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Trips Production in Khartoum State

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Abstract: The rapid increase in population, fast urbanization and change, high demand for public transport in Khartoum State necessitates development of a proper transportation plan for the state, to enable predicting the impacts that various policies and programs will have on travel. Travel demand forecasting is an essential part of the transportation planning process and trip production is the first step in the concept of four steps travel demand model. In this paper a model for trip production in Khartoum State is proposed. The trip generation model is based on data collected by the Ministry of Infrastructures and Transportation and a consultant in the period 2008-2011. The exclusion of incomplete data and outliers and the consideration of the car ownership in the development of the model, has resulted in a more realistic estimate of the number of trips produced than those predicted by the currently adopted model of Khartoum State. The results of this study predict the number of daily trips in the year 2035 at 9.56 million person-trips, creating a demand of 6.69 million person-trip/days to be covered by public transport. This will necessitate huge investments in mass transit systems to accommodate the uprising demand.

Keywords: *Transport planning; Trip purpose; Traffic analysis zones; Trips production.*

1. INTRODUCTION

Khartoum State is the capital of Sudan and one of the 18 States of Sudan with a total area of (22,142 km^2), which makes it the smallest state by area. The state lies between longitudes 31.5 and to 34 °E and latitudes 15 and to 16°N. It is surrounded by River Nile State in the North-East, in the North-West by the Northern State, in the East and Southeast by the states of Kassala, Gedaref and Gezira state, and in the West by North Kurdufan state.

Khartoum was established by Ibrahim B Pasha, as an outpost of the Egyptian army and as a regional trading post in 1821, and was proclaimed the capital of the Anglo-Egyptian Condominium in 1899 [1]. Following independence in 1956, Khartoum's population grew from 250,000 to an estimated 3.3 million in 1990 [1], [2]. By 2005, official estimates put the capital's population at 4.5 million, though unofficial estimates quote more than 7 million [1]. The latest census in 2008, found that Khartoum's population had fallen to about 5.27 million [3]. However, according to a recent report of the Sudan Civil Rolls, the number of people registered in the program, in the state, is estimated at 5.34 million as per May 2015 [4]. It was reported that, the population is 79% urban and 74% of the state's population reported their region of origin is to be outside Khartoum [3].

Regarding urban development plans efforts for Khartoum, the first plan dating from the early years of the twentieth century, during the British colonial administration. After independence, several master plans were proposed in the years 1960, 1975 and 2000. However, lack of proper implementation of these plans had led to uncontrolled urban sprawl and land misuse [5].

Thereafter, the State of Khartoum decided to develop a new plan to put an end to irregularities in land use in Khartoum, the so called Khartoum Structural Plan (2007–2033). The main aim of the plan is to integrate different neighborhoods by connecting the various parts of the city with road networks and transport systems [1]. The plan's main objective is to ease reduce congestion in the center, remove squatter settlements and replace them with so-called 'popular housing', and relocate government institutions, military barracks and educational institutions to the city's periphery. Additionally, the plan emphasizes the importance of extending services to rural areas on the fringes of the city, to accompany investment and to increase the efficiency of agricultural production, microfinance support for urban families and support to key industries. The plan also aims to curb the environmental pollution generated by population growth, including stipulations that no new project can be approved unless an environmental impact assessment is carried out. The plan also defined multiple policies to control growth of Khartoum State [5].

In the area of transportation, Khartoum Structural Plan (KPP5) defined only movement corridors EW and NS Axes to ensure the connectivity and accessibility between urban and regional levels [6]. Based on KPP5, Khartoum State developed Khartoum Transport and Mobility Master Plan (KTMMP) defining the major transport networks and projects in Khartoum in the period 2010-2035. This plan is considered as one of few of the transport plans in Sudan based on the concept of four steps demand model.

Factors like low incomes, fast urbanization and change, high demand for public transport, scarcity of resources including capital, sound data and skilled personnel, which are typical for developing countries, present a challenge that requires specific attention.

Transportation planning is needed to create the state or community's vision for its future. It includes a comprehensive consideration of possible strategies; an evaluation process that encompasses diverse viewpoints; the collaborative participation of relevant transportation-related agencies and organizations; and open, timely, and meaningful public involvement. In addition, transport planning is crucial in planning sustainable developments and ensuring accessibility for all individuals.

