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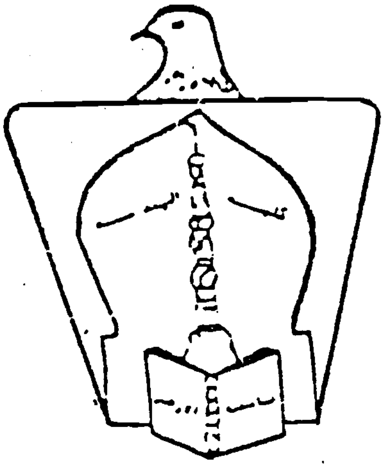

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ESTIMATION OF CONSUMPTION AND REQUIREMENT MODELS FOR BUS TRANSIT SYSTEM OPERATED BY CAIRO TRANSPORT AUTHORITY

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ABSTRACT

Mass transit systems in the city of Cairo are being mainly operated by the Cairo Transport Authority (CTA). These transit systems include buses, minibuses, trams, metros and riverbuses. In this paper, the CTA bus transit system is reviewed, where the main operational characteristics of CTA bus garages are presented. The core of the paper lies in the estimation and testing of different regression models that are meant to produce an acceptable presentation of the consumption of materials and the requirement of staff by buses operated by CTA. The development of materials consumption models include developing separate models to represent the consumption of fuel, oil and lubricants by buses. On the other hand, the development of staff requirements models include developing separate models to represent the requirement of drivers, conductors, and engineering staff by buses.

More than twenty different linear regression models are developed for each of the above mentioned consumption and requirement parameters. Comparative statistical analysis of these models are conducted and models that are judged to produce the best presentation of reality are identified.

Such consumption and requirement models present the first step in estimating operational cost for any bus transit system. These can also give guidelines for the decision maker on areas that warrant intervention so as to reduce consumption rates and minimise requirements. Ultimately this would lead to minimizing operating costs, without affecting the quality of produced services. These models can be applied at different levels, whether for individual buses, or at a garage or CTA bus sector levels. Ultimately this is meant to minimize the operating costs, without affecting the quality of produced services. The paper concludes with a set of conclusions and recommendations that are meant to improve the performance of the bus **transit system operated by CTA in Cairo.**

ملخص البحث :

تشرف هيئة النقل العام بالقاهرة على مختلف أنظمة النقل الجماعي بالقاهرة مثل الأتوبيس، الميني باص، الترام، المترو و النقل النهرى. وقد بدأ البحث بتحليل خصائص التشغيل لقطاع الأتوبيس بالهيئة موزعا على مستوى الجراجات و لتى يبلغ عددها ١٣ جراج. و يهدف البحث إلى بناء و اختبار النماذج الرياضية المختلفة للانحدار التى يمكن أن تمثل النماذج الرياضية لاستهلاك مواد التشغيل المختلفة و أيضا احتياجات العمالة لقطاع الاتوبيس. وتشمل النماذج الرياضية لاستهلاك مواد التشغيل كلا من استهلاك الوقود، استهلاك الزيوت و أيضا استهلاك الشحومات. أما احتياجات العمالة فقد شملت أعداد السائقين و المحصلين و أيضا العمالة الفنية للاتوبيس.

و تعتمد النماذج الرياضية على بيانات التشغيل للعام المالي ٩٦/٩٥ وأيضا على متوسط بيانات التشغيل للأعوام ٩٤/٩٣، ٩٥/٩٤، ٩٦/٩٥ وذلك للعوامل المستقلة وهى عدد الأتوبيسات العاملة. و عدد ساعات التشغيل و أيضا عدد

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الكيلومترات المنتجة. وقد تم بناء اكثر من ٢٠ نموذج خطى للانحدار لكل من لستهلاك مواد التشغيل و ايضا احتياجات العمالة. وقد تم عمل اختيارات إحصائية على هذه النماذج لاختيار أفضلها.

وتمثل هذه نماذج الخطوة الأولى فى تقدير تكلفة التشغيل لأي قطاع للنقل. كما تعطى الخطوط العريضة لمتخذى القرار لوضع السياسات الخاصة بتخفيض معدلات الاستهلاك وخفض تكاليف التشغيل بدون خفض مستويات الخدمة. و يمكن تطبيق هذه النماذج على مستوى خطوط الأتوبيس، أو على مستوى الجراجات أو على قطاعات الأتوبيس المختلفة. وقد أختتم البحث بعدد من النتائج و التوصيات التى يمكن من خلالها تحسين أداء قطاع الأتوبيس بالقاهرة .

1. INTRODUCTION

Among the cities of the world, Cairo probably ranks near the top for its traffic and transport problems. Transport problems in Cairo has a great impact on the economic and social life. The Cairo Transport Authority (CTA) provides and operates the five main public transit systems in Cairo, namely buses, minibuses, river buses, trams and surface metros. The bus transit system has the dominant share of the daily public transport trips in Cairo.

The bus fleet operated by CTA is probably one of the largest in the world, see Andrews 1990. CTA provides bus services for about 338 lines operated by 13 garages. Each garage has its own equipment, materials, staff and bus units but all garages follow the same operational policies decided by CTA headquarters. There is also long distance buses operated by Greater Cairo Bus Company (GCBC), a subsidiary of CTA. GCBC has 4 garages which operate about 117 bus lines connecting the three governorates of Greater Cairo. GCBC has its own budget which is subsidized by CTA. However, urban buses and long distance buses have different operating characteristics.

In this paper, CTA bus transit system is reviewed, where the main operational characteristics of CTA bus garages are presented. The core of the paper lies in the estimation and testing of different regression models that are meant to produce an acceptable presentation of the consumption of materials and the requirement of staff by buses operated by CTA. The development of materials consumption models include developing separate models to represent the consumption of fuel, oil and lubricants by buses. On the other hand, the development of staff requirements models include developing separate models to represent the requirement of drivers, conductors, and engineering staff by buses.

More than twenty different linear regression models are developed for each of the above mentioned consumption and requirement parameters. Regression models were estimated to relate theses parameters to the three generic productivity components of the garage units namely; operable buses, bus kilometers and bus operating hours. Comparative statistical analysis of these models are conducted and models that are judged to produce the best presentation of reality are identified.

Data from CTA annual statistical reports of operation achievements for the financial years 93/94, 94/95 & 95/96 were utilised. Data representing the financial year 95/96 is used for regression models. Then models based on 95/96 data are compared to those models based on the average of the three years 93/94, 94/95 & 95/96. This is meant to detect differences or similarities of bus consumptions and requirements rates over the years.

Such consumption and requirement models present the first step in estimating operational cost for any bus transit system. These can also give guidelines for the decision maker on areas that warrant intervention so as to reduce consumption rates as well as to minimise requirements. These models can also form the financial basis for the estimation of Vehicle Operating Costs for bus transport. This can be transferred to economic cost estimates and used in the economic appraisal of transport projects that involve buses. The application of such models can take place at four levels:

- Financial analysis of individual bus performance
- Financial analysis of bus garage performance
- Financial analysis of CTA bus sector
- Economic analysis of projects involving an impact by/on bus operation

2. BUS TRANSIT SYSTEM OPERATED BY CTA

In this section. some generic indicators of the operation of the bus transit system in Cairo are presented. These are meant to give an overall picture of the performance of this system. During the financial year 95/96, CTA bus fleet was composed of about 1784 units. These were used to operate a network of 338 bus lines. The commercial speed of buses operating in the streets of Cairo was reported to be 17.5 km/hrs on average. Bus units produced about 5,869 million bus trips. 10,038 million operating hours and 187,770 million bus-kilometers. These achievements present about 89-90% of the planned targets indicating an operational ineffectiveness in the range of 10%.

