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# AFRICA ACCESSIBILITY ENHANCEMENT THROUGH CROSS BORDER HIGHWAY AND RAILWAY EXPANSION

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**ABSTRACT**

Efficacious transportation facilitates tourism, trade and commerce. Developing countries often are facing transportation constraints such as inadequacy of infrastructures, institutions and regulations. Global competition for Africa natural resources has brought it under spotlight when this continent is confronting numerous political, social, environment, economic and humanitarian crises. Majority of African countries, with immense development potentials and resources, are facing inadequate land transportation facilities. More than a century of deprivation and insufficient investment in land transportation infrastructure has led to poor accessibility among most of African countries. The objective of the study reported herein was to address and appraise land transportation in Africa, focusing on its intra-continent and cross border attributes. To assess land transportation in Africa, firstly the information about existing rail and road links were collected and their regional sub-networks were defined. To complete these sub-networks, the marine links between the important seaports were added. Subsequently, the Africa continent land-sea network was characterized. This resulted in two multimodal sub-networks: rail-sea and road-sea. In the second step, the multimodal sub-networks were modeled and deployed in the form of adjacency matrices and a number of preliminary network analyses were performed. For these sub-networks, deploying network algorithms such as shortest-path, several accessibility and connectivity indices were defined and computed. To improve the accessibility of these land-sea multimodal sub-networks and to introduce efficacious trade corridors, few cross border and key land links were identified and evaluated. The proposed and expanded sub-networks were then compared with the existing sub-networks. Significant accessibility enhancement was achieved by proposed highway and railway expansions. This study is a preliminary step in appraising Africa regional transportation that could be conducive to domestic and international trade and travel facilitation and integration. Africa member states and international agencies may utilize the study approach and findings to enrich regional trade, commerce and tourism.

**Keywords:** Africa transportation, regional network, sustainable transportation, railways, highways, seaways, accessibility and connectivity.

## INTRODUCTION

Because of increasing growth in global trade and commerce, the role of transportation to facilitate and achieve national economic and social goals has become more evident than ever. The developing countries are facing several limitations such as lack of transportation infrastructures and non-uniform transportation regulations (Black, 2003). Africa is mostly consisted of developing countries with numerous opportunities and resources despite under developed and inefficient land transportation. Indeed, geography causes African countries to experience an inherent chronological remoteness (Debrie, 2010; Naude, 2009). Africa regional sustainable development of transportation infrastructure is essential when national incentives may not be symmetrical (Rasafi and Vaziri, 2003). Guidelines for transportation sustainable development could be established through pertinent cross border corridor analysis, design and development.

This study focuses on Africa intra-continent land transportation to facilitate sustainable development, bringing the continent closer together and reduce human impedance factors. Although efficacious transportation on and off the continent is both important for sustainable development, trade among African states can be fostered through cross border and intra-continent highway and railway expansion. Improving the land connectivity between north, central and south will be conducive to growth in tourism, trade and commerce, and will be an essential step for a progressive Africa. In this context, enhancing of the land connectivity of Africa east and west will also enrich continent and sub-regional economy.

The transportation networks in this study consisted of two multimodal sub-networks: road-sea sub-network, ROSS, and rail-sea sub-network, RASS. The total length of identified ROSS was around 146,000 km which around 69,000 km were road links. The total length of identified RASS was around 113,000 km which around 51,000 km were rail links. Compare to other continents, Africa is unique when the ROSS and RASS are rather separate and disconnected. Beside significant modal disconnectivity, railway development during colonial era has resulted in further technical complexity and limitations, such as presence of three gauges between Egypt and South Africa. To improve accessibility of these multimodal sub-networks, for ROSS, addition of 3 corridors, and for RASS, addition of 1 corridor, were suggested and evaluated. By adding these corridors the length of proposed road-sea sub-network, PROSS, and proposed rail-sea sub-network, PRASS, would increase to around 157,000 km and 116,000 km, respectively.

As most of the past studies, in this study, network structure was defined as a set of nodes and links. Subsequently, a number of factors and indices were defined for its appraisal (Hurst, 1974). Connectivity indicates the existence of a path or route, a sequence of distinct nodes connected by links, between any pair of origin and destination nodes of a network. Accessibility reflects the possibility and ease of getting from one node to another node of a network. A number of network relevant connectivity and accessibility indices have been defined based on graph theory (Berdica, 2002; Bhai et al, 2000). These indices have been developed to analyze regional transportation network structure (Bondy and Murty, 1976; Vaziri, 2005; Vaziri and Omrani, 2011). In this study, Africa regional land-sea network was appraised utilizing several indices associated with accessibility and connectivity. The assessment was based on present and proposed multimodal sub-networks. The accessibility could be significantly enhanced through proper cross border highway and railway expansions. The expanded land network would be conducive to domestic and international trade and tourism facilitation.

