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Improving Performance of Khartoum International Airport, Sudan

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Abstract: Khartoum airport plays a vital role in air traffic and national economy. The airport has experienced poor performance and lack of services. Serious congestion, delay and cancellation problems in flights becoming a daily habits. The study aims to evaluate the existing airport facilities and services and their ability to meet future demand. The literature concerning airport capacity and performance related issues were reviewed. The research depend on documents information, site inspection, and interviews for evaluation. The historical data of travelers at the Airport were analysed to estimate the forecasted demand. The study has identified challenges facing the increasing travel demand in the airport. Facilities that are unable to accommodate the increase in travel demand were identified for improvement. Thus, the improvement has to be done by expansion of terminal building, extending apron area for more aircraft parking spaces, additional runway length, increasing taxiways width as well as optimizing the operational processes by introducing flexibility and using technology.

Keywords: *Khartoum airport, performance, demand, improvement.*

1. INTRODUCTION

Khartoum international airport (KIA) was earlier designed and constructed in 1947. Basically to accommodate very limited movements operated by general aviation aircrafts (Type DC3). KIA is connected with the utilization of international and domestic flights. It was expanded in 1970s to accommodate the increase in air traffic and in 2010 was rehabilitated in various aspects of the airport.

Recently new generation of Aircrafts (B787, A380) enter in the service for long haul flights and this let past generation to work in regional flights. The airport design changes to wide Bodied Aircraft B777 and A380. Due to lack of airport capacity and services and location constrains, Sudan's Civil Aviation started planning and design a new airport in Omdurman city, 40 kilometers of Khartoum. Unfortunately, construction of the new airport in the short term is severely limited by the country's weak financial situation and lack of financing by international funds [1].

A major concern of airport users and operators is delay. Flights cannot be started or completed on schedule because of the queue of aircraft awaiting their turn for takeoff, landing, or use of taxiways and gates at terminal buildings. These delays translate into increased operating costs for airport users and wasted time for passengers. The cause for this delay is commonly referred to insufficient airport capacity, meaning that the airport does not have facilities such as runways, taxiways, or gates in sufficient number to accommodate all those who want to use the airport at peak periods of demand.

The solutions generally advocated by airport advisers are to build additional facilities at crowded airports or to find ways to make more efficient use of existing facilities. Therefore, the study aims to examine the capability of existing airport facilities to accommodate the travel demand in order to find out the challenges and then addressing solutions.

2. LITREATURE REVIEW

Aviation is a global industry and for standardization they established international organizations as reference for the industry standards and recommended practises, International Civil Aviation (ICAO), International Airlines Transportation (IATA), and Airports International Council (ACI). Aviation is a dynamic industry and airports always develop to cope with the industry changes.

Airport Engineers are the planners of airports consider all aspects related to airport planning, design, operation and other regarding landside use around the airport, height limitation and environmental issues. Airport engineers have plan for development in landside, terminals, and airside.

A reliable and efficient air transportation system provides substantial benefits to society by connecting distant communities in broader national and international economies. Airport capacity constraints and resulting congestion impose large costs on airlines and their passengers. At the most congested airports, scheduled demand during some hours of the day, may exceed airport capacity which generally refers to the ability of an airport to handle a given volume of traffic (demand). As demand for the use of an airport approaches the peak limit, queues of users awaiting service begin to develop, and they experience delay. Generally, the higher the demand in relation to capacity, the longer the queues and the greater the delay. Practical capacity is the number of operations (take offs and landings) that can be accommodated with no more than a given amount of delay, usually expressed in terms of maximum acceptable average delay [2].

Airport capacity has been analyzed and defined by different authors, however no objective definition can be found because of the multidimensional nature of the concept as the following review illustrates. Reichmuth et al. [3] mention that airport capacity is related to a facility's capability to handle people, freight and vehicles. Other researchers define capacity by the number of movements per hour (Barnhart et al. [4]) while Upham

et al. [5], and Graham and Guyer [6] define capacity as a function of operational and environmental constraints.