2. THEORETICAL BACKGROUND

The Transportation planning process relies on travel demand forecasting, which involves predicting the impacts that various policies and programs will have on travel in the urban areas. The forecasting process also provides detailed information, such as traffic volumes, bus patronage, and turning movements, to be used by engineers and planners in their designs. A travel demand forecast might include the number of cars on a highway in future or the number of passengers on a new express bus service. It might also predict the amount of reduction in auto-use that would occur in response to a new policy imposing taxes on central-area parking etc. [7].

There are several methods for transport planning. However, the advancement in computation power of modern computers made the analytical methodology -using mathematical models- the most popular method used for transportation planning [8]. Analytical methodology began to be applied in pioneering urban transportation studies in the late 1940s and during the 1950s. Before these studies, urban transportation planning, when accomplished, was based on existing travel demands or on travel forecasts using uniform growth factors applied on an area wide basis.

Since the early 1950s, several techniques have been proposed to model trip generation. Most methods attempted to predict the number of trips produced (or attracted) by household or zone as a function of (generally linear) relations to be defined from available data. Trip generation is commonly considered as the first step in the four-step modelling process. It is intended to address the question of how many trips of each type begin or end in each location. It is a standard practice to aggregate trips to a specific unit of geography named as traffic analysis zone (TAZ). Traffic Analysis Zones should be as homogeneous as possible in their land use and/or population composition [8].The estimated numbers of trips will be in the unit of travel that is used by the model, which is usually one of the following:

- Vehicle trips;
- Person trips by motorized modes (auto and transit); or
- Person trips by all modes, including both motorized and non-motorized (walking, bicycling) modes.

Trip generation models require explanatory variables that are related to trip-making behavior and functions that estimate the number of trips based on these explanatory variables. While these functions may be nonlinear, they are usually assumed to be linear equations, and the coefficients associated with these variables are commonly called trip rates. Whether the function is linear or nonlinear, it should always estimate zero trips when the values of the explanatory variables are all zeros. Mathematically, this is equivalent to say that the trip generation equations should include no constant terms [9].

The trip generation stage of the classical transport model aims at predicting the Origin- Destination matrix (O-D matrix). In which, the total number of trips generated by zone i (Oi) and attracted by zone j (Dj) for each zone of the study area, are presented. This can be achieved in a number of ways starting with the trips of the individuals or households who reside in each zone or directly with some of the characteristics of the zones. The following factors have been proposed for consideration in many practical studies: income, car ownership, family size, and household structure, value of land, residential density and accessibility.

Regarding trip generations modelling the following methods are commonly used:

A. Growth-factor Modelling:

Growth factor methods are mostly used in practice to predict the future number of external trips to an area; this is because they are few in the first place (so errors can be too small) and also because there are no simple ways to predict them. In some cases, they are also used, at least as a sense check, for interurban toll road studies. The growth factor is given by:

$$F_i = \frac{f(P_i^d, C_i^d, I_i^d)}{f(P_i^c, C_i^c, I_i^c)} \quad (1)$$

where:

F_i: Growth factor
P_i: Population (represented by number of Household)
C_i: Car Ownership
I_i: Income
d: Design year
C: Current year

B. Regression Analysis:

In trip generation modelling the multiple regression method has been used both with aggregate (zonal) and disaggregate (household and personal) data. The first approach has been practically abandoned in the case of trip productions, but it is still the premier method for modelling trip attraction. In a household-based application each home is taken as an input data vector in order to bring into the model all the range of observed variability about the characteristics of the household and its travel behavior.

C. Cross-Classification or Category Analysis:

Although linear regression was the early recommended approach for trip generation, from the late 1960s an alternative method for modelling trip generation appeared and quickly became popular. The method is based on estimating the response (e.g. the number of trip productions per household for a given purpose) as a function of household attributes. Its basic assumption is that trip generation rates are relatively stable over time for certain household stratifications. The method finds these rates empirically and for this it typically needs large amounts of data; in fact, a critical element is the number of households in each class [8]. The trip rate in cell h denoted by t^p (h) is given by:

$$t^p(H) = \frac{T^p(h)}{H(h)} \qquad (2)$$

where:

$t^p(h)$: Total number of trips in cell *h*, by purpose,

H (*h*): The number of households in cell *h*.

3. MATERIALS AND METHODS

3.1 Data Collection

The data used for this study were collected by the Ministry of Infrastructures and a consultant in the period 2008-2011. The data included household surveys, roadside surveys, public transport surveys, traffic counts, special surveys and freight survey. For the purpose of trip production modeling, only the household surveys will be used.

