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AN APPLICATION OF A NOVEL GREY-CODAS METHOD TO THE SELECTION OF HUB AIRPORT IN NORTH AFRICA

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Abstract: *Air transportation and airports are indispensable means of the modern world, where well-being and travel time reliability are pillars of strength. In the past few years, passengers traveling into, within, or out of Africa has enormously increased. However, the region lacks the basic facilities of linking African countries to the outside world. The research studies the possibility of assigning the optimal hub airport location in five North African countries, based on five main criteria. The criteria include airport pricing, hard and soft infrastructure, Catchment and landside access, as well as other aspects such as markets and airline partners. The study uses a hybrid grey-CODAS approach to decide the final priority of different decision alternatives. The method was implemented in steps to determine the criteria weights. Four experts participated in the evaluation to determine the importance of each criterion used for the ranking of suggested airport sites. The suggested sites include Cairo airport, Tripoli airport, Tunisia- Carthage airport, Algeria-Houari Boumediene airport, and Morocco- Mohammed V International airport. Model ranking suggested Morocco as the best alternative to locate a hub airport in North Africa.*

Key words: *Air hubs, MCDM, CODAS, GREY theory, location problem.*

1. Introduction

Airport hubs are usually used by airlines to concentrate passenger traffic, freight traffic, and flight operations at a single location. Passengers on their way to their final destination frequently stop at hubs for a stopover (Bakır et al., 2022). If the final destination is not a hub city, airlines operate flights from non-hub cities to hub cities or through hub cities (Raghavan & Chunyan, 2021). According to the U.S. Federal Aviation Administration (FAA), Hub airports are grouped into four categories based on the annual commercial enplanements each airport receives. Large hub, medium

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hub, small hub and non-hub which respectively receive 1% or more, between 0.25 to 1%, between 0.05 to 0.25%, and less than 0.05% of the annual U.S. passenger boarding's (FAA, 2022).

The proposition of air transportation industry development subjected to the right selection of a new hub airport enhances the network operational capability, lowers operating costs, and maximizes the network scale efficiency (Bellizzi et al., 2020; Button & Lall, 1999). Meanwhile, it is valuable for the proposed expansion to specifically adapt to the air transportation business evolution, more consistent with the enlargement trend of the airline sector as a whole. Airline network represents the backbone of airline operations; where the route is connected in a specific way with the aim of optimizing the allocation of airline's resource and improve revenue (Kanafani & Ghobrial, 1985). Aviation industry in developed countries utilizes flexible and useful large coverage areas known as hub structures, which are the main contributor to the transportation industry development (Oktal & Ozger, 2013).

Morocco, Algeria, Tunisia, Libya, and Egypt are North African countries located in the northern coast of Africa, the largest countries in the continent, with an approximate area of 5,589,280 km2. The region is bounded on the north by the Mediterranean Sea coastline, on the east by the red sea, on the south by the Sub-Saharan Africa, and on the west by the Atlantic Ocean. Such location enriches the great strategic importance and, hence, they have a high profile in the area. The major airports of North African countries are: Tunis-Carthage Airport in Tunisia, Adrar Airport in Algeria, Casablanca Mohammed V Airport in Morocco, Cairo Airport in Egypt, and Tripoli airport in Libya. Most of them publicly owned, for instance, the Libyan Civil Aviation Authority (LYCAA), a state entity affiliated with the Libyan Ministry of Transportation, owns and operates the airports in Libya (Elmansouri et al., 2020).

Hub airport establishment requires a different network design based upon the considered project area. For instance, Istanbul Ataturk Airport serves as a hub airport for Turkish air freight airlines. The airport has been designated as the main airport in the region; it handles half of the domestic air freight traffic in the country (Oktal & Ozger, 2013). However, one advantage of the chosen hub is that freight traffic flows in both directions with all airports in the network (Chen et al., 2017). In the same context, Maertenz et al. (2014) created a WADP (weighted average distance penalty) measure implemented to Tripoli as a prospective hub location. They concentrated on traffic between Africa and Europe and assessed the feasibility of establishing an air transportation hub in Libya.

The improvement of aviation will make an important contribution to the economy and social well-being of North African countries. Central hubs are essential for accessing many international destinations for business and leisure desires, and are also the most convenient means of traveling to other parts of Africa as well as Asia and Europe. The importance of the location of the North African countries is based on the fact that this region serves as a base station connecting Africa and Europe. An extension of its geographical interests, climate, as well as other important factors such as workforce etc. As mentioned in the literature (Maertens et al., 2014), Morocco, Algeria, Tunisia, Libya, and Egypt are the least distant from the shipping lanes in the mainland Africa. These countries have the potential to become a hub airport as an alternative corridor for other African countries that need airports for trade, and they have not yet taken advantage of their locations. In 2004 the World Food Program used Libya as a corridor to provide assistance to Darfur refugees through Chad. The aid was transported approximately 2,700 km from Benghazi in Libya to the city of Abéché in Chad (Ghashat, 2012).

