

# Khartoum sky trains network: a study on implementing caterpillar trains concept in Khartoum

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**Abstract.** The experience of using public transportation in Khartoum is hectic due to over (1.5) Million seats in daily deficit. This research explores the daunting issues of public transport in developing countries like Sudan, taking Khartoum as a case study, and studies the possible alternatives to find an innovative solution that counters them. This paper reviewed the concept presented by MIT scholars in 2017 which was an innovative idea of elevated mini-trains that are intended to run over city streets called (Caterpillar Trains). The paper investigated the use of the C-Trains when integrated with LRT to form the Khartoum Sky Trains Network (STN). It was found that the STN is an optimum model for developing countries, as they were found able to meet the demands of public transport, in both short term and long term. The expected various environmental, social and economic impacts of such large infrastructure project were also studied. Finally, the research suggests that the Build-Operate-Transfer (BOT) contracting module can be utilized to overcome the construction costs, the concession period of which was found through a FORTRAN95 program.

## 1 Introduction

Public transportation in Khartoum has been a hot topic for quite some time now, which started after South Sudan gained its independence in 2011, causing a major economic disaster for the North [1].

This instantly affected the oil prices and caused currency devaluation, which in turn caused a spike in spare parts prices and availability, leading to severe scarcity in the only available mode of transport; buses [2]. The problem was briefly relieved by buses dubbed by the public “Al-waly Buses” that had generous seating capacity.

However, that didn’t last long. The expensive spare parts due to sanctions, taxes, and customs caused Al-waly Buses’ owners, who had then become private sector drivers after the privatization of the firm, to ditch their buses; causing a severe scarcity in the number of operational buses. With the buses going scarce, the people, government and country as a whole are now suffering a number of consequences that would not be present in an otherwise stable sector. Nearly millions of dollars of productivity hours are being wasted every day, jobs are harder to access; businesses are negatively affected, and social injustice is on the rise [2].

This research aims to suggest a system of transportation that is modern and comfortable for citizens in both the short and the long term. It studies transportation and economic feasibilities as well as the social impacts of creating a transit network that covers all

areas in the state, using two types of trains; main trains to serve the more crowded lines, and the cheaper, much more flexible (C-Trains) to approximately all the roads in the city with relatively lighter traffic.

## 2 Literature review

In its Master Plan for Transport and Mobility [3], the ministry of transport and infrastructure in Khartoum states that the deficit in daily seating is over 1.5 million seats at the time of making the plan. As part of an ambitious attempt, the master plan presented several options that were considered viable for filling the deficit gap. They include Underground metro, local tram, regional train, and Bus Rapid Transit (BRT).

### 2.1 Caterpillar Trains (C-Trains)

Ashwani Kumar Upadhyaya and his colleague, Emil Jacob, both Ph.D. researchers who have interest in railway engineering, recently won an award at an MIT-held competition for their innovative idea of mini elevated C-Trains (Caterpillar trains), which are a network of lightweight elevated train cabins that will cover the whole city. [4]

## 3 Methodology

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In this section, we will discuss how the design procedure was carried out, as well as the cost-benefit analysis and the assessment of the environmental, economic, and social impacts.

### 3.1 Design and appraisal procedure

This assessment was made according to the transport appraisal process which we adopted from the Transport Analysis Guidance (TAG), provided by the UK's Department for Transport, issued in January 2014 [5]. The guidance provides a very detailed, three stages procedure to make sure every proposed project is worth the investment. The first step of this procedure is called the option development. It is concerned with preliminary studies that aim to demonstrate that a specific project is feasible. The second and third stages are conducted after the initial approval of the project and are meant to provide specific, detailed information and estimations for construction and maintenance purposes [5].

The appraisal process has several steps of "elements" that flow logically to test the feasibility of any project. These processes were tailored to meet the Sudanese conditions while keeping in mind that the overall objectives are met. These processes, or elements, are:

#### 3.1.1 "Understanding the current situation"

By means of studying past literature and careful observation, we developed an understating of the current transport sector. This included studying legislative policies, levels of service, and demand patterns.