## DATABASE DEVELOPMENT

After preliminary appraisal of several new alternative land corridors, four networks were analyzed in detail: existing and proposed road-sea sub-networks, and existing and proposed rail-sea sub-networks. For road-sea sub-network, three north-south corridors in north of African continent were considered for addition to the existing sub-network, creating an expanded and proposed road-sea sub-network. One corridor, with two segments of east-west and north-south, was considered for addition to the rail-sea sub-network. Due to lack of historical rail road development, the Africa rail-sea sub-network is scattered, and to create a connected regional rail sub-network, ideally more than twenty thousand kilometers of railways should be constructed. In this study a rather short railway corridor that seemed to have critical effect on the continent accessibility and in short term financially feasible to construct, has been considered. The characteristics of the study rail and road sub-networks are listed in Tables 1 and 2, and their locations are displayed in Figures 1 and 2, respectively. The proposed corridors in the two figures are shown in color. The proposed road-sea sub-network expansion length was around 4 times as of rail-sea sub-network expansion length. The proposed corridors are neither unique nor optimal; they are reasonable expansion links to enhance accessibility. Future deployment of network operation research and system analysis techniques can provide further clues of the network optimal scenarios and expansions.

Table 1 shows that the Africa's road-sea sub-networks ROSS and PROSS cover 48 countries with a population of more than 931 million. The 278 nodes, consisting of major cities, roadway or seaway connection points and activity centers, and 300 roadway links plus 56 seaway links are the main components of existing sub-network ROSS. The proposed sub-network PROSS has in addition to ROSS, 7 nodes and 14 roadway links with a total additional length of around 11,706 km. Table 2 shows that the Africa's rail-sea sub-networks RASS covers 34 countries with a population of more than 853 million. The 317 nodes, consisting of major cities, railway or seaway connection points and activity centers, and 354 railway links plus 36 seaway links are the main components of existing sub-network RASS. The proposed sub-network PRASS has in addition to RASS, a country with population of 10 million, 2 nodes and 5 railway links with a total additional length of around 2745 km.

**Table 1. Characteristics of Africa's road-sea sub-network**

| **Sub-network** | **ROSS** | **PROSS** |
|---|---|---|
| Countries | 48 | 48 |
| Covered population in million | 931.2 | 931.2 |
| Number of nodes | 278 | 285 |
| Number of land links | 300 | 314 |
| Number of road+sea links | 356 | 370 |
| Length of road links in km | 68,997 | 80,703 |
| Length of road+sea links in km | 145,594 | 157,300 |

**Table 2. Characteristics of Africa's rail-sea sub-network**

| Sub-network | RASS | PRASS |
|---|---|---|
| Countries | 34 | 35 |
| Covered population in million | 853.3 | 863.2 |
| Number of nodes | 317 | 319 |
| Number of land links | 354 | 359 |
| Number of rail+sea links | 390 | 395 |
| Length of rail links in km | 50,701 | 53,446 |
| Length of rail+sea links in km | 113,158 | 115,903 |