The bus fleet in Cairo is one of the largest in the world. Of the CTA bus fleet, 1541 buses (i.e. 53%) were reported to be more than ten years old. 1061 buses (37%) were within the age of two to ten years. while 304 buses (10%) were within the age of one to two years old. It is generally accepted that the older a bus is, the more it will consume operational materials such as fuel oil, lubricants. ..etc. CTA statistics indicate that during 95/96, consumed operational materials were about 120.5 million liters of fuel, 2.4 million kilograms of oil, and 61.9 thousand kilograms of lubricants. Additionally, old buses suffer from an increasing rate of default occurrence and hence maintenance requirements. Old buses are also liable to an increasing accidents' occurrence. These are also known to generate high rates of exhaust emissions causing a substantial increase in air pollution.

During the financial year 95/96, CTA staff employed for the bus sector reached 29860 employees. Of this figure, about 19387 (i.e. 65%) are bus related employees (drivers, conductors & engineering staff), while the other 10473 (i.e. 35%) are managerial and mainly administrative staff. An important indicator can be computed from these figures, namely the average staff per bus ratio. As can be shown, this is on average 16.7 staff per bus. This figure when compared with international standards (3-8 staff per bus), see Wright 1990 indicates an extremely high staff to bus ratio. There is a great need for CTA to readjust this ratio over time. Such adjustment can significantly decrease operating costs.

The CTA bus sector comprises 13 garages, where 9 garages are located in Cairo and 4 in Giza. Nasr & Fath garages are located in middle Cairo, Al- Amirya & Gisr Al-Suez in east Cairo, Mazalat, Teraa & Sawah in north Cairo and Athr Al-Nabi & Fom Al-Khalig in south Cairo. South Giza contains two garages; namely Al-Moneab & Badr while north Giza contains the other two garages; namely Giza & Embaba. In Table 1, three main characteristics for each of the 13 bus garages are presented, namely the number of bus lines operated by each garage, the total trip lengths covered by the garage and the average speed of buses operated by the particular garage. It is obvious from the table that Embaba garage provides the highest number of bus lines, however this provision is accompanied with the lowest average speed. Embaba is known to be one of the most densely populated areas in Cairo. On the other hand, Giza garage provides the lowest number of bus lines with the lowest trip lengths. The highest trip lengths are provided by Gisr Al-Suez and the highest average speed is maintained by Mazalat.

Table 1: Characteristics of CTA Bus Garages

Garage	No of Lines	Total Trip length (km)	Average Speed (km/hr)
NASR	35	970	18.3
FATH	34	833.5	17.5
AMIRYA	26	709	16.6
GISR AL- SUEZ	30	1170.9	19.9
MAZALAT	30	950	21.7
TERAA	30	971.2	18.8
SAWAH	12	477.8	19.7
ATHR AL-NABY	28	860.4	18.4
FOM AL-KHALIG	15	308.3	16.9
MONEAB	32	900.7	16.1
BADR	18	589.1	18.6
GIZA	12	262.6	16.7
EMBABA	36	726.7	15.1

3. REVIEW OF SOME PREVIOUS CTA BUS MODELS

Regression analysis is one of the generic approaches used for developing models for transit services. According to Talley, 1986 the literature has generally assumed that the specific forms for the estimation of cost functions for transport firms are one of three forms: (1) a translog function; (2) a loglinear function; and (3) a linear function. Cost regression models uses a complete set of sample data to estimate coefficients for resource variables that are thought to influence costs. These include variables such as operable vehicles, traveled kilometers, operable hours fleet age, drivers wages and others.

In this research, a synonymous is drawn where regression models are estimated to produce an acceptable presentation of the consumption of materials and the requirement of staff by buses operated by CTA. Before proceeding with presenting the findings of this research, previously developed CTA bus models are reviewed. The literature shows that few studies have been conducted and reported.

An estimation of size requirements for CTA bus fleet was reported in Cubukgil et al. 1982. This estimation was based on a demand forecast taking into consideration the effect of prevailing operational characteristics. Furthermore, a method for reducing fleet size requirements by increasing vehicle productivity in the main corridors has been proposed and simulated under limited funds conditions.

In the JICA study of 1989, Vehicle Operating Costs for the different travel modes in Cairo were estimated. In the course of estimating these costs, various consumption rates were estimated. The study showed that the consumption volume of gasoline fuel for a large bus is around 0.57 liters/km in 87/88. As for engine oil, the study have shown a rate of 0.005

liters/km in 87/88 for large buses. Additionally, an average number of crew per large bus was shown as 5.2.

A third study was concerned with the estimation of CTA bus operating costs using 1988/89 data. see ECOGIM, 1991. In this study, the Nasr bus was chosen to estimate the operating cost representing CTA bus fleet. Different mathematical models were developed to estimate the fuel consumption rate, lubricant oil rate and costs of spare parts. These were mainly developed as a function of bus life time. The following exponential function proved to give the best fit for fuel consumption.

$F = 34.33\, e^{0.0498y}$

where: F = Fuel consumption in liters per 100 kilometers, y = Bus life time in years

This model was applied for a Nasr type bus with an average age of 6 years. This resulted in estimating the fuel consumption rate to be around 46.285 liters per 100 kilometers.

As for consumption of oil and lubricants, the following exponential function proved to give the best fit.

$O = 0.776\, e^{0.104y}$

where: O = Oil consumption in kilograms per 100 kilometers, y = Bus life time in years

This model was applied for a Nasr type bus with an average age of 6 years. This resulted in estimating the oil consumption rate to be around 1.448 kilograms per 100 kilometers.

4. ESTIMATION OF CONSUMPTION AND REQUIREMENT MODELS FOR BUS TRANSIT SYSTEM OPERATED BY CAIRO TRANSPORT AUTHORITY

The development of materials consumption models include developing separate models to represent the consumption of fuel, oil and lubricants by buses. On the other hand, the development of staff requirements models include developing separate models to represent the requirement of drivers, conductors and engineering staff by buses. The algorithm used for the estimation of these regression models is depicted in Figure 1.

Data reported in CTA annual statistical reports of operation achievements for the financial years 93/94, 94/95 & 95/96 were utilised in developing the bus consumption and requirement models. Two sets of data were put to use, the first is composed of 13 cross-sectional data points representing the 13 bus garages during the financial year 95/96, while the other set is composed of 13 cross-sectional data points representing the 13 bus garages averaged over the financial years 93/94, 94/95 & 95/96.