- **Household survey collected data [10]**

  – Khartoum State includes seven Localities (**Fig. 1**), 35 Administrative Unit (AU) and 1345 quarters.
  – The total area of quarters is approximately 179,000 hectares, with an average area of approximately 133 hectares and 3,800 inhabitants per quarter.
  – The quarter`s average population density is about 83 inhabitants per hectare. The population density per quarter is shown in (**Fig. 2**). The survey was conducted on 108 quarters that represent about 8% of total number of quarters.
  – The population sample is taken around 7.3% of the total population of Khartoum, in accordance to the minimum sample size requirements [8].
  – A survey on number of people, average income and car ownership per household (HH) for 8660 household, allowed data collection of almost 45.000 trips (journeys' origin and destination), trip purpose and mode of transport.
  – The trip purpose in Khartoum State is shown in (**Fig. 3**).
  – The car ownership in Khartoum State is shown in (**Fig. 4**) [10]
  – 338 Traffic Analysis Zones (TAZ) with homogeneous characteristics have been defined by the aggregation of households and buildings.

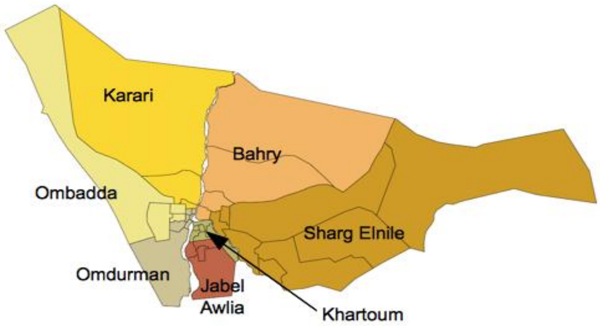

Fig. 1. Khartoum State Localities

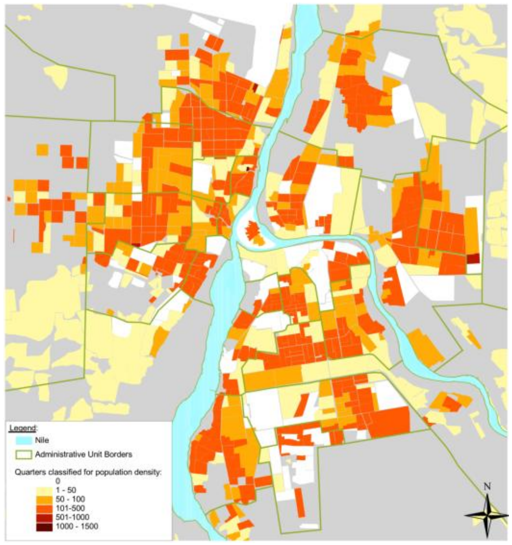

Fig.2. Khartoum population density per quarter

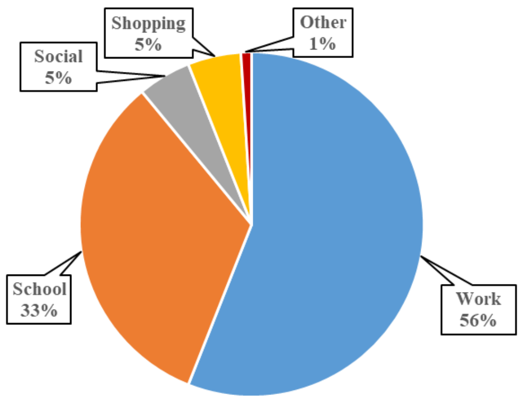

Fig.3. Trip Purpose in Khartoum State

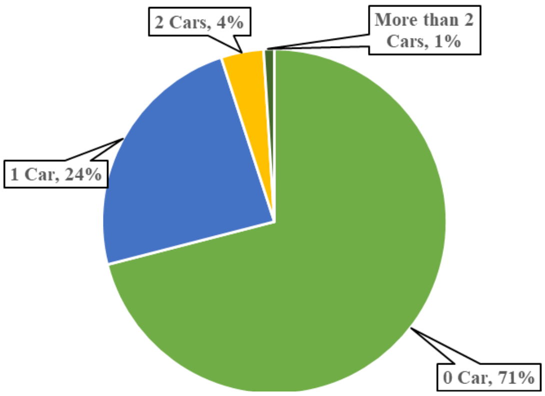

Fig. 4. Car Ownership in Khartoum State

4. RESULTSAND DISCUSSION

4.1 Proposed trip production model

The household (HH) survey data collected in the period 2008-2011 (Total No of HH = 8660) were filtered to identify incomplete dataand outliers resulted in exclusion of data of 1124 HH. Survey on number of people, average income and car ownership per HH for 7536 HH were investigated in an attempt to correlate the number of trips produced to HH income; car ownership and family size.