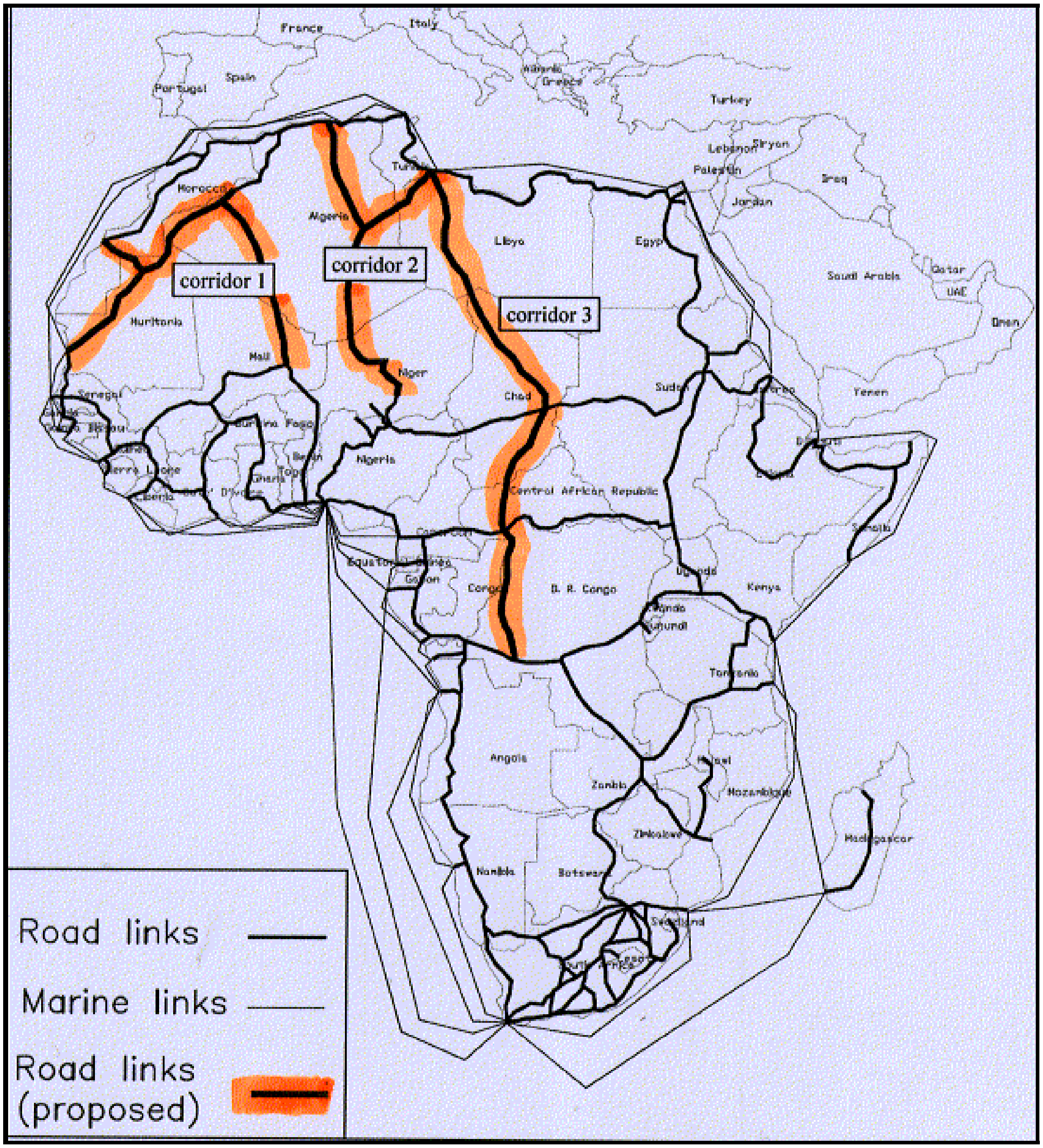


**Figure 1. Africa's road-sea sub-network (ROSS, PROSS)**

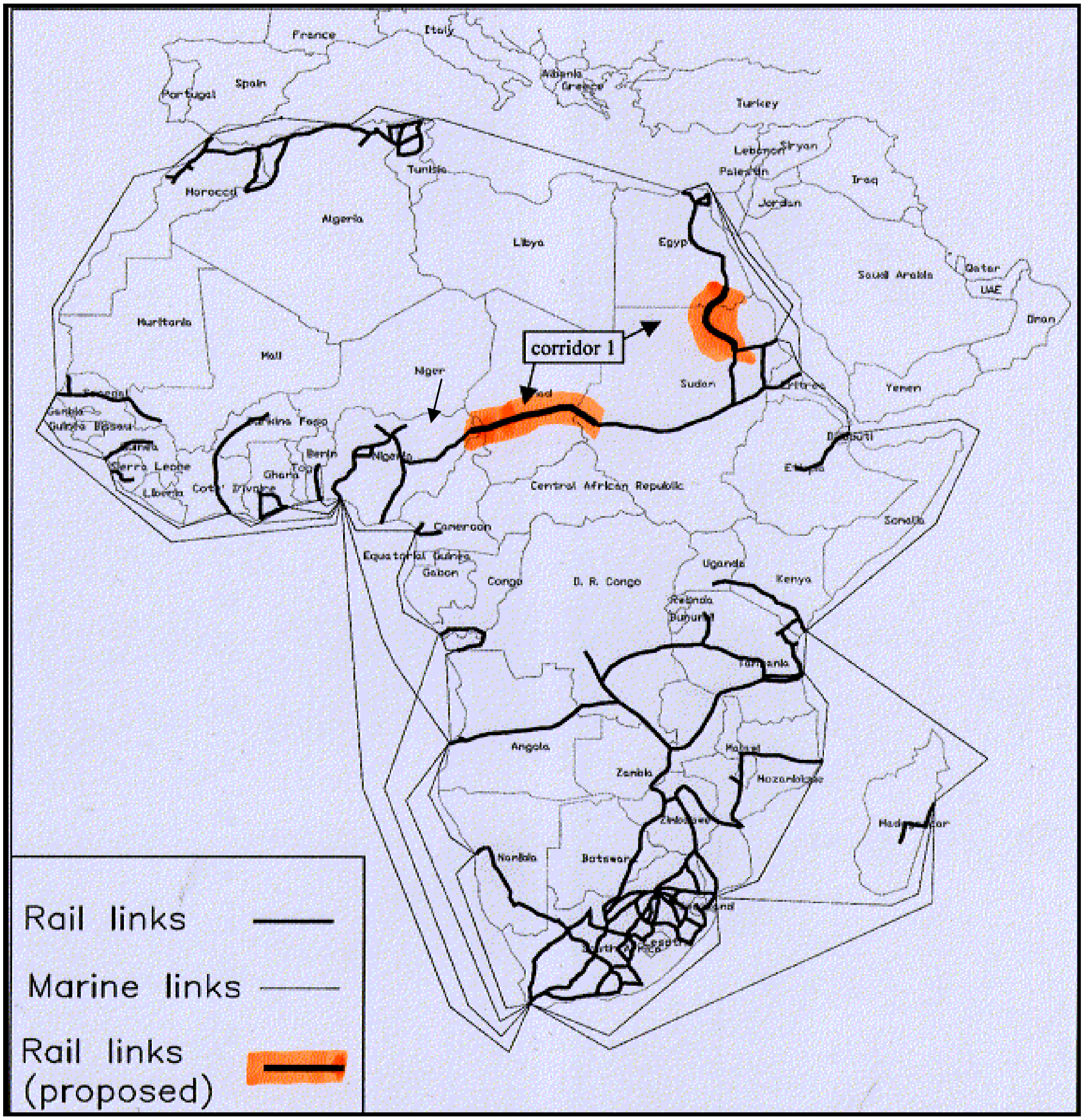


**Figure 2. Africa's rail-sea sub-networks (RASS, PRASS)**

After defining the rail-sea and road-sea sub-networks in Africa, their two metric adjacency matrices were created and analyzed. The adjacency matrix of a network with N nodes and L links is a NxN matrix with link distances are matrix cell entries. When there is no link between any node pair, a very large number is often used for their link distance.

**CONNECTIVITY APPRAISAL**

Connectivity is a key characteristic of a transportation network that indicates the existence of a path or route, a sequence of distinct nodes connected by their links, between any pair of nodes in a network. Africa road sub-network, except for Madagascar Island, has complete land connection and any node can be reached by all other nodes via roadways. The added sea links connect Madagascar to the multimodal sub-network ROSS. The limited existing railways have resulted in several small and dispersed rail sub-networks feeding Africa key seaports for intercontinental freight shipment. Adding sea links to rail sub-network, results in a connected rail-sea sub-network RASS. Many nodes in RASS are connected only through combination of rail and sea links, and are not connected only with railway mode and links. Indeed, the sea links create the key connections among important seaports of ROSS and RASS as shown in Figures 1 and 2.

Among indices defined to explain network connectivity, α and β indices are calculated for sub-networks herein (Bhai et al, 2000). The β index measures the connectivity degree of network and is the ratio of the number of links, e, to the number of nodes, v.

$$\beta = e/v \qquad (1)$$

The β is often less than 1 in simple transportation networks. In a network with any given number of nodes, the higher the number of links the higher the number of possible routes. The β is higher in more complex transportation networks such as airway networks with many links.