The use of multi-criteria decision-making methods in the aviation industry has increased recently. There are a variety of applications, such as performance evaluation (Eshtaiwi et al., 2018), measurement of passenger satisfaction (Pandey, 2016), e-service quality (Bakır & Atalık, 2021), airlines performance (Badi & Abdulshahed, 2019), and other applications. Barros and Dieke (2007) used data envelopment analysis methodology (DEA) to analyze the financial and operational performance of thirty-one Italian airports, while twenty major international airports around the world were investigated by Tseng et al. (2008). Lu et al. (2019) examined twenty-seven Chinese airports efficiency during the period 2014-2018. Ulkü (2015) conducted a comprehensive analysis of Spanish and Turkish airports to evaluate the efficiencies of the operations. Abbott (2015) studied the performance efficiency of the three main airports in New Zealand.

In this perspective, essential decisions have to be made concerning the potential hub airports in North African. Finding the optimal location of a hub is a vital decision that represents the success of decision-making process. The difficulty for the prospective hub airport location is considered a strategic planning issue that should be addressed in line with the aviation sector. In this context, a development of such beneficent projects improves the economic situation of the North African region and boosts industries other than the dominating energy sector.

The paper aims to examine a new method to find the optimal site selection, a hub airport that provides the best services and connects the North African region and the African Continent. The region suffers the absence of major Airports to face the ever-growing demand on travel. A case study of five African potential hub airports was undertaken in this study, covering both developing and fluctuating hubs. Survey Interviews with four experts were conducted and a review of policy and strategic documents. Experts like pilot and airport manager having more than thirty years of professional work experiences in the Aviation field. Methods have been developed to allocate the services taking into account decision-making variables. The authors claim that expansion and investment in hub airports and their correlated models is a non-linear task. Most of the methods used in the past are based on traditional approaches, however, the application of MCDM method is an important technique for helping the air transportation sector. The authors have developed a new technique that has never been used. A hybrid grey-CODAS (COmbinative Distance-based Assessment) model is used to evaluate the criteria weights and rank the alternatives.

2. Air transport between Europe and Africa

Modern aviation industry has a significant role in promoting economies in long-term bases. This sector employs over 58 million people worldwide and provides over $2.4 billion to the global Gross domestic product (GDP). Also, around 3.3 billion passengers and $6.4 billion worth in freight are transported each year. Since 1977 and in spite of the economic crisis, global aviation industry has grown and is expected to thrive once every 15 years which demonstrate how investments in the aviation industry are crucial to the revival of the economy. Global aviation industry is expected to rise at average annual rate of 3.6 percent within duration from 2011 to 2030, in contrast to 3.2 percent from 1990 to 2010. As the aviation industry thriving across the globe, developing countries has been economically benefitting. Southeast Asian, Latin American, and African airlines are gaining a rising percentage of overall air traffic. The primary causes for this increase are the anticipated rise in load factors as well as increase in aircraft size and capacity. It is predicted that Africa would undergo particularly fast expansion in the next years (Yao et al., 2014).

One of the most important challenges facing the aviation sector is how to accommodate the growing demand for air transportation. As illustrated in Figure 1, Europe has the highest growing demand on passenger air transportation. While demand for air transportation in Europe has increased at an average annual rate of 5.0 percent, the Middle East and Africa have seen a significant increase in air transportation recently, with an average annual growth rate of 13 percent per year. Passenger air traffic in Middle East and Africa is anticipated to achieve levels equal to those seen in Europe (Bonnefoy, 2008).

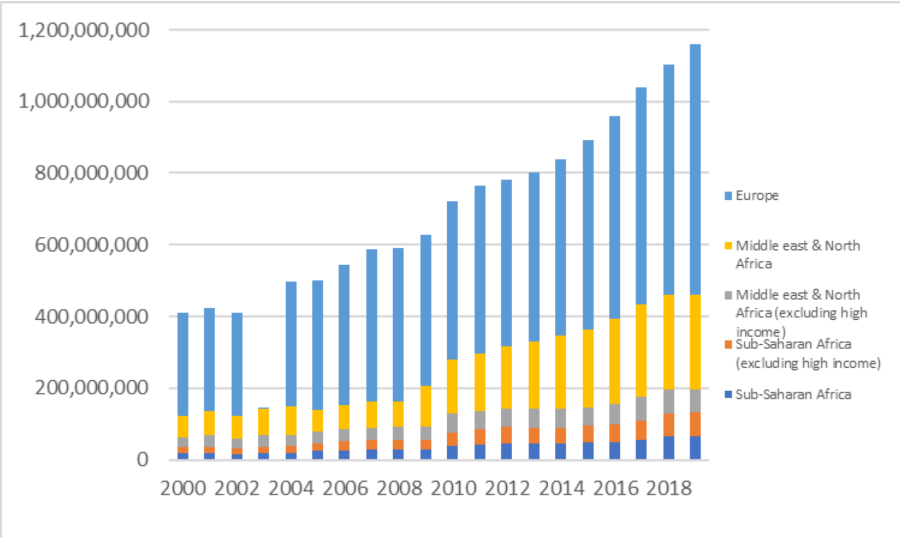

Figure 1. Historical evolution of air transportation activity across EU and Africa. Source: prepared by the authors based on data from the world bank