More than twenty different linear regression models are developed for each of the above mentioned consumption and requirement parameters All of these models share their functionality of one or more of the three generic operational parameters, namely operable buses, operable bus hours and operable bus-kilometres. The estimated models vary from being a three independent variables model with a constant to a one independent variable model without a constant. These combinations produced a total of 28 models. Comparative statistical analysis of these models are conducted. Some of the models are excluded due to unrealistic results and models that are judged to produce the best presentation of reality are identified. Three statistical criteria were utilised. The first criterion is the R-squared which shows the degree of correlation between dependent and independent variables The second criterion is

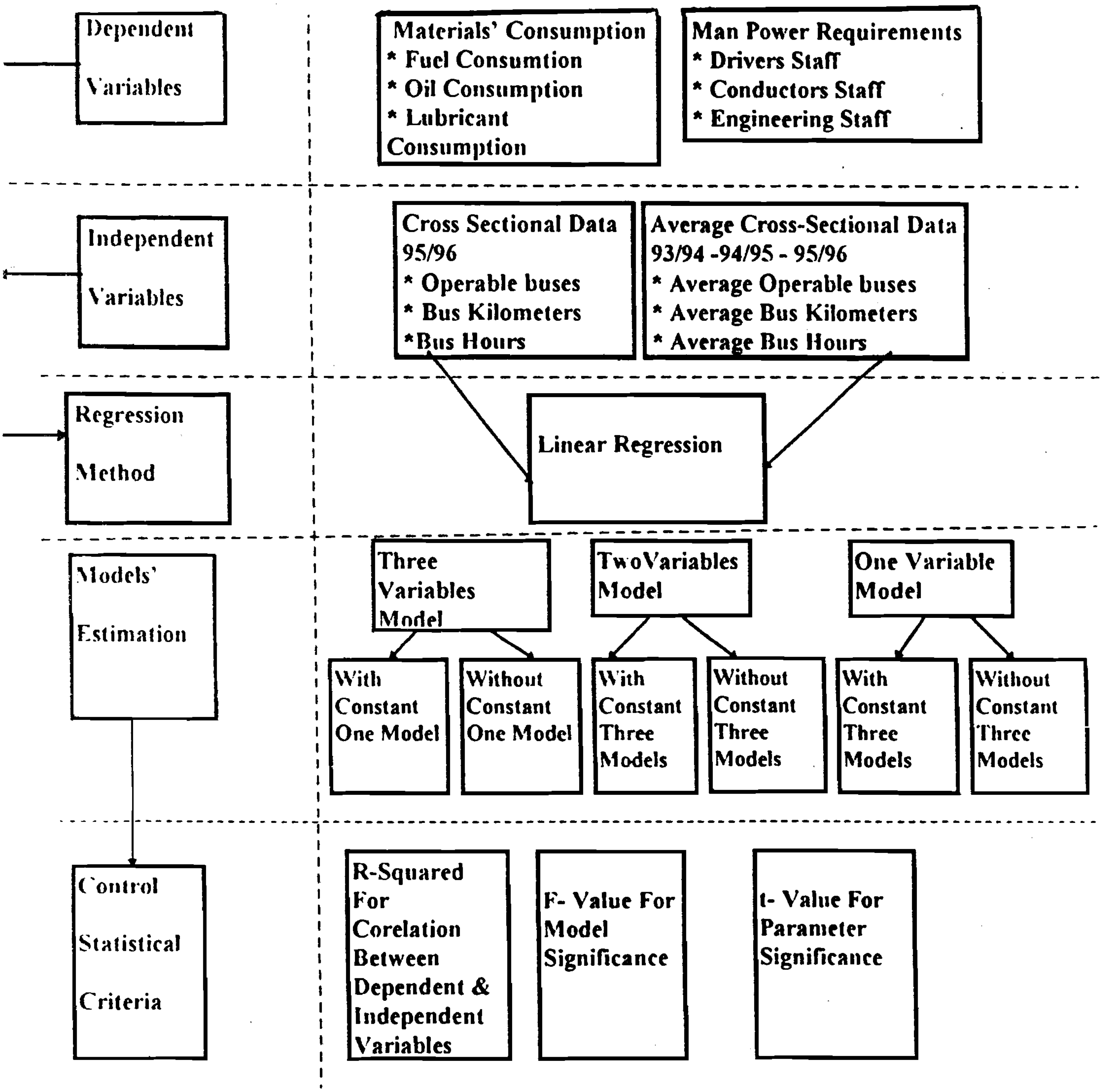

Fig. 1. Algorithm for Estimation of Material Consumption & Man Power Requirements Regression Models for CTA Buses.

the F-value which is indicative of the overall model significance. The third criterion is the t-value which denotes the significance of individual model parameters. The three statistical criteria were estimated at both 95 and 90 percent confidence levels. Threshold values for these criteria were taken as 0.6 for R^2, the highest F value, and the t-values that exceed t critical obtained from the relevant statistical tables.

4.1 Estimation of Materials Consumption Models

The main three components that constitute the consumption of materials within a bus operating entity are known to be fuel, oil and lubricants. For each of these three components, several consumption models were calibrated. These were statistically compared and the best fit models were selected.

The results of the regression analysis representing the consumption models for the three main material components modelled as functions of the generic productivity components of bus operation are shown in Tables 2, 3, & 4. Six variables are listed in the table columns as potentials for independent variables. The coefficient of determination R-squared as well as the F-statistic for each model are listed in columns 8 & 9 respectively. Each cell contains the value of the independent parameter and its corresponding t-statistic. A positive sign of the independent parameter reflect a proportional relationship. Therefore, as the independent variable increases, the dependent variable increases and vice versa. Models based on average data are compared to those based on the one year data to find out the similarity of bus operational process over the years. The shaded rows present the significant models at a 5 percent significance level. .

4.1.1 Fuel consumption models

In an urban context such as Cairo, where congestion problems are severe, it is thought appropriate to represent the consumption of fuel to be related to the number of operable bus hours. The rates of fuel consumption (liters/operable hours) for each of the 13 CTA bus garages are depicted in Figure 2. The figure shows that Athr Al-Naby and Gisr El-Suez (both operating a high number of bus lines and hence are characterised by a significant number of total trip distances) have the highest rates of fuel consumption. On the other hand, Fom Al-Khalig & Embaba show the lowest fuel consumption rates. This can be expected for Fom Al-Khalig as it has the lowest number of operated lines as well as the lowest total trip distance. In the case of Embaba, despite the high number of operable lines, yet the total trip distance seems relatively low signifying the dominance of short line trips.

The results of the regression analysis representing the fuel consumption models are shown in Table 2. Models with a single variable and no constant show significant results with regard to the three statistical criteria, namely; R-squared, F-value and t-value. The independent variables for these models are bus hours or operable buses. Models based on the average data do not significantly differ from those based on the one year data. Therefore, it can be deduced that the sensitivity of fuel consumption over the years is low. The models reveal the high fuel consumption rates, where models 9 & 18 show that a single bus requires 185 litters of fuel per day which corresponds to about 12 liters per hour taking into consideration that the number of daily working hours for a bus is 16 hours. Model 18 has the following formula:

$FC = 185.9\ OB$
(26.7)
where: FC = Fuel consumption in liters, OB= Number of Operable Buses
$R^2 = 0.98$ F= 711 t= 26.7 > t critical, where t critical = 1.363

The other significant models i.e. models 10 & 19 indicate the same consumption rates where one operating hour requires about 12 liters of fuel. These models have the following formula:

$FC = 12.066\ BH$
(35.7)
where: FC = Fuel consumption in liters, BH = Number of Bus Hours
$R^2 = 0.99$, F = 1279, t = 35.7 > t critical, where t critical = 1.363

These high fuel consumption rates can be attributed to several factors such as the aging of the CTA bus fleet, the poor mechanical conditions of the bus fleet, the poor quality of driving and certainly the severe traffic congestion problem that dominates the streets of Cairo. It can also be noted from the table that fuel consumption models dependent on bus kilometers show no model significance. This is due to the congestion situation of the road network in Cairo which causes fuel consumption to be mainly related to bus working hours rather than to traveled kilometers.