No clear relationship between number of trips produced and income was identified, as noted in many cities. The very weak correlation between the number of trips produced and income in Khartoum State might be attributed to the lack of accuracy of the income data collected, due to the fact that most Sudanese people don`t like to expose their real income.

Using the filtered data zonal based regression model for trips production and number of households and cars owned per 1000 inhabitant proposed as:

$$P_i = 3.182HH_i + 22.252C_i \qquad (3)$$

where:

Pi:Number of trips produced by zone i.
HHi: Number of household in zone i.
Ci: No. of cars per 1000 Habitant in zone i.

The linear regression statistics and coefficients are shown in **Tables 1** and **2**.

Table2 shows strong correlation between the number of zonal trips production and number of households and cars owned per 1000 inhabitant, and that the model can be used for prediction of zonal trips in Khartoum State with reasonable accuracy.

The relationships between number of trips produced and number of HH and cars ownership per zone are shown in (**Figs. 5** and **6**).

Table 1. Regression Statistics Results

Regression Statistics	
Multiple R	0.9656
R Square	0.9325
Adjusted R Square	0.9293
Standard Error	3467.52
Observations	338

Table 2. Results of linear regression analysis

	C	Standard Error	t-Stat	P-value	Lower 95%	Upper 95%
Car Ownership per 1000inhabitant	22.25	4.154	5.357	1.57 E-07	14.08	30.423
Total H.H Number	3.18	0.059	54.27	2.5 E-168	3.066	3.297

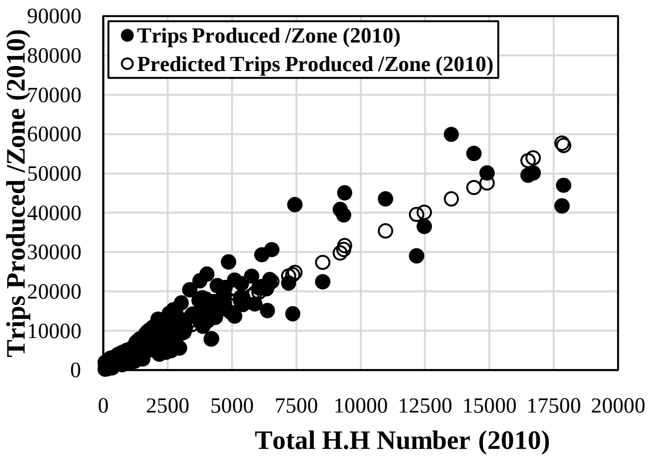

Fig. 5. Trips produced and number of H.H relationship

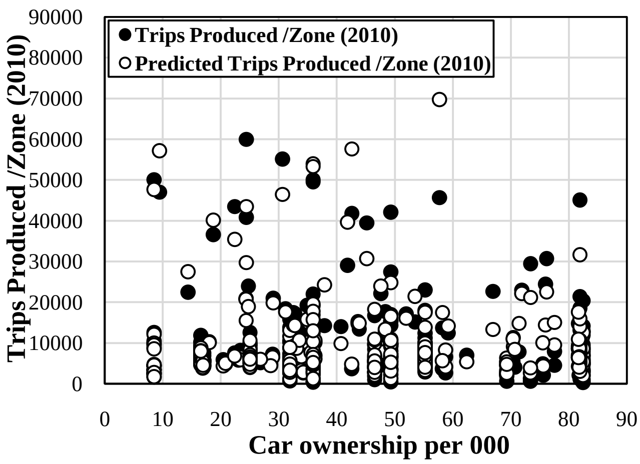

Fig. 6. Trips produced and car ownership per 1000 inhabitant relationship

The number of produced zonal trips can also be related to the population instead of number of household as:

$$P_i = 0.397PP_i + 22.458C_i \quad (4)$$

where:

Pi : Number of trips produced by zone i.
PPi :Population in zone i.
Ci : No. of cars per 1000 Habitant in zone i.

The linear regression statistics and coefficients are shown in Table 3.

4.2. Khartoum's Trip Production Model

The trip production model proposed by the consultant and adopted by Khartoum State relates the number of zonal trips to the population as follows:

$$P_i = 0.39\ population \quad (5)$$

Where:

P_i: Number of trips produced by zone i.

The only reported statistics in the consultant report is the coefficient of correlation (R^2=0.95), though it was mentioned in the report which R^2 is meant. It can also be noted that the model eliminates completely the car ownership as stimulate for trips production.