The α index is another index for connectivity which evaluates the number of existing cycles u in a network with respect to maximum number of possible cycle 2v-5. Herein, a cycle is defined as a path in a network connecting a node to itself via at least 2 intermediate nodes, consisting of more than 2 links with only a single time passing through any intermediate node. The relation for the networks with a least 3 nodes becomes:

$$\alpha = \frac{u}{2v-5} \qquad (2)$$

Where u is the number of existing cycles and v is the number of network nodes. For tree and simple networks without any cycle, α equals to 0 and for completely connected networks this index equals to 1. A completely connected network has a link between any node pairs and a network with N nodes would have 0.5(N-1)(N) links. Table 3 shows the connectivity indices for ROSS and RASS. As expected, the sub-network indices showed that the ROSS is more connected than RASS. The table also shows the three countries with highest index values for ROSS and RASS. South Africa showed the highest rankings for both indices, reflected its superior domestic railway and roadway connectivity.

**Table 3. Connectivity indices in Africa's sub-networks**

| **α index** | | | | | |
|---|---|---|---|---|---|
| ROSS | | | RASS | | |
| Rank | country | value | Rank | country | value |
| 1 | South Africa | 0.149 | 1 | South Africa | 0.198 |
| 2 | Zambia | 0.091 | 2 | Tunisia | 0.172 |
| 3 | Kenya | 0.077 | 3 | Egypt | 0.151 |
| Total sub-network | | 0.152 | Total sub-network | | 0.122 |
| **β index** | | | | | |
| ROSS | | | RASS | | |
| Rank | country | value | Rank | country | value |
| 1 | South Africa | 1.261 | 1 | South Africa | 1.368 |
| 2 | Egypt | 1.074 | 2 | Egypt | 1.256 |
| 3 | Algeria | 1 | 3 | Tunisia | 1.235 |
| Total sub-network | | 1.298 | Total sub-network | | 1.238 |

For the proposed sub-networks, the ranking of countries did not change in the PROSS and PRASS. This was because the majority of expansions were cross border links. The effects of proposed network structural changes are shown in the Figure 3.