It is difficult to predict parameters in the field of air transportation and there will usually be some variation from expectations for some parts of the world. The International Civil Aviation Organization (ICAO) developed two prediction models, one optimistic and the other pessimistic, to assess and predict the future of air transportation. The global average annual growth rate for passenger air transportation is expected to range between 5.1% and 3.6% per year for optimistic and pessimistic scenarios respectively (Yao et al., 2014).

Future expectations for airline registration can be formulated either by region or route group. The majority of world countries assign the local airline companies for their domestic air transportation. Cross-border air traffic for a route group will mainly be supplied by regional airlines; however, airlines from different zone may have the rights of the international air transportation for that region.

Commercial air transportation has had substantial traffic growth over the previous decades, resulting in the formation of several new commercial air transportation companies. Subsequently, the need for trained aviation professionals, such as pilots, aircraft maintenance workers, and air traffic controllers, will increase to handle the demand for the following years (Yao et al., 2014).

Africa is a developing continent; this also applies to the aviation market. Currently, Africa is responsible for only 3% of global air business while 17% of the world's population lives in this continent. The top 10 largest airports in North Africa, for example, three airports from Egypt in the cities of Cairo, Hurghada and Sharm El

Sheikh, and Casablanca's Mohammed V International Airport in Moroco accounted for more than a third of the total annual departures from this region. During the period 2000-2010, the total number of passengers for the five countries was 310.1 million. Figure 2 shows the percentage of the total number of passengers shared by each country. More than one third of the total passengers use Egyptian airports to travel, while 26 percent of the total trips lands on Morocco.

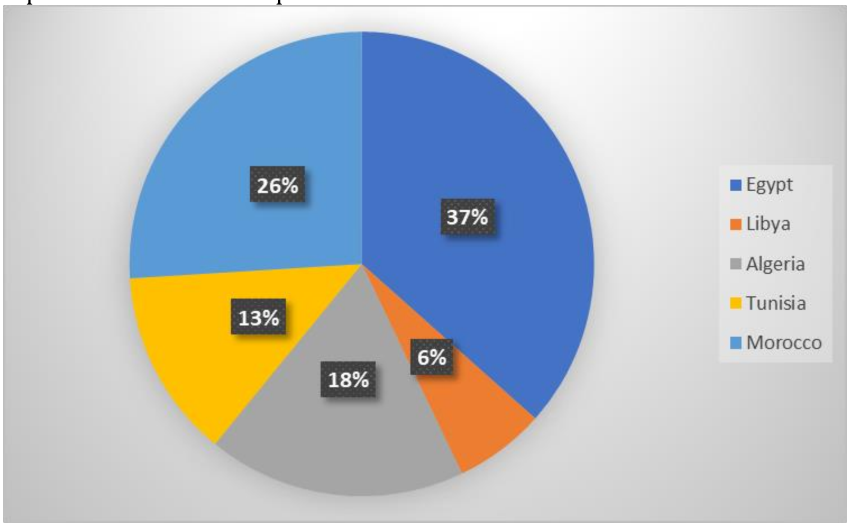

Figure 2. Percentage of the total number of passengers shared by each country. Source: Own calculations based on data from Eurostat.

Table 1 shows the top five ranked destinations and number of passengers from five EU airports to Africa. Cairo airport plays a significant role in connecting Europe with Africa and operates with different airline partners from all destinations. The number of passengers is calculated for the period 2009-2019.

Table 1. Top five ranked destinations for five main EURO airports. Source: Own calculations based on Eurostat.

No.	Origin	Destination	#PAX
1	LONDON HEATHROW airport	O.R TAMBO	2,729,472
2		NAIROBI/JOMO	2,172,302
3		LAGOS/MURTALA MUHAMMED	2,166,918
4		CAPE TOWN	1,993,102
5		Cairo	1,974,654
1	ROMA/FIUMICINO airport	Cairo/INTL	1,308,059
2		TUNIS/CARTHAGE	1,121,703
3		CASABLANCA/MOHAMMED V	898,795
4		ALGER/HOUARI BOUMEDIENE	667,809
5		ADDIS ABABA	460,099
1	PARIS-CHARLES DE GAULLE airport	ALGER/HOUARI BOUMEDIENE	2,903,455
2		CASABLANCA/MOHAMMED V	2,251,388
3		TUNIS/CARTHAGE	1,928,780
4		SIR SEEWOOSAGUR RAMGOOLAM	1,916,157
5		CAIRO/INTL	1,583,887
1	FRANKFURT/MAIN airport	CAIRO/INTL airport	1,551,838
2		O.R TAMBO INTERNATIONAL airport	1,424,294
3		HURGHADA / INTL airport	1,131,879