4.1.2 Oil consumption models

The rates of oil consumption (measured in kilograms/operable hours) for each of the 13 CTA bus garages are depicted in Figure 3. The figure shows that Mazalat has the highest rate of oil consumption. Moneab & Athr Al Naby are ranked as second.. On the other hand, Fath and Sawah show the lowest oil consumption rates.

The results of the regression analysis representing the oil consumption models are shown in Table 3. Models with a single variable show the highest R^2, the highest F-value and an accepted t-value for its single parameter. The independent variables for these models are bus hours or operable buses. Models based on the average data do not significantly differ from those based on the one year data. Therefore, it can be deduced that the sensitivity of oil consumption over the years is low. The models reveal the high oil consumption rates, where models 12 & 19 show that a single bus requires 3.7 kilograms of oil per day which corresponds to about 0.23 kilograms per hour taking into consideration that the number of daily working hours for a bus is 16 hours. The mathematical formula of the model is as follows:

$OC = 3.903\ OB$
(20.4)
where: OC = Oil consumption in kilograms, OB= Number of Operable Buses
$R^2 = 0.97$, F = 418, t = 20.4 > t critical, where t critical = 1.363

The other significant models i.e. models 13 & 21 indicate the same consumption .rates where one operating hour requires about 0.25 kilograms of oil. These models have the following formula:

$OC = 0.253\ BH$
(21.87)
where: OC = Oil consumption in kilograms, BH= Number of Bus Hours
$R^2 = 0.69$, $F = 478$, $t = 21.87 > t$ critical, where t critical = 1.363

Again, these high oil consumption rates can be attributed to factors such as the aging of the bus fleet, the poor mechanical conditions of the bus fleet, the poor quality of driving and certainly the severe traffic congestion problem that dominates the streets of Cairo. It can also be noted from the table that oil consumption models dependent on bus kilometers show no model significance. This is due to the congestion situation of the road network in Cairo which results in buses stopping for long periods of time during their journeys, which results in the consumption of materials being mainly dependent on the operated bus hours.

4.1.3 Lubricant consumption models

The rates of lubricant consumption (measured in kilograms/operable hours) for each of the 13 CTA bus garages are shown in Figure 4. The figure shows that Fom Al Khalig has the highest rate of lubricant consumption. Moneab and Sawah are ranked as second. On the other hand, Giza shows the lowest lubricant consumption rate.

The results of the regression analysis representing the lubricant consumption models are shown in Table 4. The one model variable based on bus hours shows, in relative terms, the most statistically significant results with a calibration value of 6.27, see model 13. To obtain reasonable results, the independent variables units were taken in thousands. This means that each 1000 working hours requires 6.27 kilograms of lubricants as shown in the following formula.

$LC = 6.27\ BH$
(15.2)
where: LC = Lubricant consumption in kilograms, BH= Number of Bus Hours
$R^2 = 0.53$, $F = 13.29$, $t = 15.2 > t$ critical, where t critical = 1.363

Lubricant consumption models based on average data show no significance. Therefore, it might be deduced that lubricant consumption does not follow the same trend over years.

Again, this high lubricant consumption rates can be attributed to factors such as the aging of the bus fleet, the poor mechanical conditions of the bus fleet, the poor quality of driving and certainly the severe traffic congestion problem that dominates the streets of Cairo. It can also be noted from the table that lubricant consumption models dependent on bus kilometers show no model significance. This is due to the congestion situation of the road network in Cairo which results in buses stopping for long periods of time during their journeys, which results in the consumption of materials being mainly dependent on the operated bus hours.

4.2 Estimation of Staff Requirements Models

CTA staff is mainly composed of drivers, conductors, engineering staff as well as other administrative and managerial staff. For each of these staff categories, several requirement models were calibrated. These were statistically compared and the best fit models were selected.

The results of the regression analysis representing the requirement models for the three main staff categories modelled as functions of the generic productivity components of bus operation are shown in Tables 5, 6, & 7. Six variables are listed in the table columns as potentials for independent variables. The coefficient of determination R-squared as well as the F-statistic for each model are listed in columns 8 & 9 respectively. Each cell contains the value of the independent parameter and its corresponding t-statistic. A positive sign of the independent parameter reflect a proportional relationship. Therefore, as the independent variable increases, the dependent variable increases and vice versa. Models based on average data are compared to those based on the one year data to find out the similarity of bus operational process over the years. The shaded rows present the significant models at a 10 percent significance level.

4.2.1 Drivers requirements model

The numbers of drivers per operable bus for each of the 13 CTA bus garages are shown in Figure 5. The figure shows that Al-Moneab garage has the highest ratio of driver staff per operable bus. On the other hand, Athr Al-Naby shows the lowest driver staff per operable bus ratio.

The results of the regression analysis representing the drivers requirement models are shown in Table 5. Five models show significant results with respect to previously mentioned control statistical criteria. The independent variables for these models are bus hours or operable buses. Models based on the average data do not significantly differ from those based on the one year data. Therefore, it can be deduced that the sensitivity of driver requirement over the years is low. The models reveal the high driver requirement levels where models 12 & 24 show that each 1000 operable buses requires around 8.72 drivers which corresponds to about 0.55 drivers per 1000 operable hours taking into consideration that the number of daily working hours for a bus is 16 hours Other significant models i.e. models 13 & 25 indicate the same hourly requirement rates. Model 21 is considered as the best fitting model at a 10 percent probability level. It is a one variable model with a constant, where the constant reflects the effect of other independent variables affecting the driver staff requirements. Model 21 has the following form:

$$DV = 7.61\ OB + 69.84$$
$$(9.44) \qquad (1.72)$$

where: DV = Number of Drivers, OB = Number of Operable Buses in Thousands

$R^2 = 0.89$, $F = 89.26$, $t = 1.72 >$ t critical, where t critical = 1.372

This high driver requirement rates can be attributed to several factors such as the government imposed policy of hiring more staff causing a substantial under-employment problem at CTA.

4.2.2 Conductors requirements model

The number of conductors per bus for each of the 13 CTA bus garages are shown in Figure 6. Again the figure shows that Al-Moneab garage has the highest ratio of conductor staff per operable bus. On the other hand, Athr Al-Naby shows the lowest conductor staff per operable bus ratio.

The results of the regression analysis representing the conductors requirement models are shown in Table 6 Seven models show significant results with respect to the three statistical control criteria. Models 7, 9 & 22 are significant at a 10% significance level, while models 12, 13, 25 & 26 show significant results at a 5% significance level. The independent variables for these models are bus hours or operable buses. Models based on the average data do not significantly differ from those based on the one year data. Therefore, it can be deduced that the sensitivity of conductor requirement over the years is low. The models reveal the high conductor requirement levels where models 9 & 22 show that each 1000 operable buses requires around 8 conductors which corresponds to about 0.5 conductors per 1000 operable hours taking into consideration that the number of daily working hours for a bus is 16 hours. The other significant models indicate the same requirement rates. Model 7 is selected to represent the rate of conductors requirements per operable bus.

$$CO = 4.55\ OB + 0.271\ BH$$
$$(1.67) \qquad (1.51)$$

where:

CO = Number of Conductors, OB = Number of Operable Buses, BH = Number of Bus Hours

$R^2 = 0.96$, $F = 135.45$, $t = 1.51 > t$ critical, where t critical = 1.372

This high conductor requirement rates can be attributed to several factors such as the government imposed policy of hiring more staff causing a massive under-employment problem at CTA.