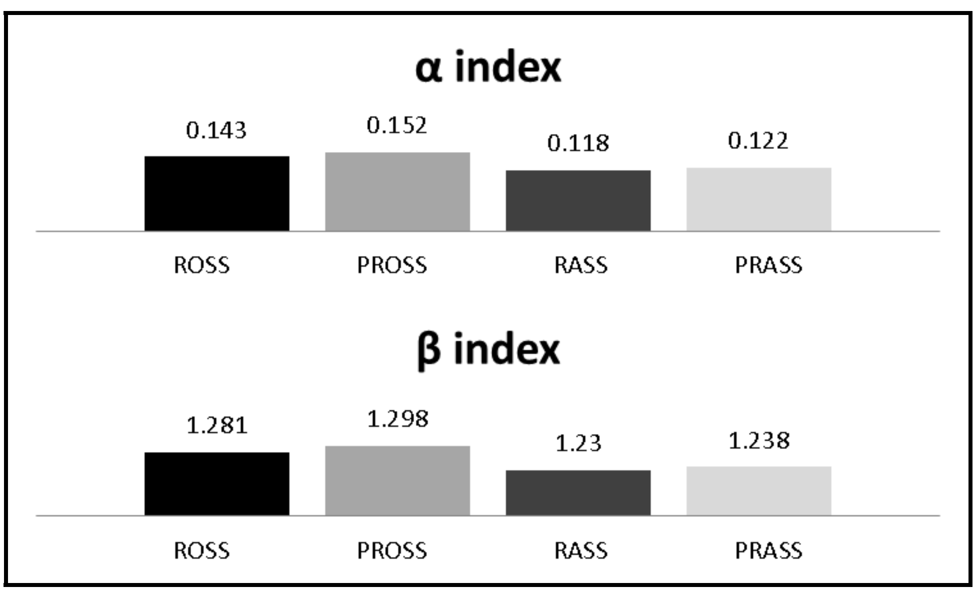


**Figure 3. Connectivity indices for Africa's sub-networks**

## ACCESSIBILITY APPRAISAL

For Africa rail-sea and road-sea sub-networks, several metric accessibility indices were computed and evaluated. These were indices that have been mostly used in past studies, and could furnish discrete or continuous values, easily estimated and understood (D'Este and Taylor, 2001; Lee, 1980; Murray-Tuite and Mahmassani, 2004; Vaziri, 2005). The node indices are defined in the literature as accessibility indices when accessibility decreases as they increase. In other words, they are actually inaccessibility indices with smaller values reflecting higher levels of accessibility. The finally selected accessibility indices in this study were: associate and accessibility numbers for nodes and importance number for links. These indices are neither standard, nor unique; nevertheless they are suggested as suitable for Africa sub-networks preliminary accessibility appraisal as reported herein.

The Associated number for a node i, $AS_i$, is the maximum of the "distances" from node i to all other nodes in a given network with the set of v nodes, excluding in the distance computation the non-existing links with the assumed very large values of the adjacency matrix. Indeed, the metric "distance" $d_{ij}$ of a node i to a node j is the length between these nodes in kilometer in the network shortest path from the node i to the node j. That is:

$$AS_i = \max(d_{ij}) \qquad \forall j \in V \tag{3}$$

Table 4 shows the minimum and maximum of the computed AS index for present road-sea and rail-sea sub-networks ROSS and RASS, and proposed PROSS and PRASS. The table shows nodes with the largest and smallest associate numbers for the four sub-networks. Table 4 shows that the minimum AS numbers computed in road-sea sub-networks were less than in rail-sea sub-networks. The maximum AS numbers or diameters of present and proposed sub-networks were the same. The diameter of road-sea sub-networks ROSS-PROSS was about 1600 kilometer less than rail-sea sub-networks RASS-PRASS. By adding the proposed corridors to ROSS the node with minimum AS, the central place, was changed from Sudan to Egypt and related value decreased by around 400 kilometer. Adding the proposed corridor to RASS caused that the central place changing from Sierra Leone to Cameron and the related value decreased by around 2400 kilometer. The 2400 kilometer decrease in AS number of central place in rail sub-network showed that the added corridor plays an important role in network accessibility enhancement when the RASS is highly disconnected via railway links.

**Table 4. Associated number for Africa's sub-networks**

| ROSS | | | RASS | | |
|---|---|---|---|---|---|
| | Node name | Value (km) | | Node name | Value (km) |
| Min | Alubayyid (Sudan) | 8180 | Min | Free town (Sierra Leone) | 11320 |
| Max | Mahajanga(Madagascar) - Agadir(Morocco) | 13606 | Max | Bechar (Algeria) - Nacala (Mozambique) | 15268 |
| **PROSS** | | | **PRASS** | | |
| | Node Name | Value (km) | | Node Name | Value (km) |
| Min | Ismailia (Egypt) | 7786 | Min | Douala (Cameron) | 8931 |
| Max | Mahajanga(Madagascar) - Agadir(Morocco) | 13606 | Max | Be char (Algeria) - Nacala (Mozambique) | 15268 |

In addition to the AS, the accessibility number, AC, was calculated and averaged at the country level. Accessibility number for a node i, $AC_i$, is the average of "distances" from node i to all other nodes in a given network with v nodes. The metric "distance" $d_{ij}$ of a node i to a node j is defined the same as for Equation 3. That is:

$$AC_i = \sum_{j \in V} d_{ij}/(v-1) \quad (4)$$

The average of node accessibility numbers for a given network at the continent, sub-region or country level, AAC, is an index reflecting the aggregate and average accessibility for the defined level and geographical scope. Table 5 shows the first 3 countries and last 3 countries in sub-networks according to AAC index ranking. The smaller values reflect superior accessibility.