No.	Origin	Destination	#PAX
4		ADDIS ABABA/BOLE COM/MET/NOF airport	892,269
5		TUNIS/CARTHAGE airport	804,138
1	ADOLFO SUAREZ MADRID-BARAJAS airport	MARRAKECH/MENARA airport	1,494,603
2		CASABLANCA/MOHAMMED V airport	1,235,644
3		TANGER/IBN BATOUTA airport	982,686
4		CAIRO/INTL airport	651,184
5		DAKAR/YOFF airport	561,756

3. Methodology

MCDM (Multi-criteria decision making) is an approach used by researchers in the making of decisions that comprise prioritizing, ranking, or selecting between preferences (Pmucar, 2020). MCDM system integrates preference's conduct across various quantitative, qualitative, or contradicting criteria and effects in a proposition requiring a consensus. Skills amassed from various fields, information systems, economics, computer applied science, behavioral decision theory, and others are utilized. Various MCDM procedures have been established and prompted efficiently in various areas of necessity (Bakır et al., 2021).

There are various MCDM methods such as analytical network process, fuzzy decision-making, and data envelopment analysis (Durmić et al., 2020). Despite various researches implementing the methods, MCDM remains the rapidly developing problem area in diverse departments (Bouraima et al., 2021). However, each of the methods has the same ability to make decisions under distrust, and each holds its privilege.

Grey system theory is a mathematical methodology that was initially introduced by Deng in 1982. The theory has been effectively used for modelling problems with limited amount of data and incorporating uncertainty in systems (Li et al., 2007). Unlike traditional methods which require large number of samples, the grey theory is designed to study and model systems lacking sufficient information. The grey system theory has been successfully used in different research areas such as finance, engineering, social and economics (Badi & Pamucar, 2020). When all of the information is known, the system is called white, and when all of the information is unknown, the system is called black (Abdulshahed et al., 2017). It is called grey system when the information is being incomplete (Liu et al., 2012).

Grey number can be defined as a measure where we only know the range of values rather than the exact value (Eshtaiwi et. al., 2017). The unknown parameters of the grey system are expressed by discrete or continuous grey number represented by the symbol$\otimes$. The theory include a variety of features and operations on grey numbers, including the core of the number$\hat{\otimes}$, its degree of greyness $g°$, and the grey number's whitening degree which indicates how a number prefers to be in the middle of a range of feasible values (Badi et al., 2018). The CODAS method is developed by Keshavarz et al. (Keshavarz Ghorabaee et al., 2016). It is widely used for many multi criteria decision making problems (Badi et al., 2018).

This research uses a hybrid grey-CODAS method to examine the assessment of decision makers to determine the proper location for an airport hub. The aim of this research is to implement this hybrid approach for determining the optimal location for an airport hub in northern African countries. Five airports were chosen to represent the inspected sites as follows; S1: Cairo airport, S2: Tripoli airport, S3:

Algeria airport, S4: Tunis/Carthage airport, S5: Mohammed V airport, Morocco. The priority weights of the alternatives were determined using MS Excel macros based on the questionnaire forms that were used to compare major attributes and alternatives.

The Grey-CODAS model is conducted on 11 steps as follows:

Step 1: Choosing set of the most crucial attributes and suggest alternatives.

Step 2: Calculate the weight of attributes W_j using the following equations:

$$\otimes W_j = \frac{1}{K}\left[\otimes W_j^1 + \otimes W_j^2 + \cdots + \otimes W_j^K\right] \quad (1)$$

$$\otimes W_j^K = \left[\underline{W}_j^K, \underline{W}_j^K\right] \quad (2)$$

Step 3: Experts assess the alternatives: expert's feedback will be on either linguistic or verbal factors depending on the criteria.

$\otimes G_{ij}^K, (i = 1,2,\ldots,m; j = 1,2,\ldots,n)$is the value of the attribute obtained from the k^th^ expert to any of the alternatives which is represented as, $\otimes G_{ij}^K = \left[\underline{G}_{ij}^K, \overline{G}_{ij}^K\right]$ and calculated using the following formula:$\otimes G_j = \frac{1}{K}\left[\otimes G_j^1 + \otimes G_j^2 + \cdots + \otimes G_j^K\right]$

Step 4: Forming the Grey Decision Matrix:

$$G = \begin{bmatrix} \otimes G_{11} & \otimes G_{12} & \cdots & \cdots & \otimes G_{1n} \\ \otimes G_{21} & \otimes G_{22} & \cdots & \cdots & \otimes G_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \\ \otimes G_{m1} & \otimes G_{m2} & \cdots & \cdots & \otimes G_{mn} \end{bmatrix} \quad (3)$$