4.2.3 Engineering staff requirements model

The number of engineering staff per bus for each of the 13 CTA bus garages are shown in Figure 7. Once again the figure shows that Al-Moneab garage has the highest ratio of engineering staff per operable bus. On the other hand, Embaba shows the lowest engineering staff per operable bus ratio.

The results of the regression analysis representing the engineering staff requirement models are shown in Table 7. Six models show significant results with respect to the three statistical control criteria. Models 12, 13, 25 & 26 are significant at a 5% significance level, while models 20 & 22 show significant results at a 10% significance level. The independent variables for these models are bus hours or operable buses. Models based on the average data do not significantly differ from those based on the one year data. Therefore, it can be deduced that the sensitivity of engineering staff requirement over the years is low. The models reveal the high engineering staff requirement levels where models 12 & 25 show that each 1000 operable buses requires around 8.7 engineering staff which corresponds to about 0.54 engineering staff per 1000 operable hours taking into consideration that the number of daily working hours for a bus is 16 hours. The other significant models i.e. models 13 & 26 indicate the same requirement rates. Model 20, which is a two variable model, is selected to represent the rate of engineering staff requirements per operable bus.

$$ENG = 3.85\ OB + 0.32\ BH$$
$$(1.67) \qquad (2.17)$$

where:

ENG = Number of Engineering Staff, OB = Number of Operable Buses, BH = Number of Bus Hours

$R^2 = 0.93$, $F = 69.24$, $t = 1.67 > t$ critical, where t critical = 1.372

This high engineering staff requirement rates can be attributed to several factors such as the government imposed policy of hiring more staff causing a massive under-employment problem at CTA.

It must be noted that, the above staff requirements models are meant to represent the reality in terms of actual needs for bus operation.

5. RESULTS AND CONCLUSIONS

In this paper, an assessment of CTA bus transit system was presented. An estimation of regression models for materials' consumption and staff requirements for CTA bus sector was conducted. The main findings of this paper can be summarised as follows:

- Operating bus hours and operating operable buses are found to be significant explanatory factors in all the regression models developed for materials consumption. One variable models containing one of these two factors are found to be the most significant under a 5-percent probability level.
- Operating bus hours and operating operable buses are found to be significant explanatory factors in all the regression models developed for staff requirements. Two variable models containing these two factors are found to be the most significant under a 10 percent probability level.
- Bus kilometers seem to be an insignificant factor in explaining materials consumption, and staff requirements models. This can be mainly attributed to the fact that traffic congestion makes vehicles consume more fuel, oil lubricants without gaining extra kilometers.
- The models reveal the high amount of materials consumption. One operable bus requires 185 liters of fuel per day and about 3.7 kilograms of oil per day. One working hour requires about 12 liters of fuel and about 0.25 kilograms of oil Models dependent on operable buses as well as those depending on bus working hours models show consistent results.
- Each 1000 working hours require 6.27 kilogram of lubricants Therefore during an operable year, about 50 kilogram of lubricants are consumed.
- Scraping aging fleet, periodical overhaul of existing fleet (that did not exceed their life span), and procurement of new bus fleet are bound to reduce material consumption's and consequently operating cost
- The one model variable reveals that each 1000 operable bus require 8.65 conductors, 8.72 drivers, and 8.66 engineering staff.
- The bus sector is overwhelmed by extra staff which increase the operating costs, and by turn cause a significant reduction in the profitability of CTA. It is essential to downsize the number of staff working in this sector and to link wages, incentives and bonuses to employee productivity.
- Regression models based on historical data are found to be significant in some cases such as fuel consumption, and lubricant consumption. However, these show no significance in other cases such as in models for oil consumption, and staff requirements.

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Table 2 Estimation of Fuel Consumption Models For CTA Bus Operation

	O Bus	Bus Kms	Bus Hrs	Avg O Bus	Avg B Kms	Avg B Hrs	Const.	R2	F
Model 1	79.7 (0.56)	.001 (0.09)	7.900 (0.8)				-743.6 (0.56)	0.88	22
Model 2	90.91 (0.66)	0.002 (0.24)	6.2 (0.68)					0.87	23
Model 3	191.6 (7.62)	0.004 (0.37)					-412.022 (-.33)	0.87	33
Model 4	76.32 (0.59)		8.2 (0.92)				-773.720 (-0.63)	0.87	36
Model 5		-.0006 (-.05)	13.3 (7.77)				-849.51 (-.665)	0.87	34
Model 6	194.6 (8.52)						-484.8 (-.41)	0.86	72
Model 7		0.031 (1.2)					8673.0 (9.51)	0.11	1.4
Model 8			13.32 (8.75)				-834.9 (-.7)	0.87	76
Model 9*	**185.6 (33.7)**							**0.87**	**77**
Model 10*			**12.29 (34.0)**					**0.86**	**79**
Model 11				-24.45 (-.33)	0.011 (0.35)	13.41 (2.79)	0.00	0.99	363
Model 12				178.82 (12.2)	0.022 (0.56)		0.00	0.98	335
Model 13				-38.47 (-.52)		15.78 (3.0)	-993867 (-.87)	0.89	42.
Model 14				-24.22 (-.342)		13.63 (2.98)	0.00	0.99	592
Model 15					0.011 (0.37)	11.84 (16.4)		0.99	593
Model 16				173.97 (0.61)			631607. (0.475)	0.79	43.7
Model 17						13.132 (9.49)	-859704 (-.796)	.89	90.2
Model 18*				**185.9 (26.7)**				**.98**	**711**
Model 19*						**12.066 (35.7)**		**0.99**	**1279**

* Significant model at 5 percent probability level

Table 3 : Estimation of Oil Consumption Models For CTA Bus Operation

	O Bus	Bus Km	Bus Hrs	Avg O Bus	Avg B Km	Avg B Hrs		R2	F
Model 1	6.01 (1.31)	-.00006 (-.144)	-.187 (-.585)				30.4 (0.7)	0.67	5.98
Model 2	5.555 (1.25)	-0.0001 (-.331)	-.117 (-.395)					0.65	6.12
Model 3	3.37 (4.21)	-.0001 (-.359)					22.5 (0.6)	0.65	9.42
Model 4	6.18 (1.46)		-.2 (-.7)				31.9 (0.8)	0.67	9.93
Model 5		-.0002 (-.48)	0.224 (3.77)				22.4 (0.5)	0.6	7.6
Model 6	3.81 (16.71)	-.0002 (-.46)						0.64	9.87
Model 7	5.895 (1.42)		-.143 (-.52)					0.64	9.93
Model 8		-.0002 (-.62)	0.253 (15.61)					0.59	7.99
Model 9	3.278 (4.51)						24.8 (0.6)	0.64	20.32
Model 10		0.0004 (0.66)					182. (9.9)	0.03	0.43
Model 11			0.213 (4.00)				26.9 (0.6)	0.59	16.0
Model 12*	**3.741 (21.14)**							**0.64**	**20.8**
Model 13*			**0.247 (19.61)**					**0.58**	**16.4**
Model 14				0.81 (0.33)	-.001 (-.67)	0.22 (1.33)		0.98	140
Model 15				4.08 (10.5)	-.001 (-.49)			0.97	196
Model 16					-.001 (-.7)	0.27 (11.04)		0.98	229
Model 17				3.33 (4.72)			3022 (0.8)	0.67	22.3
Model 18						0.242 (4.98)	8803 (0.2)	0.692	24.7
Model 19*				**3.903 (20.4)**				**0.97**	**418**
Model 20					0.009 (5.51)			0.43	30.4
Model 21*						**0.253 (21.87)**		**0.69**	**478**

* Significant model at 5 percent probability level

Table 4: Estimation of Lubricant Consumption Models For CTA Bus Operation (Kg.)