**Table 5. Average accessibility index for Africa's sub-networks**

| ROSS | | | | RASS | | | |
|---|---|---|---|---|---|---|---|
| | Rank | Country | AAC (km) | | Rank | Country | AAC (km) |
| 3 first countries | 1 | Togo | 4658 | 3 first countries | 1 | Zambia | 5816 |
| | 2 | Benin | 4688 | | 2 | Tanzania | 6022 |
| | 3 | Equatorial Guinea | 4692 | | 3 | South Africa | 6103 |
| 3 last countries | 46 | Morocco | 7137 | 3 last countries | 32 | Malawi | 7527 |
| | 47 | Tunisia | 7143 | | 33 | Sudan | 7608 |
| | 48 | Algeria | 7282 | | 34 | Mali | 8085 |
| Total sub-network | | 5748 | | Total sub-network | | 6698 | |
| **PROSS** | | | | **PRASS** | | | |
| | Rank | Country | AAC (km) | | Rank | Country | AAC (km) |
| 3 first countries | 1 | Equatorial Guinea | 4342 | 3 first countries | 1 | Djibouti | 5574 |
| | 2 | Benin | 4349 | | 2 | Eritrea | 5594 |
| | 3 | Togo | 4364 | | 3 | Zambia | 5800 |
| 3 last countries | 46 | Swaziland | 6642 | 3 last countries | 33 | Morocco | 7451 |
| | 47 | Malawi | 6772 | | 34 | Malawi | 7517 |
| | 48 | Madagascar | 7038 | | 35 | Mali | 8015 |
| Total sub-network | | 5506 | | Total sub-network | | 6434 | |

The table shows that the country rankings are different for ROSS-PROSS when compared with RASS-PRASS, reflecting the significant differences in the history of roadway and railway development in African countries. The landlocked countries have none or inadequate railway networks when compared with countries with seaports. According to Table 5, the AAC for road-sea sub-networks ROSS-PROSS were less than for rail-sea sub-networks RASS-PRASS. As expected, this confirms that the African countries are more accessible by roadway than railway. In road-sea and rail-sea sub-networks, adding the proposed corridors lead to overall sub-network AAC's to decrease and improve accessibility of around 250 kilometers for all the network nodes. This occurred when the proposed road-sea sub-network PROSS expansion length was around 4 times as compared with rail-sea sub-network PRASS expansion length. By adding the corridors to ROSS the northern countries such as Morocco, Tunisia and Algeria became more accessible among African countries. Majority of countries with low AAC's are the countries that are more continent centrally located and are landlocked.

Importance number for a link, route or corridor, $IM_C$, is an index reflecting the importance of link, route or corridor failure and elimination in accessibility. For situations that link, route or corridor drop does not result in disconnected or separated networks, the increase of network average accessibility number, AAC, as defined by Equation 4, specifies importance number by:

$$IM_c = AAC_{-C} - AAC_{+C} \tag{5}$$

Where $AAC_{-C}$ and $AAC_{+C}$ are average accessibility numbers for the network without and with link, route or corridor C, respectively. Equation 5 applies to any link, route or corridor that its elimination will not result in disconnected networks. The $IM_C$ is always a nonnegative number. If a network disconnection is created due to link, route or corridor elimination, then the importance number is assumed to be a very large number and is not used to compare with abovementioned cases.

Figure 4 shows the ACC for existing road-sea sub-network with combination of proposed corridors. The effect of adding single, different combination of two, and three corridors on average accessibility index are shown in this figure. Table 5 also lists the AAC and $IM_c$ for the addition of proposed corridors.