#### 3.1.2 "Understanding the Future Situation"

This step mainly focused on studying population growth based on the UN's population forecast and, consequently, the changes in the demand, LOS, and the transportation systems themselves. This allowed us to anticipate a range of possible scenarios that helped us greatly in assessing possible options.

#### 3.1.3 "Establishing the Need for Intervention"

Drawing on the aforementioned information, we then made a sound body of arguments to show that the current and future situations indeed need an intervention. The legislative deficiencies at the ministry of transport in Khartoum state, and its interlined authority with the local state, the federal government, and traffic police were some of the main arguments that led to this result.

#### 3.1.4 "Identifying Objectives"

Reflecting on the previously discussed issues, we arrived at a preliminary set of targeted objectives that we wish to accomplish: These objectives were identified based primarily on the six features of the modern public transport, as well as an examination of failed past projects and inspection of the criteria needed to avoid those

failures. The objectives are High Accessibility, High Frequency, Acceptable Speed, Comfort, Low Costs, reduced emissions and noise pollution, and Clear administrative status. [4]

#### 3.1.5 "Generating Options"

In accordance with TAG guidelines, we developed a wide range of possible substitutes considering all modes, substructure, guidelines, and pricing, that are likely to meet all the objectives mentioned above, and are applicable in Khartoum. These options included many transport options already considered by the ministry, as well as the C-Trains. These alternatives included the Metro, Light rail transit, regional rail transit, and Bus Rapid Transit (BRT) network.

#### 3.1.6 "Initial Sifting"

With the help of the Early Assessment and Sifting Tool, and based on the evidence acquired from Khartoum transportation master plan, we arrived at the following:

1. While the light rail transit system and the C-Train network don't quite address all the issues separately, when combined, they became better capable of doing so. Therefore, they were branded as one potential option for further assessment.
2. In spite of the fact that it strongly meets all the objectives, the Metro network option was omitted due to issues concerning its high cost and the surface water table issue in Khartoum, caused by inadequate sanitary systems. Issues with the width of the streets and low land availability caused the elimination of the regional rail transit option as well.
3. The absence of basic road infrastructure makes the otherwise perfect option of BRT network very costly to deliver and is, therefore, rejected.

#### 3.1.7 "Option Assessment Report"

In this step, we needed to shorten the list of options to only include the best-performing ones by gathering information regarding costs, advantages, and their impacts. Then we assessed them against the Transport Business Case criteria using the Option Assessment Framework provided by the TAG.[5]

Having collected the current and future demand in the previous stages and done all the desk-based work, the most important parts of which will be shown in the calculations section, we arrived at the optimum mode of transfer in Khartoum state to be, indeed, the STN network.

### 3.2 Environmental, Economic & Social Impacts

#### 3.2.1 Environmental Impact

The Environmental Impact Assessment (EIA) was conducted in accordance with the transport analysis

guide. At this early stage, this assessment was based on literature published by specialists or people with a far-reaching understanding of how the evaluation of this impact area is carried out.

### 3.2.1.1 Noise Impact

In a study on a newly proposed line of construction of the BLRT extension project [6], it was established that short-term elevated noise levels are expected and cannot be avoided for a project of this kind during the construction phase. However, they can be mitigated by barriers. [7]

### 3.2.1.2 Greenhouse Gases

From the Federal Transit Administration (FTA) Greenhouse Gas Emissions Programmatic Assessment, carried out to analyze the GHG emission rates produced by transit projects [8], results for light rail projects suggest that projects with high ridership are expected to lower the overall GHG emissions regardless of number of stations, length of trips, or alignment.

### 3.2.1.3 Air Quality

A report from the American Public Transit Association (APTA) presents evidence that every individual shifting from driving a private vehicle to riding a light rail transit mode reduces the hydrocarbon, nitrogen oxide, and carbon monoxide emissions drastically [9].

### 3.2.1.4 Landscape

The C-train was designed with the intention of making it far less visually intrusive than any other kind of elevated transit in mind. This is obvious in that the train is around half the height and width of any monorail system and the fact that the arches which hold the train are not any more invasive than a normal concrete pole [10].