	O Bus	Bus Km	Bus Hrs	Avg O Bus	Avg B Km	Avg B Hrs	Const.	R2	F
Model 1	-98.77 (-0.62)	0.01 (0.74)	12.25 (1.12)				229.68 (0.155)	0.58	4.22
Model 2	-102.2 (-0.69)	0.009 (0.77)	12.78 (1.29)					0.58	4.67
	74.6 (2.59)	0.015 (1.14)					743.6 (0.52)	0.53	5.565
Model 3	-129 (-.87)		14.85 (1.46)				-34.96 (-.02)	0.55	6.33
Model 4		0.012 (0.97)	5.5 (2.88)				360.8 (0.25)	0.57	6.53
Model 5	88.92 (10.9)	0.014 (1.11)						0.51	5.81
Model 6	-128.7 (-.911)		14.79 (1.58)				-	0.56	6.96
Model 7		0.0115 (0.98)	5.965 (11.5)					0.56	7.1
Model 8	85.22 (3.09)						488.1 (0.34)	0.46	9.54
Model 9		0.0256 (1.69)					4280.21 (8.29)	0.21	2.885
Model 10			6.19 (3.49)				68.59 (0.04)	0.52	12.19
Model 11	94.34 (14.2)							0.45	10.17
Model 12*			**6.27 (15.2)**					**0.53**	**13.29**
Model 13				0.062 (0.62)	0.00 (.73)	0.001 (0.21)		0.94	49.64
Model 14				0.078 (0.76)		0.00 (-0.05)	1088.5 (.69)	0.41	3.4
Model 15				0.082 (5.57)	0.00 (0.79)			0.94	81.52
Model 16				0.062 (0.64)		0.002 (0.31)	-	0.934	77.52
Model 17					0.00 (.75)	0.005 (5.44)		0.94	78.65
Model 18				0.072 (2.74)			1046.63 (0.78)	0.41	7.5
Model 19						0.005 (2.54)	817.2 (0.54)	0.37	6.47
Model 20				0.092 (12.9)				0.37	167.6
Model 21					0.00 (6.14)			0.759	37.7
Model 22						0.005 (12.7)		0.35	6.5

* Significant model at 5 percent probability level

Table 5 : Estimation of Drivers staff Requirement Models for CTA Bus Operation

	O Bus	Bus Kms	Bus Hrs	Avg O Bus	Avg B Kms	Avg B Hrs	Const.	R2	F
Model 1	4.79 (1.41)	-.00019 (0.68)	0.241 (1.02)				19.53 (0.61)	0.95	66.78
Model 2	4.49 (1.38)	-.00024 (-.88)	0.286 (1.32)					0.96	71.07
Model 3	8.21 (13.44)	-.0001 (-.37)					29.66 (0.97)	0.95	99.05
Model 4	5.38 (1.69)		0.19 (0.88)				24.71 (0.82)	0.95	105.6
Model 5		-0.0003 (-1.03)	0.56 (12.81)				13.16 (0.39)	0.95	90.0
Model 6	8.78 (49.03)	-.0001 (-.53)						0.94	98.95
Model 7	5.16 (1.65)		0.24 (1.14)					0.95	108.4
Model 8		-0.0003 (-1.18)	0.58 (48.67)					0.94	97.43
Model 9	8.13 (14.65)						31.44 (1.09)	0.95	214.77
Model 10		0.0001 (1.002)					418.9 (11.3)	0.08	1.005
Model 11			0.55 (13.34)				20.39 (0.63)	0.94	178.0
Model 12*	**8.72 (62.49)**							**0.94**	**210.11**
Model 13*			**0.57 (59.14)**					**0.93**	**186.9**
Model 13				2.328 (0.87)	-.0007 (-.621)	0.412 (2.115)	24.52 (0.577)	0.93	38.04
Model 14				1.98 (0.79)	-.0008 (-.78)	0.468 (2.86)		0.92	40.64
Model 15				7.68 (7.79)	-.0002 (-.16)		69.04 (1.61)	0.89	40.68
Model 16				2.39 (0.92)		0.39 (2.09)	29.95 (0.74)	0.89	60
Model 17					-.2227 (-.66)	0.574 (9.36)	16.13 (0.39)	0.92	58.07
Model 18				9.078 (18.04)	-.0004 (-.32)			0.86	34.41
Model 19				1.96 (0.79)		0.45 (2.83)		0.91	62.87
Model 20					-.0008 (-.79)	0.596 (23.78)		0.91	62.82
Model 21**				**7.61 (9.44)**			**69.84 (1.72)**	**0.89**	**89.26**
Model 22					0.005 (1.79)		362.9 (6.99)	0.22	3.19
Model 23						0.55 (11.04)	21.61 (0.55)	0.91	121.92
Model 24*				**8.94 (37.57)**				**0.86**	**74.24**
Model 25*						**0.48 (48.13)**		**0.91**	**129.1**

* Significant model at 5 percent probability level

** Significant model at 10 percent probability level

Table 6 Estimation of Conductors Staff Requirement Models for CTA Bus Operation

	O. Bus	Bus Kms	Bus Hrs	Avg O Bus	Avg B Kms	Avg B Hrs	Const.	R2	F
Model 1	3.9135 1.46)	-0.0003 (-1.31)	0.294 (1.58)				22.1.24	0.97	101.65
Model 2	3.581 (-1.59)	-0.0003 (1.366)	0.345 (1.971)				0	0.96	103.78
Model 3	8.08 (15.59)	-0.0002 (-0.8)					34.5 (0.64)	0.96	131.54
Model 4	4.82 (1.79)		0.217 (1.182)				30.08 (1.185)	0.96	141.16
Model 5		-0.0004 (-1.66)	0.56 (15.86)				16.93 (0.46)	0.96	136.01
Model 6	8.74 (55.46)	-.0002 (-.991)						0.95	121.78
Model 7**	**4.55 (1.67)**		**0.271 (1.51)**					**0.96**	**135.45**
Model 8		-.0004 (-1.89)	0.584 (60.02)					0.96	143.45
Model 9**	**7.95 (16.47)**						**37.7 (1.51)**	**0.96**	**271.12**
Model 10		0.001 (0.92)					417.53 (11.52)	0.07	0.86
Model 11			0.54 (15.24)				26.2 (0.94)	0.95	232.11
Model 12*	**8.65 (68.33)**							**0.95**	**242.93**
Model 13*			**0.57 67.01**					**0.95**	**233.28**
Model 15				1.81 (0.55)	0.377 (1.56)	0.0003 (0.24)	43.44 (0.82)	0.87	21.35
Model 16				1.187 (0.37)	0.475 (2.31)	0.0001 (0.07)		0.86	21.81
Model 17				6.69 (5.97)		0.0008 (0.54)	84.1 (1.72)	0.84	26.9
Model 18					0.5 (6.8)	0.0003 (0.233)	36.92 (0.74)	0.87	34.28
Model 19				1.19 (0.39)	0.47 (2.45)			0.87	35.95
Model 20				8.39 (14.45)		0.0005 (0.31)		0.8	21.55
Model 21					0.55 (17.93)	0.0001 (0.08)		0.86	35.4
Model 22**				**7.01 (7.55)**			**80.87 (1.73)**	**0.83**	**57.13**
Model 23					0.51 (8.65)		34.6 (0.75)	0.87	74.94
Model 24						0.005 (2.08)	340.1 (7.17)	0.28	4.35
Model 25*				**8.55 (31.17)**				**0.79**	**46.49**
Model 26*					**0.55 (38.57)**			**0.86**	**77.19**