Many researches study airport capacity through investigating the relationship between airports and airlines, and their respective business models [7]. According to Janic [8], capacity and development of airports can be seen as the interaction between four main factors: operational, sizing and design of airside and landside infrastructure; economics; environmental restrictions and regulations and social perception towards airport infrastructures. Jacquillat and Odoni [9] investigated the relationship between airport capacity and flight schedules and how to mitigate delays. The FAA [10] provides many factors that affect capacity constraints such as noise, emission reduction, airport slots, separation intervals for landing and departures, meteorological conditions, aerodrome design, runway configuration, arrival/departure ratio, air traffic flow type, aircraft characteristics, and demand-related issues (like fleet mix, runway occupancy time and average ground speed on final approach). It can be concluded that airport capacity is not a static factor that defines the amount of aircraft or passengers/cargo handled but that dynamic factors like flight schedules, aircraft types and weather conditions also play an important role in defining airport capacity.

Airports can operate with different numbers and configurations of runways. These can be a single runway, one or pairs of parallel or intersecting runways, and their combinations. Assigning runway to the landing/take-off aircraft is a technical decision made by controllers. The runway assignment is typically dependent on the airport configuration, the direction of arriving aircraft (arrival feeder gate), and departure routes of the aircraft, which is normally specified by the flight plan [11]. While an aircraft approaches the runways, adjustments can be made to the flight plan by assigning the aircraft to an alternative runway, which is known as runway allocation, in order to balance both the landing/take-off on each runway and the controllers' workload [12].

The runway capacity is generally dependent on number of factors such as the runway occupancy time, mix of aircraft using the runway, availability of taxiways, aircraft type/performance, spacing between parallel runways, intersecting point of runways, mode of operation (segregated or mixed), performance of the current Air Traffic Management (ATM) systems, weather condition (visibility, wind strength and direction), and noise restriction [13], [14].

Researchers consider the mode of use of the runway, which can either segregated mode or mixed mode. In segregated mode, the runway is solely used for either landing or take-off of the aircraft, while in mixed mode, it can be used for both landing and take-off. Mixed-mode is usually more efficient than segregated mode since alternating landings and take-offs on the runway is effective in reducing or eliminating delays due to wake vortex constraints [15]. The airport capacity model presented by Newell [16] shows that capacity can increase in mixed-mode.

Since increasing the number of runways is often impractical, air traffic controllers aim to use methods and techniques to maximize the available runway throughput. A study by Butler and Poole [17] established a method that can lead to a new way of looking at airport capacity challenges. Depending on the airport, a new runway might not be needed after all, or a new runway could be created inside the current property line, or new aircraft routings can open up existing airports that have been constrained. For airports with a single runway, the primary means of increasing capacity is by reducing in-trail separation between aircrafts. A method to sequence various size aircraft can be implemented that will create an arrival flow that places larger aircraft closer behind smaller aircraft to reduce the separation between them. Airports with shorter runways cannot use this method.

3. Research Methodology

One of the initial task in the research is the collection of information on the condition of existing facilities and services in Khartoum airport. Secondly, on-site visits for visual inspection of the airport infrastructures were conducted by a technical team of civil engineers. Finally, direct interviews were conducted with a representative sample of airport officials, airlines personals, passengers, and airport civil engineers.

The data collected is necessary to evaluate the physical attributes of airside and landside infrastructures of the airport. Information collected focuses on the use, size, quantity, type, area, operational intent, and other characteristics of the airside and landside components of the airport. Typical categories of information collected include history, physical infra-structures, and travel demand.

Several sources of information were referenced to compile a comprehensive database of facilities and services in Khartoum International Airport. These included, but were not limited to, the previous Airport Master Plan, recent reports and documents published by Sudan Civil Aviation Authority and Khartoum Airport Engineering Company, and the Airport Layout Plan. In addition, Books, studies, references, research papers, professional and scientific papers in the fields of the study published and unpublished studies and web sites.

Information collected during the study provides a method to evaluate the conditions of existing Airport facilities and provide a baseline to measure how well current infrastructure will be able to accommodate future aviation demand. Through a review of the information presented in this section, subsequent study tasks can be conducted to determine what improvements will be necessary at the Airport to meet the air transportation requirements.

In comparison with future aviation demand projections, alternatives can be developed to identify a plan on how the Airport will address the required improvements. Khartoum Airport has continually evolved over its history to meet the demand of its users, and this study effort will help direct the prospective growth and expansion of existing Airport facilities to meet future aviation needs.