Step 5: Normalizing the Decision Matrix:

$$D^* = \begin{bmatrix} \otimes G_{11}^* & \otimes G_{12}^* & \cdots & \cdots & \otimes G_{1n}^* \\ \otimes G_{21}^* & \otimes G_{22}^* & \cdots & \cdots & \otimes G_{2n}^* \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \\ \otimes G_{m1}^* & \otimes G_{m2}^* & \cdots & \cdots & \otimes G_{mn}^* \end{bmatrix} \quad (4)$$

Benefit attribute $\otimes G_{ij}^*$ is formed as

$\otimes G_{ij}^* = \left[\frac{G_{ij}}{G_j^{max}}, \frac{\overline{G}_{ij}}{G_j^{max}}\right]$where $G_j^{max} = max_{1<i<m}\{\overline{G}_{ij}\}$ and a cost attribute $\otimes G_{ij}^*$ is formed as

$\otimes G_{ij}^* = \left[\frac{G_j^{min}}{\overline{G}_{ij}}, \frac{G_j^{min}}{\underline{G}_{ij}}\right]$where $G_j^{min} = min_{1<i<m}\{\underline{G}_{ij}\}$.

Step 6: Calculating the elements of weighted normalized grey decision matrix using the following formula.

$$\otimes V_{ij} = \otimes G_{ij}^* X \otimes W_j$$

Forming the weighted normalised grey decision matrix D_W^*.

$$D_W^* = \begin{bmatrix} \otimes V_{11} & \otimes V_{12} & \cdots & \cdots & \otimes V_{1n} \\ \otimes V_{21} & \otimes V_{22} & \cdots & \cdots & \otimes V_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \\ \otimes V_{m1} & \otimes V_{m2} & \cdots & \cdots & \otimes V_{mn} \end{bmatrix} \quad (5)$$

Step 7: Determine the negative-ideal solution using equation (6).

$$ns = \left[ns_j\right]_{1\times m}$$
$$ns_j = min_i r_{ij} \quad (6)$$

Step 8. Applying the negative-ideal solution to compute the Euclidean and Taxicab distances using equations (7) and (8) respectively.

$$E_i = \sqrt{\sum_{j=1}^{m}\left(r_{ij} - ns_j\right)^2} \quad (7)$$

$$T_i = \sum_{j=1}^{m}\left|r_{ij} - ns_j\right| \quad (8)$$

Step 9: Forming the relative assessment matrix using equation (9).

$$R_a = [h_{ik}]_{n\times n} \quad (9)$$

$$h_{ik} = (E_i - E_k) + \left(\psi(E_i - E_k) \times (T_i - T_k)\right)$$

Where $k \in \{1, 2, \ldots, n\}$ and ψ indicates a threshold function to judge the equality of the Euclidean.

$$\psi(x) = \begin{cases} 1 & if\ |x| \geq \tau \\ 0 & if\ |x| < \tau \end{cases}$$

τ is a threshold parameter that is defined by decision makers, and is set within a range of values of 0.01 and 0.05. The study evaluated alternatives base on Taxicab distance, where the variance between Euclidean distances of two alternatives does not exceed τ. Model Calculations were based on a value of τ = 0.02.

Step 10: Calculate the assessment score of each alternative using equation (10).

$$H_i = \sum_{k=1}^{n} h_{ik} \quad (10)$$

Step 11: Put alternatives score (H) on descending order, so that the highest H is the best choice among the alternatives.

4. The case study

In this research study, qualitative parameters for the airport hub site selection problem are identified using questionnaire forms. Table 2 shows the five different factors that are taken into account. Except for the first, which is a cost criterion, all of these criteria are classified as benefit criteria. The model was programmed using macros in Microsoft Excel to make the procedure easier.

Table 2. Criteria used (Maertens et al., 2014)

Category	Factors
Airport expenses	Airport usage cost (landing, passenger services, ground handling, ATC services charges, fuel cost, etc.) Deduction, Marketing services
"Hard" airport infrastructure	Runways and taxiways, terminal and apron facilities/Marking Possibility of Airport expansion passenger transit services, suitable connection flights Offering maintenance facilities
"Soft" airport infrastructure	Airport slot capacity Business hours Work regulations
Catchment and landside access	Large-scale location (world/continent/country level) Minor-scale location (local region, considering local factors such as obstacle clearance)

	Demand drivers in the catchment area (GDP, population, standard of living, industrial base, socio-economic factors and ethnic factors)
	Competition from nearby airports
Other	Airlines facilities at airport (competing carriers etc.)
	Airline partnership availability

Four experts were invited to evaluate each of the proposed criteria in the examination of potential airport locations. Table 3 shows a scale that can be used to express linguistic variables in grey numbers. Sites were scored on a grey scale in Table 4 for their performance on many attributes.