## 3.2.2 Economic Impact

We assessed projected changes in consumer surplus, economic development, and Land and property values by Studying previous, similar economic impact assessments on rail transit projects to identify the direction on which the STN will steer the local economy.

### 3.2.2.1 Changes in Consumer Surplus

While the exact amount was not determined, it is established that the STN, when compared with the current transport system, will have no problem in saving more than enough time for riders which, in turn, will increase the consumer surplus. [11]

### 3.2.2.2 Economic Development

RIMS II is a set of regional multipliers maintained by the Bureau of Economic Analysis, used to predict the future

impact of large infrastructure projects. Since Sudan is yet to develop an independent RIMS II Model, we adopted an already made model for Florida, U.S. [12], closest to represent the circumstance in Khartoum at the time. The analysis indicated that the impact of this kind of transit projects tends to give back generously.

### 3.2.2.3 Land and Property Value

Improved accessibility to urban areas can cause major development projects in them. Demonstrating this positive impact is a case study of property prices and sales conducted in the area of Atlanta [13], The study focused on the link between property values and mass transit stations. A model was presented and analyzed, and the results indicated a general rise of prices in these areas. The results cite a \$62 rise for floors above the mean number of floors, determined at 5, among many other findings.

### 3.2.3 Social Impact

The Social Impact study is an indirect result of the previous two impact studies. To cite a compelling point supporting this argument is [14]: “The lower costs and increased accessibility due to transport improvements reduce the costs of the households’ travel and, in turn, increase demand for goods and services. Such changes ripple through the market, increasing employment, output, and income in the short run. Over time, dynamic development effects derive from the mechanisms set in motion when transport service improvements activate a variety of interconnected economy-wide processes and yield a range of sectoral, spatial, and regional effects, that augment overall productivity.”

It could be argued that these changes will result in boosted employment rates and in an expansion in transport-using firms, which is expected to result in increasing the social inclusion of the ignored parts of the society.

## 3.3 Calculations

### 3.3.1 Demand Calculation

#### 3.3.1.1 Key Assumptions

1. C-Trains’ Utility Function being a third of the demand for transportation.
2. Linear growth of demand.
3. Patterns of demand are not changing.

#### 3.3.1.2 Basic Data

1. The C-Trains capacity is 50 passengers per carriage [15].
2. The C-Trains practical lower limit on headway is 1.5 minutes during rush hour [16].
3. Maximum capacity of Light rail trains is 300 per train [17].

#### 3.3.1.3 Future demand of the network:

Peak demand percentage = Total population of the state in 2011 ÷ Peak hourly demand for public transport [3].  
 = 2,000 ÷ 8,000,000 = 0.025%

Putting to use the UN Population forecast; the population of Khartoum state in their last forecasted year, 2100, was calculated and found to be 30.6 Million [18].

Demand = 70 % of Khartoum’s population [3]  
 = 21,392,266 Passengers

Demand for STN = Total demand × STN Utility Function  
 = 7,273,370 Passengers

Peak hourly demand in 2100 = Khartoum population × peak demand percentage  
 = 7640 Passengers/ lane/ hour

C-Trains hourly capacity = Trains per hour × Capacity of train × No. of tracks (two; above and below)  
 = 4000 Passenger/hour/lane

When the peak demand exceeds 4000, the integration of an LRT system that covers high demand areas will be needed. Interpolation between the existing demands and the calculated demand in 2100 found that 2054 is the year when the integration of the LRT system into the STN will be needed.