3.1 Airport Location

Khartoum Airport is an international airport located in the centre of Khartoum, capital of Sudan, the largest international airport in Sudan. The Airport is located at latitude 15° 35′ 22.19″ North and longitude 32° 33′11.38″ East, and at an elevation of 386 meter. Fig 1 illustrates the location of the airport in Khartoum city. As shown in Fig, the airport is located in the core of the capital and is surrounded by a residential area and more crowed zone in Khartoum city. To the north, the Blue Nile River borders the airport along with residential areas located to the north and south of the approach ends of the runway.

The surrounding areas are zoned for different land uses such as government and private offices, military areas, universities and institutes, commercial and industrial, recreational and various other uses.

3.2 Terminal Building

The terminal building is located in the eastern side of the Airport. It has four gates equipped with four baggage claim devices, and

two security checkpoints. The terminal building is divided into four terminals, international departure; international arrival; domestic flights; and Hajj terminal.

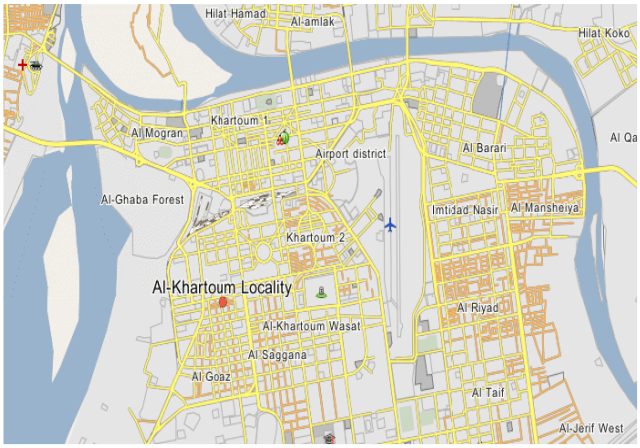

Fig 1: the Airport location map

The international terminal for departure passengers is located in the west north part of the terminal where airline check-in counters are located on the public side and the security screening checkpoint. The terminal area is about 1600 square meter and can accommodate 950 passengers per hour. Prior to entering the security checkpoint, two small coffee shops provide passengers food and drinks and the gift shop sells reading materials, travel essentials as well as vending machines. There is a VIP Lounge in the international terminal, located north to the departure terminal. It has small area 600 square meter and single gate, check-in desks, security checkpoint, immigration and customs counter. Fig 2 shows the check-in desks in international departure terminal.

The international terminal for arrival passengers, the eastern part of the terminal building can accommodate four flights at the same time about 1200 passengers per hour and equipped with six baggage conveyer belts. The terminal area is about 5400 square meter and contains immigration and customs counters, baggage claims, guest services such as duty-free shops, money exchange office, rental cars and hotels, and communication services (see Fig 3).

The domestic flights area in the terminal building is located between the international departure and arrival terminals. This terminal can accommodate two flights about 900 passengers per hour and contains check-in desks, immigration and customs counters, and passenger boarding lounges. Hajj Terminal accommodates about 900 passengers per hour, and is divided into areas for check-in desks, customs, immigration, greeters', passenger boarding lounges. It has a well-equipped health unit, a civil defence facility and two passenger gates.

Airport security is managed by the Department of Civil Aviation. All accesses for passengers, freight, services and maintenance units are controlled, and all official personnel are required to wear identification badges. Passenger monitoring and luggage x-rays are in place at all access points before accessing the flights check in terminal. There are no air bridges, passengers are conveyed to/from terminals/aircraft by bus. Medical services are available in the International Terminal. WiFi facility is available in the airport lounge.

3.3 Airside Area

This is an aircraft manoeuvring area located in the eastern side of the Airport. It includes the runway, taxiways, and aprons. The Airport has a single runway, Runway 18/36, is located in the eastern side of the airport. The runway is oriented in a north/south direction, and is 2980 meter in length, 45 meter in width, and paved in asphalt, as specified by ICAO [18]. It has paved shoulders of width 7.5 meter. There is no helipad, helicopters land on the main runway and park in a designated area. Fig 4 shows the runway strip area.