Table 3. The importance of grey number for the weights of the criteria.

Importance	Abbreviation	Scale of grey number $\otimes W$
Very Low	VL	[0.0, 0.1]
Low	L	[0.1, 0.3]
Medium Low	ML	[0.3, 0.4]
Medium	M	[0.4, 0.5]
Medium High	MH	[0.5, 0.6]
High	H	[0.6, 0.8]
Very High	VH	[0.8, 1.0]

Table 4. Linguistic assessment and the associated grey values.

Performance	Abbreviation	Scale of grey number $\otimes W$
Very Poor	VP	[0.0, 1.0]
Poor	P	[1.0, 2.0]
Medium Poor	MP	[2.0, 4.0]
Fair	F	[4.0, 5.0]
Medium Good	MG	[5.0, 6.0]
Good	G	[6.0, 8.0]
Very Good	VG	[8.0, 10.]

Table 5 summarize the expert responses in evaluating the targeted attributes. Weights of attributes are calculated using equation 2.

Table 5. The linguistic assessment of the attributes by experts.

C_i	Expert #1	Expert #2	Expert #3	Expert #4	$\otimes W$		Whitening degree
C_1	H	ML	H	H	0.53	0.70	0.6125
C_2	VH	H	VH	VH	0.75	0.95	0.8500
C_3	MH	M	H	H	0.53	0.68	0.6000
C_4	MH	MH	VH	VH	0.65	0.80	0.7250
C_5	H	MH	M	MH	0.50	0.63	0.5625

As presented in table 5, the second attribute, which denotes to the airport infrastructures, is ranked as the top priority among all attributes followed by the catchment and landside access attribute. Airports have a vital contribution in the economy of a country. The quality of airport infrastructure, which is an important part of the entire transportation network, has a significant role to attract foreign investment. Airline companies require affordable, safe and functional airport infrastructures to expand their passenger and cargo services. A successful hub requires a location on or near major traffic flows. Detour factors will be too high if a hub is too far away for major traffic flows. Large detours mean higher costs due to longer flight times, greater fuel usage, and more employees and other factors.

Table 6 shows the experts' linguistic evaluations of each site. As stated in Table 3 and equation 3, convert the linguistic variables into grey numbers using the scales of grey numbers. The grey decision matrix D is calculated based on the consequence's assessment. The suggested sites include Cairo airport (S1), Tripoli airport (S2), Tunisia- Carthage airport (S3), Algeria- Houari Boumediene airport (S4), and Morocco- Mohammed V International airport (S5).

Table 6. Experts views on suggested sites selection criteria.

C_j	Sites	Expert #1	Expert #2	Expert #3	Expert #4	$\otimes G_{ij}$
C_1	Site #1	G	G	MG	MG	[5.50 7.00]
	Site #2	VG	G	VG	VG	[7.50 9.50]
	Site #3	VP	P	G	G	[3.25 4.75]
	Site #4	VG	MG	VG	G	[6.75 8.50]
	Site #5	VG	G	G	G	[6.50 8.50]
C_2	Site #1	G	G	VG	G	[6.50 8.50]
	Site #2	VP	G	G	F	[4.00 5.00]
	Site #3	MP	P	G	G	[3.75 5.50]
	Site #4	F	F	G	F	[4.50 5.75]
	Site #5	VG	G	VG	G	[7.00 9.00]
C_3	Site #1	MP	G	G	G	[5.00 7.00]
	Site #2	VP	G	G	MG	[4.25 5.75]
	Site #3	P	P	G	G	[3.50 5.00]
	Site #4	F	G	VG	VG	[6.50 8.25]
	Site #5	MG	G	VG	VG	[6.75 8.50]
C_4	Site #1	MG	F	G	MG	[5.00 6.25]
	Site #2	VG	G	G	VG	[7.00 9.00]
	Site #3	MG	G	VG	G	[6.25 8.00]
	Site #4	VG	G	VG	VG	[7.50 9.50]
	Site #5	VG	MG	G	MG	[6.00 7.50]
C_5	Site #1	G	G	G	MG	[5.75 7.50]
	Site #2	VP	F	VG	F	[4.00 5.25]
	Site #3	G	G	VG	G	[6.50 8.50]
	Site #4	F	F	VG	MG	[5.25 6.50]
	Site #5	G	MG	VG	G	[6.25 8.00]

The Decision Matrix "D" is normalized, so the grey elements range between 0 and 1.