Light Rail capacity = Trains per hour × Capacity of trains × No. of tracks (one) = 9000 Passenger/hour/lane

### 3.3.2 Costs Calculations

#### 3.3.2.1 Initial construction costs

*Basic Data:*

1. Costs of building the C-Train network was estimated by the researchers to be \$1.7M per kilometer. [19]
2. The length of the network that needs to be covered by C-Trains is approximately 470 Km, while the LRT will cover approximately only 130 Km. [20]
3. Cost of the 600 MWA Thermal plant to run the network = \$850 Million. [21]

∴ Total Construction Costs = \$3.2 Billion

#### 3.3.2.2 Running Costs:

Annual running costs; which includes the operation and maintenance costs (O&M), personnel hiring costs, electricity costs, among others, were evaluated using the LRT model to perform a sensitivity analysis, introduced by Utpal Dutta of Detroit Mercy University [22]:

$$O\&M = 223462.7 \times (\text{Route Miles})^{0.744} \times (\text{Car-Miles})^{0.144}$$

*Definition of System Variables:*

**Annual Route Miles (Route Miles):** Stands for the miles taken in a directional route, average of 10 Km was used:

$$\text{Route miles (D)} = 2 \times \text{Route length (one-way)}$$

$$\text{Route miles (D)} = 2 \times (10 \text{ kilometers}) = 12.42742 \text{ Miles}$$

**Annual Car Revenue-Miles (Car-Miles):** It is the total number of miles served by all the trains: Car-Miles = Number of cycles during one day × Number of operating days in a year × Route miles per cycles × Number of cars per train

$$\text{Cycles during peak hours} = 40 \text{ cycles per hour}$$

$$\text{Cycles during off-peak hours} = 6 \text{ cycles per hour}$$

it is estimated that there are six peak hours and an additional 12 off-peak hours in a typical working day: total number of cycles = 6 × 40 + 6 × 12 = 312 cycle/day

Adopting an estimate of 300 working days per year based on the assumptions, and lastly, the C-Trains prototype is dependent on one car per train.

$$\therefore \text{Car-Miles} = 312 \times 300 \times 12.42742 \times 1 = 939512.952 \text{ Miles}$$

$$\therefore \text{Total annual network O\&M cost using LRT model} = \$10.6 \text{ Million/year}$$

$$\text{Total annual O\&M cost of the plant} = \$11.3 \text{ Million/year [21]}$$

$$\therefore \text{Total annual O\&M costs are approximated at } \$22 \text{ Million/year.}$$

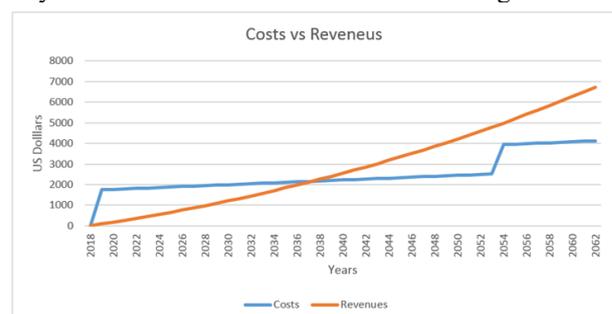
### 3.3.3 Cost-Benefit Analysis

For a project this big, the most suitable way to provide the necessary funding is by using a BOT contract. we conducted a cost-benefit analysis to decide whether a BOT contract is feasible. As we already calculated the costs of the project, we only need to calculate the profits and the payback plus profits period.

#### 3.3.3.1 Total Revenues: Key Assumptions:

1. The number of passengers throughout a given year will be constant.
2. Only the daily ridership will be taken into consideration, the other viable side-investments (Like advertisement or small shop rentals) are ignored.
3. The initial Inflation rate will be taken as 55.6%, with an annual increase of 12%, as it stood in March 2018 at the time of this analysis. [23]
4. The initial ticket price of 10 SDG will be adopted, with the exchange rate to USD being 45 SDGs, as it stood in March 2018. [23]

The Costs vs Revenues chart was developed using a FORTRAN95 Software specifically programmed for this purpose using a function to adjust the ticket prices over the years to account for the inflation rates being at 12%.



**Figure 1.** Costs vs Revenues of the STN.

As clearly seen from the Cost-benefit analysis, the breakeven point would take place somewhere around 2037, with the full capital invested retrieved in equivalent US dollars.