Fig 2: the Airport international departure terminal

Fig 3: the Airport international arrival terminal

Fig 4: the Airport single Runway 18/36

Taxiways are defined pavement surfaces used for aircraft to travel safely between the runway and other airfield destinations such as aprons, hangars, and terminals. As a result of having a single runway and a linear organization of facilities, the taxiway configuration at the Airport is relatively simple and is comprised of connector taxiways, and high speed exit taxiways. Connector taxiways include Taxiway A, Taxiway B, Taxiway C, and Taxiway D, intersect the runway perpendicularly, connecting airfield destinations and the runway with the taxiway system. The

high speed exit taxiways are Taxiway G, and Taxiway M offer aircraft an acute angle to quickly exit the runway after landing, increasing its throughput capacity during periods of frequent aircraft operations. Airport taxiway is 23m in width and from 100m to 450m in length. Fig 5 illustrates the taxiway configuration at the Airport.

Fig 5: the Airport Taxiway Configuration

Aprons are large paved surfaces designed for the parking and servicing of aircraft. Aprons provide access to terminal and hangar. The Airport has four primary aprons that serve the main terminal building, and the numerous corporate and private hangars based on the airfield. The terminal apron (3), approximately 100,000 square meter in area, is located adjacent to the main terminal building and is intended for the exclusive use of commercial airlines to transfer passengers and luggage to and from aircraft. This apron is also intended for the commercial airlines to service, fuel, and deice aircraft. The north apron (4) offers parking locations for transient aircraft as well as access to aircraft services facilities. The south aprons (1) and (2), approximately 33,000 square meter in area, provides access to aircraft hangars for long stay or maintenance and private aircrafts. Fig 6 illustrates the locations of the four apron areas at the Airport.

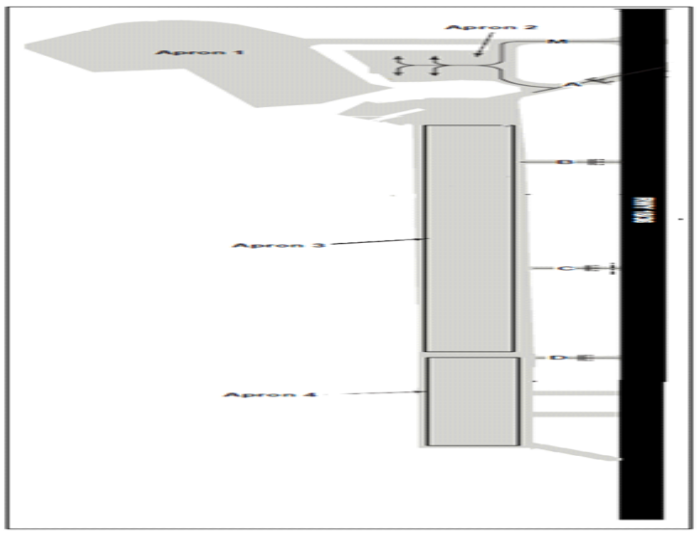

Fig 6: the Airport apron locations

3.4 Other Airport Facilities

There are other existing facilities such as navigational aids equipment, control tower, and other airport services. The Navigational aids (NAVAIDs) are forms of visual and electronic equipment designed to assist pilots in identifying and navigating to an Airport. NAVAIDs that emit electronic signals are especially useful to pilots operating properly equipped aircraft

when navigating an approach to an airport in poor visibility weather conditions. While most NAVAIDs are ground-based equipment that are installed on an airfield, some are satellite-based that provide navigational signals for properly equipped aircraft.

Visual NAVAIDs are those allow a pilot to visually identify the airfield on approach to landing, when taxiing after landing or prior to takeoff. The visual NAVAIDs located at the Airport include Rotating Beacon, wind indicators, precision approach path indicators, runway edge lighting, runway centre line lights, runway touchdown zone lights, runway pavement markings, airfield signs, and taxiway edge lighting.

Electronic based NAVAIDs serve an important function at the Airport as they allow aircraft to operate during conditions where visibility is limited. Complementing the visual NAVAIDs, electronic NAVAIDs allow an airport to remain open and increase the rate at which aircraft can arrive and depart during conditions that limit a pilot to visually navigate an aircraft. They operate by transmitting electronic signals which are received by avionic equipment installed on an aircraft providing position, altitude, and speed information which allows a properly trained and certified pilot to navigate an aircraft using the instrumentation in the cockpit. Methods of providing electronic navigational information range from ground-based transmitters installed on the airfield of an airport to satellites orbiting the Earth. Electronic NAVAIDs utilized at the Airport are Instrument Landing System and Global Positioning System.