$$D* = \begin{bmatrix} [0.4643\ \ 0.5909] & [0.7222\ \ 0.9444] & [0.5882\ \ 0.8235] & [0.5263\ \ 0.6579] & [0.6765\ \ 0.8824] \\ [0.3421\ \ 0.4333] & [0.4444\ \ 0.6111] & [0.5000\ \ 0.6765] & [0.7368\ \ 0.9474] & [0.4706\ \ 0.6176] \\ [0.6842\ \ 1.0000] & [0.4167\ \ 0.6111] & [0.4118\ \ 0.5882] & [0.6579\ \ 0.8421] & [0.7647\ \ 1.0000] \\ [0.3824\ \ 0.4815] & [0.5000\ \ 0.6389] & [0.7647\ \ 0.9706] & [0.7895\ \ 1.0000] & [0.6176\ \ 0.7647] \\ [0.3824\ \ 0.5000] & [0.7778\ \ 1.0000] & [0.7941\ \ 1.0000] & [0.6316\ \ 0.7895] & [0.7353\ \ 0.9412] \end{bmatrix} \quad (11)$$

Weights of criteria are calculated using equation (6) using grey multiplication. Weights allocated to attributes are multiplied by the corresponding elements of the normalized grey decision matrix.

$$Dw* = \begin{bmatrix} [0.2438\ \ 0.4136] & [0.5417\ \ 0.8972] & [0.3088\ \ 0.5559] & [0.2763\ \ 0.4441] & [0.4397\ \ 0.7059] \\ [0.1796\ \ 0.3033] & [0.3333\ \ 0.5806] & [0.2625\ \ 0.4566] & [0.3868\ \ 0.6395] & [0.3059\ \ 0.4941] \\ [0.3595\ \ 0.7000] & [0.3125\ \ 0.5806] & [0.2162\ \ 0.3971] & [0.3454\ \ 0.5684] & [0.4971\ \ 0.8000] \\ [0.2007\ \ 0.3370] & [0.3750\ \ 0.6069] & [0.4015\ \ 0.6551] & [0.4145\ \ 0.6750] & [0.4015\ \ 0.6118] \\ [0.2007\ \ 0.3500] & [0.5833\ \ 0.9500] & [0.4169\ \ 0.6750] & [0.3316\ \ 0.5329] & [0.4779\ \ 0.7529] \end{bmatrix} \quad (12)$$

Table 7 contains weights of criteria that have been used to determine the values of normalized performance. Then, data utilized to compute the negative-ideal solution, which is subsequently applied to determine the Euclidean and Taxicab distances of alternatives (Badi et al., 2018). Table 7 summarizes the findings.

Table 7. The weighted normalized decision matrix and the negative-ideal solution

Alternatives	Airport pricing	Hard infrastruct	Soft infrastructure	Landside access	Others	Distances	
						Euclidean	Taxica
	0.3287	0.7194	0.4324	0.3602	0.5728	**0.3574**	**0.658**
	0.2415	0.4569	0.3596	0.5132	0.4000	**0.1622**	**0.216**
	0.5296	0.4465	0.3066	0.4569	0.6485	**0.3926**	**0.633**
	0.2689	0.4910	0.5283	0.5447	0.5066	**0.3119**	**0.584**
	0.2754	0.7667	0.5460	0.4322	0.6154	**0.4610**	**0.880**
Negative-ideal solution	0.2415	0.4465	0.3066	0.3602	0.4000		

Table 7 and Equation 7 can be used to compute the relative assessment matrix and the assessment scores (H) of alternatives assuming the value of τ = 0.02. Results are summarized in Table 8.

Table 8. The relative assessment matrix and the assessment scores of alternatives

S1	S2	S3	S4	S5	H
0	0.6376	-0.0099	0.11947	-0.326	**0.4214**
-0.6376	0	-0.6475	-0.51812	-0.963	**-2.7665**
0.0099	0.6475	0	0.12935	-0.316	**0.4708**
-0.1195	0.5181	-0.1294	0	-0.445	**-0.1759**
0.3258	0.9633	0.31588	0.44523	0	**2.0502**

Table 8 shows that site number 5 has the highest value of H. As a result, when it comes to CODAS approach evaluation, S5 is the best site. Also, a sensitivity analysis was performed to assess the results' validity and stability. To examine their effect on site ranking, fourteen values of τ ranging from 0.01 to 1.00 were chosen. The values of τ and their impact on site ranking are shown in Table 9.

Table 9. Sites ranking with different values of τ

	τ													
	0.01	**0.02**	**0.03**	**0.04**	**0.05**	**0.06**	**0.07**	**0.08**	**0.09**	**0.10**	**0.15**	**0.30**	**0.50**	**1.00**
S1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
S2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
S3	3	3	3	4	4	4	4	4	4	4	4	4	4	4
S4	5	5	5	5	5	5	5	5	5	5	5	5	5	5
S5	4	4	4	3	3	3	3	3	3	3	3	3	3	3

Figure 3 illustrates that the fifth site (S5) is the best among all sites. Also, it can be noted that changing the parameter τ has a minimal impact on the ranking of alternatives.