4.3. Prediction of Future Trips Produced in Khartoum State

In practice, future produced trips are normally predicted using the growth factor method. The growth factor for trip production in Khartoum State may be given by:

$$F_i = \frac{f(P_i^d, C_i^d)}{f(P_i^c, C_i^c)} \quad (6)$$

Where:

F_i : Growth factor.
P_i : Population (represented by number of Household)
C_i : Car Ownership
D :Design year
C : Current year

In Khartoum State, the population and the car ownership growth rate are estimated at 3.5 % and 2.25 %respectively (KPP5), this will yield an annual growth factor of 1.0583 for trips produced in the state.

Future trips can then be estimated using equation (7):

$$T_{fut} = T_{base}\,(1 + F)^n \quad (7)$$

where:

T_{fut} :Future number of trips
T_{base}: Base year number of trips
F :Trips annual year growth
N :Design period

Table 3. Regression Statistics Results

Regression Statistics	
Multiple R	0.9651
R Square	0.9315
Adjusted R Square	0.9283
Standard Error	3492.66
Observations	338

Table 4. Number of produced trips predicted by proposed and Khartoum State's Models

Year	Estimated Number of trips per day	
	Proposed model	Khartoum State's model
2010	3,087,524	2,675,824
2015	4,092,971	3,178,040
2025	5,425,840	4,482,939
2035	9,562,137	6,323,628

The total number of trips produced per day in Khartoum State for the years 2010, 2015, 2025 and 2035, as predicted by the proposed model and Khartoum State's model are shown in **Table (4).**

Recent data collected by Ministry of Infrastructures and Transportation of Khartoum State[11] has shown that, the average number of people using buses and mini-buses, in a typical working day, at the main bus terminals, is estimated at 2.55 million. Assuming that 70% of trips in Khartoum State are made by public transport, according to the demand model developed by the consultant and adopted by Khartoum State [10], this will mean that the total numbers of person-trips produced in Khartoum State are around 3.64 million person-trip/day compared to 3.18 million predicted by Khartoum State's model.

In fact, it is expected that the actual number of people travelling by public transport is higher than what was reported by the Ministry, for the following reasons:

- Public transport data was collected only at main bus terminals, eliminating data from smaller terminals, where significant number of people travel from/to them.
- The trips covered by around 48,000 Rickshaws, 10,400 Taxis and 14,700 small vans (amjads) operating in Khartoum State, are also not included in the above estimate of the Ministry [12].

This indicates clearly that the model proposed by the consultant, underestimates the number of trips produced in Khartoum State. Using the modal split model adopted by Khartoum State, the proposed model predicts the trips made by public transport in Khartoum State in 2015 at 2.87 million person-trips/day, which seems to be a more realistic estimate.

To verify the practicability of the models, data published by Higher Council for Strategic Planning- Khartoum State [13] on number of pupils/students in Khartoum State in the year 2013 was used. According to the report their number is estimated at 1.36 million. This would mean that the total number of generated trips, according to the trip purpose model adopted by Khartoum State is about 4.12 million. The proposed model and Khartoum State adopted model estimate the total daily number of trips generated in 2013 at 3.46 million and 2.87 million, respectively.

This is another indication that the model adopted by Khartoum State might underestimate the number of trips generated, and can result in serious consequences on the prioritization of the state's infrastructures projects.

However, it is clear that, the proposed model needs further development and consideration of other factors that might affect the trips generation in Khartoum State.

5. CONCLUSIONS

Based on the study results, the conclusions drawn as follows:

- The main purposes for travel in Khartoum State are work and school, counting for around 56% and 33% of total trips, respectively.
- Around 70 % of households in Khartoum State do not own a car, 24% own one car and 6% own two cars or more.
- The main factors that influence trips production in Khartoum State are number of households and car ownership.
- The exclusion of incomplete data and outliers and the consideration of the car ownership in development of trip generation model has resulted in a more realistic estimate of number of produced trips than the currently adopted model of Khartoum State.
- If the growth of the population and car ownership remain at the same rate, the number of trips produced/day in the year 2035 will be 9.56 million person-trip/day, and a demand for 6.69 million person-trip/day to be covered by public transport. This will exert huge pressure on the state and necessitates huge investments in mass transit systems.
- The proposed model needs further development and consideration of other factors that might affect the generation of trips in Khartoum State As the nature of transport modelling is dynamic, the State of Khartoum is strongly encouraged to establish a special unit, or hire a consultant to be tasked with continuous data collection, models development and verification

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