Air Traffic Control (ATC) at the Airport is responsible for the safe separation of aircraft, while the Terminal Radar Approach Control Facility (TRACON) facility is responsible for the safe transition of aircraft into and out of the airspace surrounding the Airport. In addition, the ATCT and TRACON facilities also provide traffic advisories when requested by pilots. Both ATC units are located in the control tower as shown in Fig 7.

Fig 7: Airport Control Tower

The services provided in the Airport include fuelling, ground handling, limousine, meteorological, civil defence, services for people with special needs, and VIP and businessmen services.

3.5 Automobile Parking

At the Airport, there are parking spaces for commercial airline passengers, terminal building tenant employees, and rental car vehicles divided between five different lots. The public long-term parking lot, located south to the departure terminal building, has

the largest parking capacity about 120 available spaces. South of the domestic terminal building is a lot for public parking that are designated only for vehicles waiting to pick up arriving passengers.

South of the arrival terminal building near the baggage claim entrance is a lot is designated short-term lot that provides parking capacity about 80 available spaces. In combination with the rental car service that has a capacity of 60 vehicles.

Parking for employees at the Airport is available at two lots east of the rental car lot that have a combined capacity of 50 vehicles while parking for VIP employees and passengers is available at lot adjacent to the VIP terminal building that have a combined capacity of 30 vehicles. In addition to these lots, a lot located south of arrival terminal for public parking that are designated only for vehicles waiting to pick up arriving passengers.

4. Travel Demand Analysis

Travel demand is an important element of the study, as it provides the basis for evaluating the capacity of existing airport facilities and their ability to accommodate future travel demand. This section analyses and examines the passenger data and describes future passenger projection.

The data collected of passengers boarding commercial service aircraft that transported to and from the Airport and include on scheduled commercial service aircraft or unscheduled charter aircraft were analysed. The Passenger data is provided to Airport management by commercial passenger service carriers, who maintain counts on the number of people that are arrived to and departed from an airport. Fig 8 illustrates the historical passengers at the Airport for the period between 2012 and 2018.

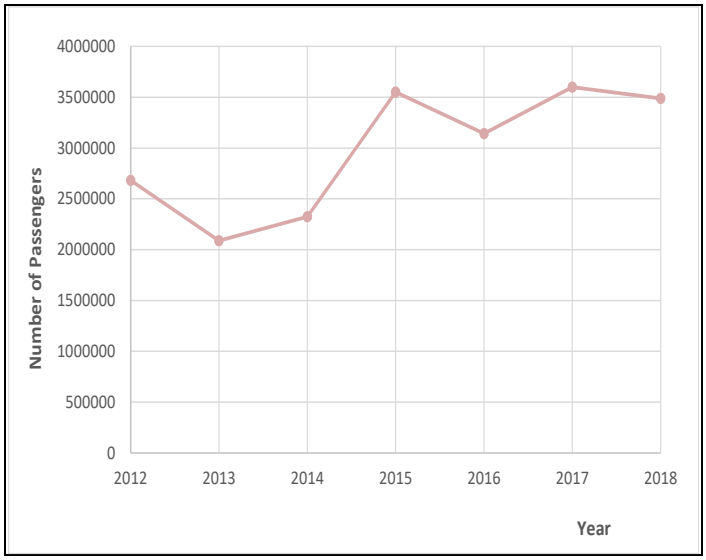

Fig 8: the Airport Passengers during 2012 – 2018

As shown in Fig 8, the historical number of passengers at Airport fluctuated between a low of 2,088,918 in 2013 and a high of 3,600,121 in 2017. From 2012 through 2018, passengers have increased from 2,681,986 to 3,488,252 respectively, at a Compounded Annual Growth Rate (CAGR) of 5.0 percent.

The growth rate methodology is used to develop projection for passenger. The growth rate methodology examines the percent change in activity between two points in time, and assumes that future activity will change at this rate throughout the forecasting period. Between 2012 and 2018, there was a 5.0 percent annual increase in passenger. Applying this CAGR, passenger are forecasted to grow to 5,581,203 in 2030, and 7,325,329 in 2040.