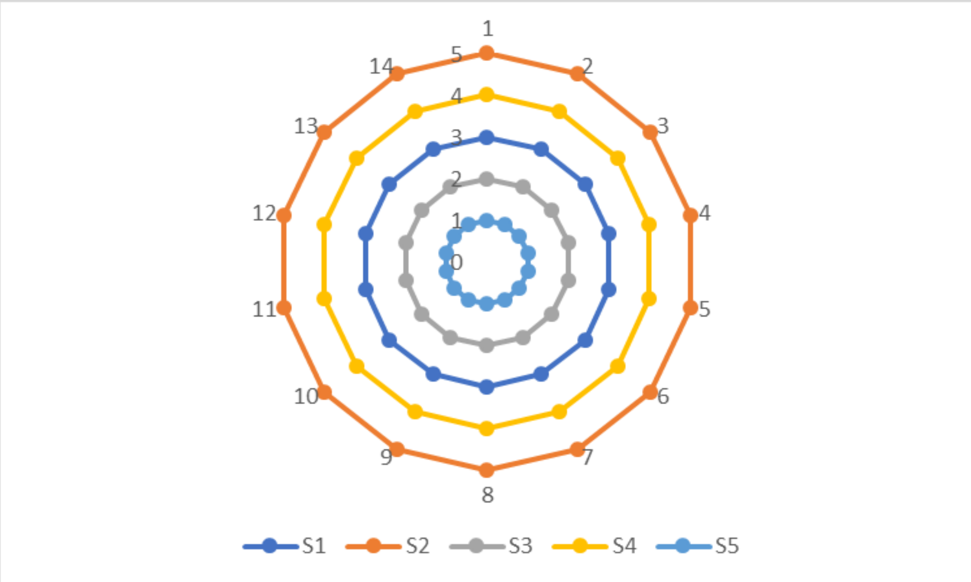

Figure 3. sites ranking with different values of τ

5. Discussion.

Most African countries are destitute of a regional hub airport that has the ability to connect them with the outside world. Due to the everlasting and continuous growth of demand for air transportation, a new hub airport needs to be constructed in North Africa. The area compared to the rest of the continent has the resources and the capability to help the region and the continent to provide such services and to connect the countries of the world with Africa. Moreover, North Africa geostrategic location enhances the benefits of the project, where the region situated at the crossroads of Africa, Europe, and Asia.

Although the importance of the geographic location when allocating hub airports, the results show that infrastructure is the most important criterion. The number of people and goods transported depends on the basic airport facilities such as airport area, runways, terminals, and the availability of other services, maintenance for instance. Therefore, freight and passengers could be transported efficiently with the least journey time, and maximum flight capacity. Nevertheless, the geographic location is ranked second and so forth. On the other hand, Maertens et al. (2014) evaluated hub airports in Libya, Algeria, Egypt and other regional countries with respect to their geographic location and passenger traffic. Moreover, Oktal & Ozger (2013) suggested that aircraft range, travel cost, and other aspects are considered as major factors affecting hub locations.

The results also indicate that Morocco's airport is the best alternative between the five locations. The country in the past few years has invested in infrastructure projects as well as airports. Various international airlines provide quality and competitive services to the customers. The political system is very stable, aiming to help tourists visit the country. On the contrary, Tripoli is the worst alternative, given the current situation in Libya. The airport infrastructure is dilapidated, and the country is in crisis. Consequently, international airlines are banned and out of service. Unlikely, Maertens et al. (2014) ranked Cairo and Tripoli among the best airports in the region. The five alternatives were studied under different circumstances by conducting a sensitivity analysis. Results show that differences between values are insignificant and the alternatives ranking model is valid.

Libya is located in the center of the North African coast, and the GDP is very high compared to the neighboring countries and to the rest of African countries in general. The country is also an oil exporter, and the fuel prices are very low. Hence, new job opportunities will be created based on the substantial investments expected in the future. Despite of the ongoing circumstances in Libya, the ranking of the five alternatives may alter at any instant.

6. Conclusion

Constructing a new hub airport in North Africa is a vital to the region and to the African continent. Such crucial projects could assist countries to improve infrastructure, socioeconomic status, and prosperity of the African nations. The study focused on selecting the optimal alternative from five major airport locations located in North Africa. The main purpose is to link Africa with the rest of the world and to connect Long-Haul Flights between the countries as a transit station taking into account the immense number of passengers travelling from and to African territories.

Infrastructure, geographic location, and three major criteria have been chosen to evaluate each location, where the infrastructure was ranked as the most significant. The study came to an end that Morocco is distinguished as the best choice to allocate the project. The limitation to this research is that it does not guarantee that one obtained location is the optimal, in the case of the criteria has been changed. The topic remains open for further studies using a broader range of samples and applying different modeling hypothesis. Given the exceptional situation of Libya; deteriorated infrastructure, and instability of the country; the country's economic situation is still secure. Libya also possesses a fleet of aircraft that is the best in the region.

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