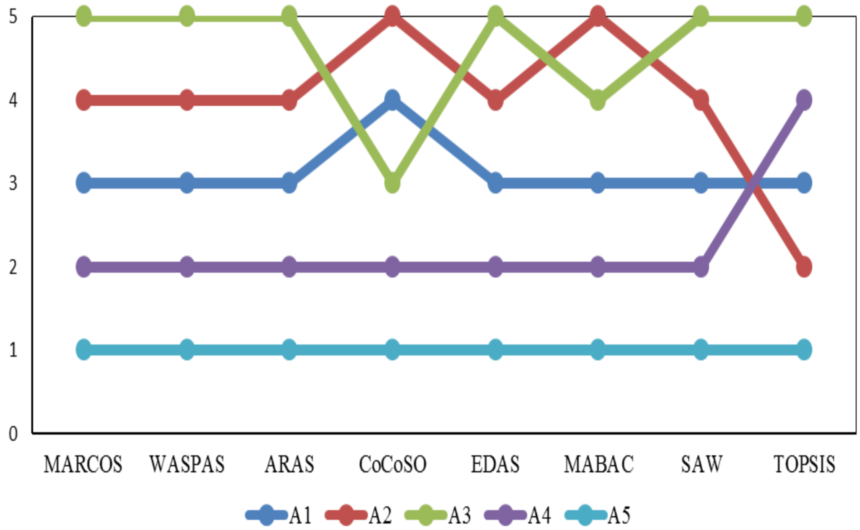


Figure 5. Ranking in a comparative analysis of different methods

The WS coefficient developed by Salabun and Urbaniak (2020) was computed to examine the rankings similarity as shown in Figure 6. The benefit of this coefficient relies on the fact that locations at the summit of the classification have a powerful influence on the similarity than those more distant, which is accurate in the process of decision making.

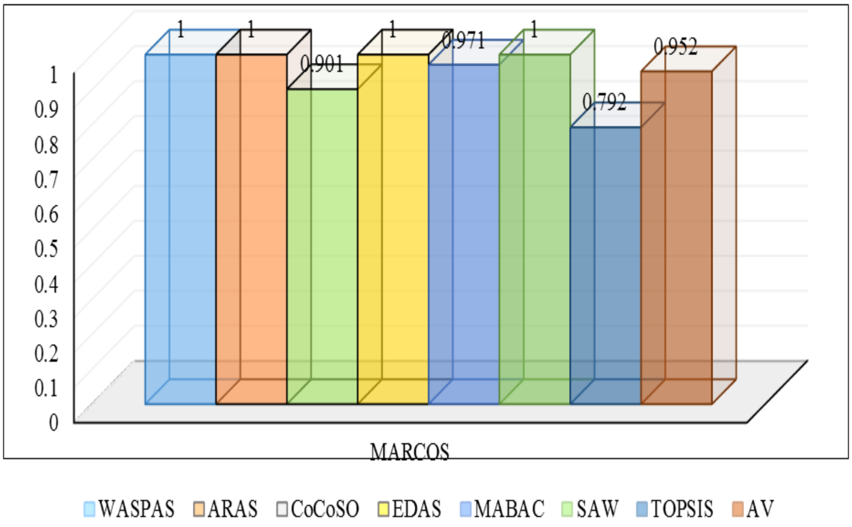


Figure 6. Determination of the WS coefficient

As can be seen in Figure 6, the previous discussion where the WS coefficient has values 1 (WASPAS, ARAS, EDAS, and SAW), and 0.971 (MABAC) show an extremely high correlation in ranking alternatives. A little bit of correlation of MARCOS method with CoCoSo exists and the value is 0.901, whereas the difference is large for MARCOS method in comparison to the TOPSIS method, i.e., the smallest correlation with a value of 0.792.

6. Conclusion

In this paper, an assessment of Sub-Saharan African railways performance was conducted. A multi-criteria model consisting of six main criteria and five alternatives was formed. For their evaluation, a new integrated Entropy-MARCOS model was proposed and applied. The results showed that labor productivity is the most weighted sub-criterion. Considering the ranking of the railway's performance, Kenya is the best alternative with a higher utility function value of 0.830 followed by Ethiopia with 0.731 as the utility function value. Cameroon and Nigeria came in the third and fourth positions with approximately the same utility function value of 0.531 and 0.516, respectively. Ghana represents the worst alternative with the lowest utility function value of 0.487. The results obtained in the paper were validated through an extensive sensitivity analysis. The findings of this paper can assist decision-makers to consider these parameters as insert indicators for all operative, designing, and planning investigations. In addition, the findings can also serve as a benchmark for the performance analysis of other railway systems in other African countries.

The continuity of this study pertains to the incessant surveying and repeated assessment of the railway transportation system in the sub-Saharan Africa region together with the newly built standard gauges' railways across the region, which can contribute to the socio-economic and regional inter-trade integration and wealth of the region. Although a new integrated entropy-MARCOS is proposed in this research, the future study may apply the use of integrated FUCOM- MARCOS, fuzzy PIPRECIA-DEA, Delphi-SWARA-MABAC, and fuzzy-AHP for the evaluation of railway transportation system or factors that impede its sustainability. Also, the analysis of the railway system should be at the continental level.

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