Sudan's Civil Aviation organizes trips to a foreign station, about 16 in Africa and the Gulf and the Middle East. The longest flight from Khartoum to the Nigerian city of Kano. In spite of the problem of US sanctions that faced Sudan in the last thirty years, the market for airlines shows huge growth, only five companies were flying to Khartoum in 2002 the number had increased to 35 companies and Sudan Airways transported 167 thousand passengers in domestic flights in 2018 and the number rose to 260 thousand in 2019.

5. Challenges and Constrains

The study identified challenges and constrains facing the increasing number of travellers in Khartoum airport. This is supported by the documentation and discussions with airport managers, airlines, Sudan Civil Aviation and airport users. Efforts are being made to address these issues. There are still obstacles to be overcome, including the cost of implementation, potential disruptions to ongoing operations and the country under the USA sanctions.

5.1 Physical boundaries restrictions

The physical boundaries of the Airport are the main challenging for increasing airport capacity. The Airport is located in the core of Khartoum city, the more crowded area in the capital of Sudan. The eastern and western boundaries of the Airport are surrounded by residential areas. The neighbouring areas are zoned primarily for office use, military area, universities and institutes, commercial and industrial uses, recreational uses and various other uses. It should be noted that adjacent areas surrounding the airport prevent any expansion for future development. Available land on- and off-airport offers limitations for increasing airport capacity. This will constrain the approaching and departure routes. Given the land scarcity in airport surroundings there is a big pressure from area neighbouring community to expand the Airport. Therefore, it seems impossible to expand the Airport's size for improving airport capacity.

5.2 Infrastructure limitations

The far more difficult problem is the limitation of the existing infrastructure of the Airport for increasing its capacity. It is not possible to expand the air-side capacity by addition of runways and taxiways for more planes to take off and land. The general layout of the apron at Airport was not desirable for handling wide body aircraft and parking irregularly reduces the space of apron. Furthermore, the vehicular and aircraft movement around a parked aircraft were of concern. The aprons were poorly lit. The airside area suffered severe distresses such as potholes, fatigue and longitudinal cracking, deterioration of asphalt pavement, lack of drainage system and maintenance.

The challenges of using congested international arrival terminal for transit passengers, concessions area and toilets. Toilet facility is still a major problem in Khartoum airport. Air Traffic Control (ATC) in the busy terminal area is becoming one of the main challenges confronting air traffic controllers.

5.3 Operational restrictions

The Airport functions under the operating constraints of the high temperature, thus the quiet period for the airport is 12:00 to 17:00, and the busy period is from 17:00 through to 05:00 with the inward and outward passenger and freight movement. The technical peak hour capacity and handling capacity of terminal and landside combined with the level of service standard. This peak hour capacity is based on the available facilities and use of

airport space. The physical effort involved in standing, waiting in line, lifting heavy bags, and walking long distances cause fatigue to passengers. If the airport capacity is not expanded, continued growth in air travel demand will lead to ever-worsening congestion.

5.4 Sudan Airways under sanctions

After the country was placed on a US sanctions list in 2006 for war crimes against its own people and support for known terrorists, the company found it difficult to source new aircraft, spare parts and all the other services that are required to allow an airline to function. Struggling to maintain services, it was forced to acquire aircraft wherever possible. Those aircraft fly seven international routes as well as four domestic destinations. The October 2017 decision to ease sanctions allowed US companies to trade with the African nation once again. However, Sudan remains on the US list of state sponsors of terrorism, which means the airline's equipment situation is unlikely to improve in the near future.

5.5 Environmental constraints

The environmental capacity caused by the airport to the environment and population. The most limiting factor is the amount of noise produced. The environmental capacity can be further limited by other conditions like emissions or safety. The residents surrounding the airport are impacted by noise, pollutants, safety zones and land-based traffic corridors which are often very congested due to local and airport designated traffic.

5.6 Car parking problems

The parking spaces available at the airport are insufficient to accommodate the increasing number of the employee automobiles and rental car as well as arrival waiting cars. Way finding difficulties in airport roadways, parking facilities, and terminal building.

6. Procedures for Improvement

Actions or solutions to address the challenges describe in the previous section were identified during this research through discussion with airport mangers, airlines, pilots, and government authorities. The study provides tools for airport managers and government authorities to improve the current airport performance. The following summarizes key issues, the efforts currently being made to address them and proposal solutions.