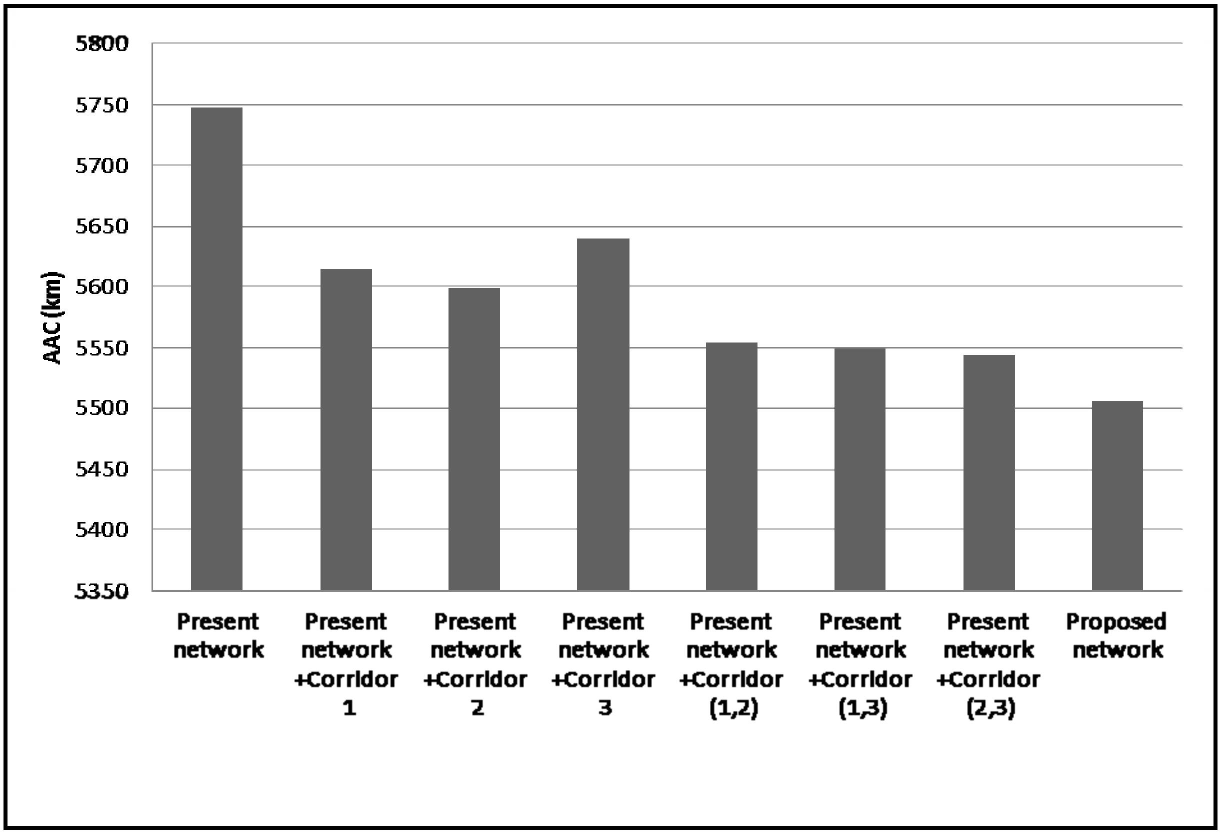


**Figure 4. Proposed corridor effects on average accessibility index**

**Table 6. Importance number for road sub-networks**

| Network | ROSS | ROSS+ Corridor 1 | ROSS+ Corridor 2 | ROSS+ Corridor 3 | ROSS+ Corridor (1,2) | ROSS+ Corridor (1,3) | ROSS + Corridor (2,3) | PROSS |
|---|---|---|---|---|---|---|---|---|
| AAC (km) | 5748 | 5615 | 5599 | 5640 | 5554 | 5550 | 5544 | 5506 |
| $IM_c$ (km) | - | 133 | 149 | 108 | 194 | 198 | 204 | 242 |
| Percent of AAC improvement | - | 2.31 | 2.59 | 1.88 | 3.38 | 3.44 | 3.55 | 4.21 |

As Figure 4 and Table 6 confirm, corridor 2, which is more centrally located than the other two corridors, results in more accessibility improvement. In combinations, adding corridor 3 to corridor 2 decreased AAC index more than adding corridor 1. According to $IM_c$ index, optimal network stage expansion strategy would be the construction of corridors 2, 3 and 1, respectively. Based on Table 6, adding corridor 2 to ROSS, will decrease AAC index of around 3%, and adding all proposed corridors will improve the continent accessibility index more than 4%. The accessibility improvement was found to be more for northern countries of Africa.

Another index is the potential accessibility index, which in addition to the distance between nodes, the importance of each node is also considered (Black, 2003; Vaziri, 2005). The importance can be any node characteristics such as population, economic or social characteristics. Population is one of the common characteristics used in this index. Potential accessibility matrix is not symmetrical because the deployed characteristics of different nodes are not the same. Two attributes of "attraction" and "emission or production" are used, and Equations 6 and 7 show their computations:

$$ACp_i^e = \sum_{\substack{j=1 \\ j\neq i}}^{n} P_j/d_{ij} \quad (6)$$

$$ACp_i^a = \sum_{\substack{j=1 \\ j\neq i}}^{n} P_i/d_{ij} \quad (7)$$

Where $P_i$ is an attribute of place i, such as population, $d_{ij}$ is the shortest distance between i and j. In this study, the emission and attraction potential accessibility indices, were calculated using node's population. Table 7 shows the value of $ACp^a$ and $ACp^e$ for the highest 3 capitals in the multimodal sub-networks.