* Significant model at 5 percent probability level

** Significant model at 10 percent probability level

Table 7 : Estimation of Engineering Staff Requirement Models for CTA Bus Operation

	O Bus	Bus Km	Bus Hrs	Avg O Bus	Avg B Km	Avg B Hrs	Const.	R2	F
Model 1	3.8911 (0.75)	-0.0001 (-0.32)	0.2826 (0.784)				30.018 (0.615)	0.89	26.51
Model 2	3.4405 (0.692)	-0.0002 (-.504)	0.3515 (1.058)					0.8940	28.136
Model 3	7.89 (8.61)	=0					41.87 (0.921)	0.89	41.05
Model 4	4.327 (0.904)		0.245 (0.751)				33.83 (0.748)	0.89	43.61
Model 5		-.0002 (-.55)	0.5488 (8.63)				24.85 (.526)	0.89	41.29
Model 6	8.697 (32.51)	≈0						0.89	44.05
Model 7	4.023 (0.86)		0.307 (0.99)					0.89	45.14
Model 8		-0.0003 (-.7)	0.581 (33.5)					0.89	44.05
Model 9	7.86 (9.5)						42.47 (0.99)	0.89	90.23
Model 10		0.001 (1.026)					415.96 (11.26)	0.08	1.05
Model 11			0.536 (9.37)				30.36 (0.68)	0.88	87.86
Model 12*	**8.66 (41.96)**							**0.88**	**89.37**
Model 13*			**0.573 (42.40)**					**0.88**	**91.5**
Model 14				4.44 (1.83)	-.0004 (-.42)	0.245 (1.38)	40.73 (1.05)	0.94	44.76
Model 15				3.86 (1.62)	-.0006 (-.65)	0.34 (2.18)		0.93	43.89
Model 16				7.64 (9.48)	-.0001 (-.13)		67.25 (1.92)	0.92	60.55
Model 17				4.48 (1.93)		0.23 (1.38)	44.09 (1.21)	0.94	73.04
Model 18					-.0005 (-.44)	0.55 (8.85)	24.7 (0.59)	0.91	52.95
Model 19				8.99 (20.98)	-.0003 (-.32)			0.89	47.19
Model 20**				**3.85 (1.67)**		**0.32 (2.17)**		**0.93**	**69.24**
Model 21					-.0006 (-.59)	0.58 (22.73)		0.91	56.09
Model 22**				**7.58 (11.53)**			**67.8 (2.04)**	**0.92**	**132.96**
Model 23					0.005 (1.85)		359.3 (7.12)	0.23	3.43
Model 24						0.54 (10.67)	28.46 (0.72)	0.91	114.01
Model 25*				**8.87 (43.80)**				**0.89**	**101.8**
Model 26*						**0.57 (46.8)**		**0.9**	**118.2**