The easier problem to solve is the terminal building capacity, the size and serviceability of terminals (number of gates, size of boarding lounges, amount of parking, etc.). There is room to expand terminal capacity supported by airport revenues such as passenger facility charges, space rentals, etc. Establishing a hall in the terminal building for transit passengers passing through the airport for long hours to void overcrowded arrival hall. Relocation of the ATC is the solution to expand the terminal building area. Easing navigation by the use of modern technologies to help with signage or digital way finding. Solutions to way finding issues focus on efforts to improve public service signage in terminals and airport helpers to assist passengers through the airport. It is needed to make retail and food service concessions more easily accessible. More toilet facilities and restrooms for passengers are urgently needed.

It is possible to increase an air-side capacity without having to expand the airport's size. Additional runway length to be 4000 meter which make it possible for big aircraft to take off and land. Paved shoulders are required for all taxiways to increase their width of safety area and object-free area for future Aircraft Design. Extending the apron to the east for two additional aircraft parking locations and adopt an angled parking system which in most cases allowed aircraft to arrive and depart without accidents. Major rehabilitation of deteriorated pavement and repaint the markings are needed. Improving the existing drainage system by adding more drains to facilitate drainage of surface water.

The study suggests to reduce fatigue that passengers experience at the Airport, availability of bag delivery services relieve travellers of difficulties handling luggage. Enhancing customer services by facilitating airport staff to be able to handle customer requests immediately and effectively through pad devices or wearable technologies. Adding more seating at check-in, in the bag claim hall, and in terminal halls. Reducing waiting time by utilising technology to monitor waiting time and to expedite processes. Providing necessary and real-time information such as the flight time, flight schedules, baggage on the belt, and special discounts in the duty free. Using social media to engage with passengers in open communication, and to receive feedback. Streamlining the customer experience by using mobile applications to order food online or providing payment options at the parking facility to streamline the process.

Sudan Airways are struggling to survive under sanctions. This will have no solution until Sudan removed from the list of states sponsoring terrorism. In the past, the company has used aircraft on operating leases from other Sudanese and foreign companies to maintain services. Nowadays, aircraft are sometimes leased from Sudanese operators such as Badr Airlines and Tarco Air.

After the revolution change of the government in April 2020, there are glimmers of light on the horizon. After these sanctions have been partly removed, Sudan airways starting to have contacts with aircraft manufacturers such as Boeing and get new aircraft. The airline has an eye to longer-range routes in the future and hopes that the role of Khartoum Airport can be enhanced.

New socio-technological trends can influence the traffic developments as well as the behaviour of passengers and cargo at the airport. Airport usage and utilisation can change dramatically due to these developments with a major impact on capacity requirement. Smart personal technology can be used to optimise the operational processes and commercial activities. In future dwelling times of passengers and cargo at Khartoum airport can be reduced with a large impact on the business model while the use of telecommunications tool will foster the use of airlines.

The parking problem can be solved by additional spaces for long-term parking and expansion of rental car/ready return lot.

7. Conclusion

The study undertaken to evaluate the existing facilities of Khartoum airport and its ability to accommodate forecasted demand has identified challenges for increasing travel demand. Addressing these challenges by improving existing facilities and services will enhance the performance of the airport. The conclusion drawn as follows:

- The historical data of passengers at the Airport for the period from 2012 to 2018 showed that the number of passengers have increased from 2,681,986 to 3,488,252 respectively at a growth rate of 5.0 percent. Applying this growth rate, the passengers are forecasted to grow to 5,581,203 in 2030, and 7,325,329 in 2040.
- Evaluation of existing facilities and services of the Airport has identified challenges facing the increasing number of

passengers which include physical boundaries, existing infrastructure, operational processes, Sudan Airways under sanctions, environmental constrains, and car parking problems.

- The study identified the terminal building and operational procedures as the main constraint for improving the airport performance. Therefore, the improvement has to be done by expanding the terminal building and optimizing the operation procedures and commercial activities, by introducing flexibility and using modern technologies.
- There is a need for increasing the airport capacity in the airside area by additional runway length, increasing taxiways width and extending apron area for additional aircraft barking spaces. Furthermore, rehabilitation of deteriorated pavement and improving the drainage system are needed.
- The airport of Khartoum City will continue operating until the new airport of Omdurman City is ready. Thus, the study provided some proposals and actions, as a tool supporting the decision makers for increasing the current capacity as much as possible.
- It appears clear that an integrated and collaborative effort among airport managers, airlines, and Sudan civil aviation will be required for the successful development of the airport capacity in future.