**Table 7. Potential accessibility indices for Africa's sub-networks**

| $ACp^a$ (thousand persons/kilometer) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Rank | Country | ROSS | PROSS | Rank | Country | RASS | PRASS |
| 1 | Free town (Sierra Leone) | 26.41 | 26.61 | 1 | Free town (Sierra Leone) | 20.43 | 20.67 |
| 2 | Loma (Togo) | 25.34 | 25.65 | 2 | Conakry (Guinea) | 19.01 | 19.34 |
| 3 | Banjul (Gambia) | 25.15 | 25.32 | 3 | Porto novo (Benin) | 14.61 | 15.42 |
| **$ACp^e$ (thousand persons/kilometer)** | | | | | | | |
| Rank | Country | ROSS | PROSS | Rank | Country | RASS | PRASS |
| 1 | Kinshasa (DRC) | 63.75 | 64.22 | 1 | Cairo (Egypt) | 34.46 | 36.94 |
| 2 | Cairo (Egypt) | 58.12 | 58.77 | 2 | Kinshasa (DRC) | 29.18 | 30.71 |
| 3 | Accra (Ghana) | 48.07 | 48.17 | 3 | Conakry (Guinea) | 23.01 | 23.55 |

According to the definition of ACp's, the nodes with higher value have more potential accessibility. Population, reflecting node's production and activity potentials, directly affects attraction and production potential accessibility indices. As Table 7 shows, the attraction and production potential accessibility in road-sea sub-networks are around twice when compared with rail-sea sub-networks. The index improvement of proposed corridors was often found to be more considerable for rail-sea sub-network when compared with road-sea sub-network.

## CONCLUSION

Transportation facilities and services are crucial in promoting domestic and international trades and economic development. They are key ingredients of sustainable development. The developing countries are facing several limitations such as lack of transportation infrastructures and non-uniform regulations. Africa is consisted of developing countries with numerous opportunities and resources despite under developed land transportation networks. Insufficient investment in land transportation infrastructure has led to poor accessibility among African countries. To achieve national and regional transportation sustainable development, domestic and international accessibility should be efficaciously addressed.

The objective of the study was to assess land transportation in the African continent. Collecting relevant information from centralized databases, the rail, road and sea links were identified. Subsequently two continent multimodal sub-networks were defined, namely: road-sea multimodal sub-network, ROSS, and rail-sea multimodal sub-network, RASS. The total length of ROSS was around 146,000 km with around 69,000 km of road links. The total length of RASS was around 113,000 km with around 51,000 km of rail links. Considering addition and construction of three corridors to ROSS and one corridor to RASS, existing and proposed multimodal sub-networks, PROSS and PRASS, were specified. The sub-networks were presented in adjacency matrices, and were deployed in accessibility and connectivity indices development.

As a preliminary step to address accessibility of the sub-networks, the connectivity indices of β and α were calculated. As expected road-sea sub-network was found more connected than rail-sea sub-network. Subsequently, four accessibility indices were developed. In this part associated number, accessibility number, importance number and potential accessibility indices were developed. Since the missing railway links of the rail-sea sub-network was extensive when compared with missing roadway links of the road-sea sub-network, the associated number was found to be significantly higher for the rail-sea sub-network RASS. By calculating average accessibility numbers, it became clear that the African countries are more accessible by roadway mode than by railway mode. The average accessibility index for road-sea sub-network was around 5750 km and for rail-sea sub-network was around 6700 km, respectively. For road and rail sub-networks, adding the proposed corridors resulted in average accessibility numbers to enhance and decrease by around 250 km. This is when the proposed road-sea sub-network PROSS expansion length was around 4 times as of rail-sea sub-network PRASS expansion length. Addition of corridors to ROSS resulted in more improved average accessibility for the northern countries, such as for Morocco, Tunisia and Algeria. Another index computed was importance number for corridors, reflecting the effects of corridor failure and elimination in network accessibility. This index was calculated for proposed corridors for the ROSS. According to this index, corridor 2, which is more continent centrally located than other two corridors, had more effect on improvement of network accessibility. In combinations, adding corridor 3 to corridor 2 enhanced average accessibility index more than adding corridor 1. According to importance number, optimal network stage expansion strategy would be the construction of corridors 2, 3 and 1, respectively. The production and attraction potential accessibility indices were calculated for capital nodes. Node's population greatly influenced production potential accessibility index. For attraction potential accessibility index, the distance to high population centers of each capital node became more influential. The attraction and production potential accessibility numbers for road-sea sub-networks were around twice as for rail-sea sub-networks. The potential accessibility number improvements were more significant for PRASS when compared with PROSS.

Recent global competition to access natural resources has brought Africa into spotlight when this continent is fronting numerous political, social, environment, economic and humanitarian crises and instabilities. This study is a preliminary step in understanding, developing and enhancing Africa regional transportation that could be conducive to sustainable development and trade facilitation. The appraisal of proposed highway and railway expansions presents an exercise of such alternative network expansion analysis and design. Other facets should be incorporated in network appraisals, including financial, economical, institutional, cultural, political, religion, technological, historical, social and environmental. The deployed accessibility and connectivity indices were neither unique nor standard; nevertheless they can be utilized for other transportation network and geographic scope appraisals.

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