## 4 Discussion and Conclusion

Upon examination, we concluded that the suggestions offered by the government were poorly planned and do not fully satisfy the current much less the future demand. The concept of Caterpillar Trains, however, is both cheap and convenient for solving the transportation problem. In this research, we investigated the impacts of applying a rail network using this particular mode in Sudan.

Our findings indicated that the use of the C-train in constructing the STN as a solution is quite satisfactory from an engineering point of view. In fact, it will have a positive impact on traffic as there are major congestions in the city due to poor infrastructure.

These results also suggest that this mode of transport can be implemented in any developing country as it is economic, lightweight, fast, and can easily run over the narrowest of roads. Also, the C-Train is expected to have minimal visual invasiveness, little noise impact, and reduce Greenhouse Gases (GHG).

We also found that the most convenient option to fund this project is through a BOT contract. The Cost-Benefit-Analysis of the STN then was calculated using a programmed FORTRAN95 software.

## References

1. A. Maasho, "Sudan, South Sudan reach oil deal, will hold border talks."
2. Intibaha Newspaper, "Alwaly buses - manufacturing problems awaiting a solution", 2016.
3. Ministry of Transport and Infrastructures, "Khartoum Transport and Mobility Master Plan," 2010.
4. Jacob Innovations, "Jacob Innovations' MINI ELEVATED C-Trains (caterpillar train)," 2016. [Online]. Available: <http://jacob-innovations.com/cTrain.html>.
5. Department for Transport, "Transport Appraisal Guide," 2014, pp. 1–35.
6. Donald W. MacGlashan, "Analysis: Impact of Noise from the Purple Line Project Prepared," Federal Transit Administration, pp. 1–12.
7. I. (CSA) the metropolitan council in cooperation with Cross-Spectrum Acoustics, "Noise and Vibration Technical Report."
8. G. Filosa, C. Poe, and M. Sarna, "Greenhouse Gas Emissions from Transit Projects: Programmatic Assessment," Federal Transit Administrative Report No. 0097, no. 0097, 2017.
9. American Public Transit Association: Transit Fact Book. Washington, D.C. 104, 1993.
10. E. Jacob, "Elevated Trains Made Feasible - Station design challenge," Jacob Innov.
11. D. J. Forkenbrock and S. Benshoff, "Assessing the Social and Economic Effects of Transportation Projects," National Cooperation of Highways Research Program, vol. 31, no. February 2001.
12. T. Lynch, "Analyzing the Economic Impact of Transportation Projects Using RIMS II, IMPLAN, and REMI", vol. 22181, no. 703. 2000.
13. A. Nelson, "Transit stations and commercial property values: a case study with policy and land-use implications," Journal of Public Transport, vol. 2, no. 3, pp. 77–93, 1991.
14. T. R. Lakshmanan, "The broader economic consequences of transport infrastructure investments," Journal of Transport and Geography, vol. 19, no. 1, pp. 1–12, 2011.
15. K. Kumar, "Gurgaon considers caterpillar train for improved connectivity," Hindustan Times, 2016. [Online]. Available: <https://www.hindustantimes.com/gurgaon/gurgaon-considers-caterpillar-train-for-improved-connectivity/story-uFdOIWX0yHr2BbQTGMnyFO.html>.
16. Transit Information, "Transit Technology Choice Report," 2009.
17. "South Florida East Coast Corridor Transit Analysis Study: Environmental Impact Statement," 2006.
18. "United Nations Population Division DESA," 2019.
19. "Mini Elevated GreenTrains - complete transit solution - powered by green energy," 2016. [Online]. Available: <https://www.climatecolab.org/contests/2016/transportation/c/proposal/1329506>.
20. Researchers work; using Satellite Imagery. 2018.
21. A. A. Sulieman Nada, O Osama, "Construction of Infrastructure Projects in Sudan Using BOT," University of Khartoum, 2009.
22. D. Zhong, "An LRT Operation & Maintenance (O & M) Cost Model to Perform Sensitivity Analysis," Transp. Res. Board, 92nd Annu. Meet., vol. 820, 2013.
23. Central Bureau of Statistics, Republic of Sudan, "Inflation Rate in Sudan from April 2017 to March 2018", 2018.