* Significant model at 5 percent probability level

** Significant model at 10 percent probability level

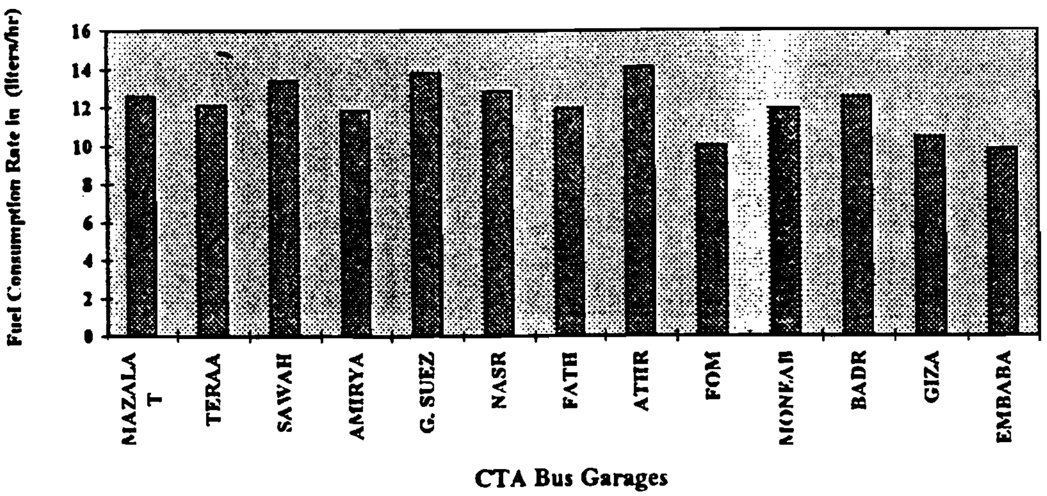

Fig. 2 : Fuel Consumption Rates by CTA Bus Garages

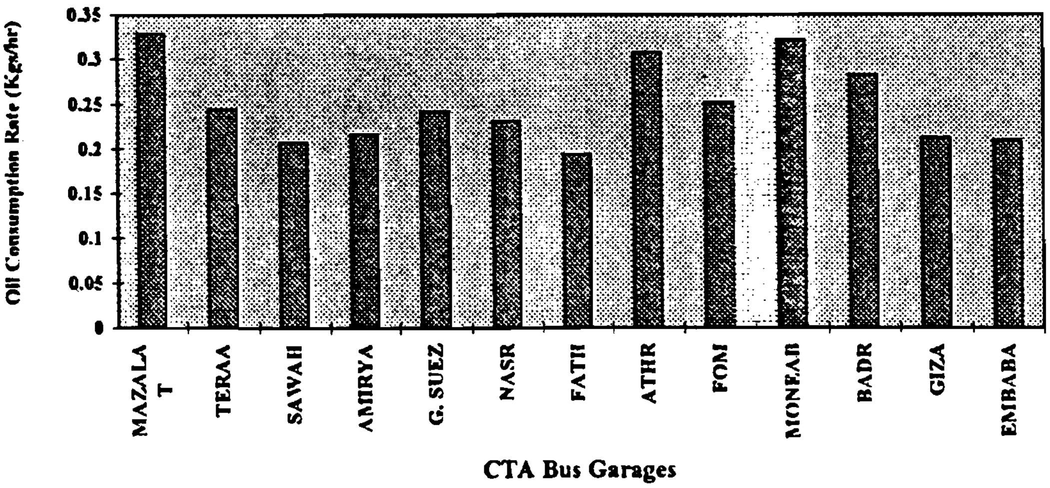

Fig. 3 Oil Consumption Rates By CTA Bus Garages

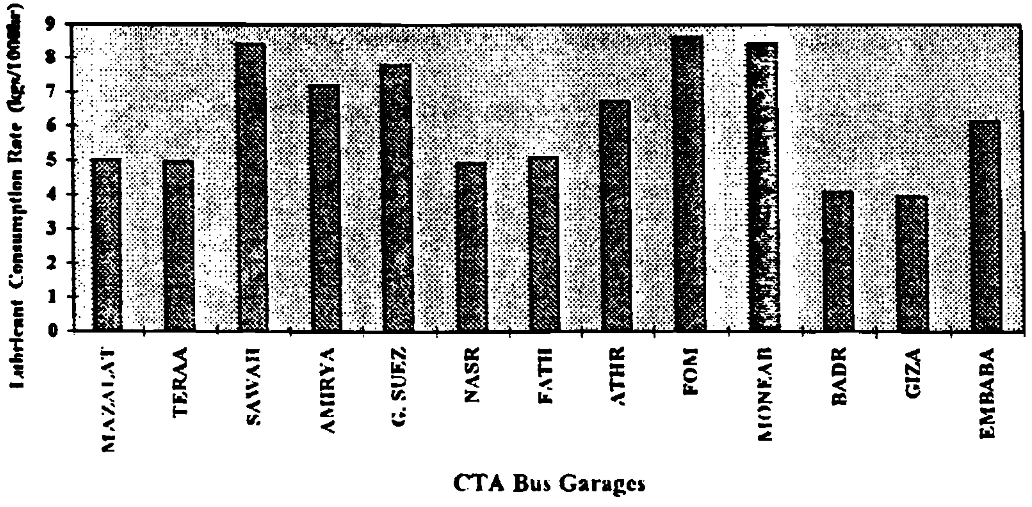

Fig. 4 Lubricant Consumption Rates By CTA Bus Garages

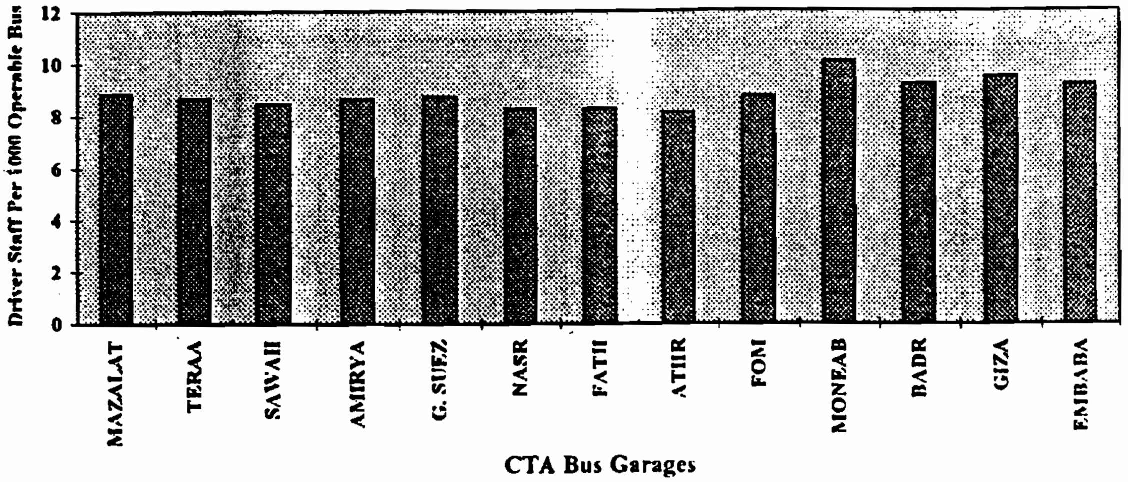

Fig. 5 : Driver Staff per 1000 operable Bus for CTA Bus Garage

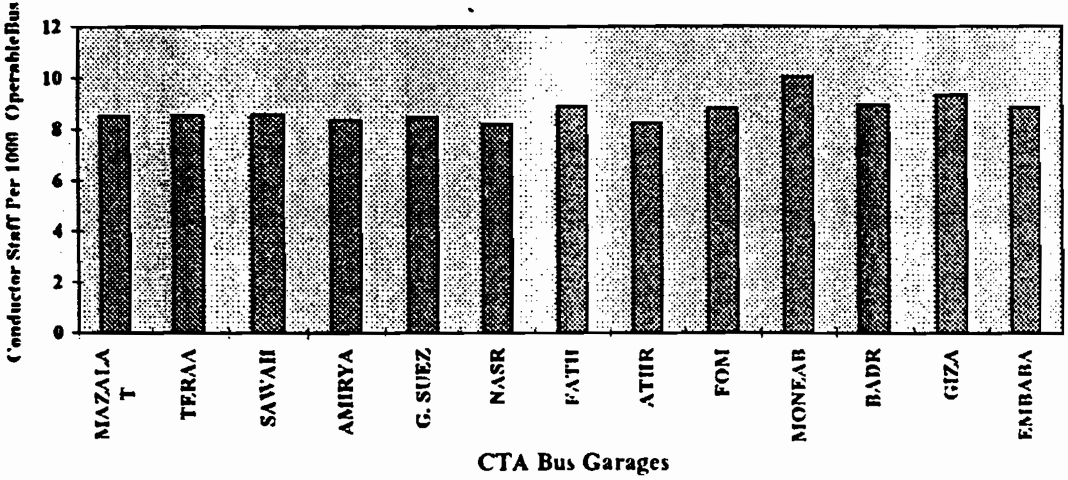

Fig. 6: Conductor Staff Per 1000 Operable Buses For CTA Bus Garages

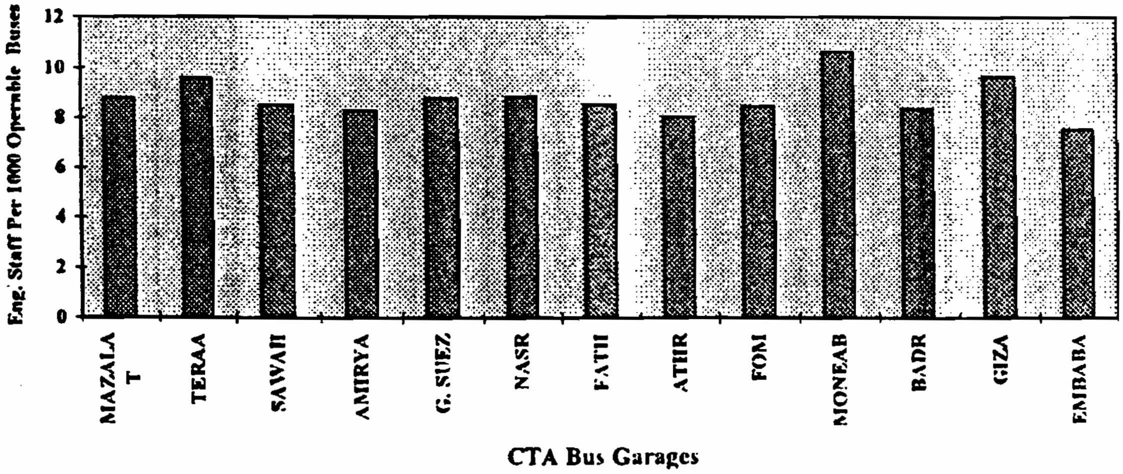

Fig. 7 : Engineering Staff Per 1000 Operable Buses For CTA Bus Garages