References

[1] Sudan Civil Aviation Authority, "Sudan Airports: Information Directory", TM for Printing Co. Ltd, Khartoum, 2007.

[2] FAA 1981, Airfield and Airspace Capacity/Delay Policy Analysis, FAAAPO-81-14, Washington, DC: Federal Aviation Administration, Office of Aviation Policy and Plans, December 1981.

[3] Reichmuth, J., P. Berster and M.C. Gelhausen (2011), "Airport Capacity Constraints: Future avenues for growth of global traffic". CEAS Aeronautical Journal, Vol. 2/1-4, pp. 21-34. DOI:10.1007/s13272-011-0034-4

[4] Barnhart, C., D. Fearing, A. Odoni and V. Vaze (2012), "Demand and capacity management in air transportation". EURO Journal on Transportation and Logistics, Vol. 1/1, pp. 135-155. DOI:10.1007/s13676-012-0006-9

[5] Upham, P., C. Thomas, D. Gillingwater and D. Raper (2003), "Environmental Capacity and Airport Operations: Current issues and future prospects". Journal of Air Transport Management, Vol. 9/3, pp. 145-151. DOI:10.1016/s0969-6997(02)00078-9

[6] Graham, B. and C. Guyer (1999), "Environmental sustainability, airport capacity and European air transport liberalization: irreconcilable goals?" Journal of Transport Geography, Vol. 7/3, pp. 165180. DOI: 10.1016/S0966-6923(99)00005-8

[7] D'Alfonso, T. and A. Nastasi (2014), "Airport–Airline Interaction: Some food for thought". Transport Reviews, Vol. 34/6, pp. 730-748. DOI:10.1080/01441647.2014.971470.

[8] Janic, M. (2008), "The Future Development of Airports: A Multidimensional Examination". Transportation Planning and Technology, Vol. 31/1, pp. 113-134. DOI:10.1080/03081060701835803

[9] Jacquillat, A. and A. Odoni (2015), "Endogenous control of service rates in stochastic and dynamic queuing models of airport congestion". Transportation Research Part E: Logistics and Transportation Review, Vol. 73, pp. 133-151. DOI:10.1016/j.tre.2014.10.014

[10] FAA (2015), FACT3: Airport Capacity Needs in the National Airspace System. https://www.faa.gov/airports/planning_capacity/media/FACT3-Airport-Capacity-Needs-in-theNAS.pdf

[11] Brinton CR (1982) An Implicit Enumeration Algorithm for Arrival Aircraft Scheduling. In: Proceedings of the IEEE/AIAA 11th Digital Avionics Systems Conference, Seattle, WA, USA, October 5-8

[12] Isaacson DR, Davis TJ, Robinson JE (1997) Knowledge-Based Runway Assignment for Arrival Aircraft in the Terminal Area. In: Proceedings of AIAA Guidance, Navigation, and Control Conference, New Orleans, LA, USA, August 11-13.

[13] Bazargan M, Fleming K, Subramanian P (2002) A Simulation Study to Investigate Runway Capacity Using TAAM. In: Proceeding of the 34th Winter Simulation Conference (WSC'02), San Diego, California, USA, December 8-11

[14] de Neufville R, Odoni AR (2003) Airport Systems: Planning, Design, and Management. McGraw-Hill, New York

[15] Atkin JAD, Burke EK, Greenwood JS, Reeson D (2008) On-line Decision Support for Take-off Runway Scheduling with Uncertain Taxi Times at London Heathrow Airport. Journal of Scheduling 11(5):323346

[16] G. F. Newell, Airport Capacity and Delays, Transportation Science, 13(3), 201–241, 1979.

[17] V. Butler and R. W. Poole, "Increasing Airport Capacity without Increasing Airport Size," Policy Study 368, Reason Foundation, Los Angeles, CA 90034, P 49, March 2008.

[18] International Civil Aviation Organization (ICAO), "Aerodrome Design Manual, Part 2, Taxiways, Aprons, and Holding Bays, 4th Ed, Doc 9157, AN/901, 2005.