MODELLING BUS TRANSIT OPERATION:
A BASIS FOR BUDGETING AND FARE DETERMINATION

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1. INTRODUCTION

Transit planning and management is a combination of art and science. The proposed research aims at investigating and developing the rules, practices, procedures, steps and policies involved in the planning and management of a bus transit company. This is followed by integrating these rules and procedures, as mathematical formulations and algorithms, within a model that simulates the interactions among the components of the bus transit system. The developed model consists of several interrelated modules, the bus maintenance, operation, procurement, fare determination and cost accounting modules, which represent the supply aspects of bus industry. In addition, the demand analysis module, representing the demand side of bus industry.

The model is meant to provide better understanding and insight into the feedback relationships that exist between components forming the supply parameters of bus transit as well as affecting the demand. Overall, such model is needed to provide practical and credible support to transit managers to explore a wide variety of alternative scenarios and examine their effects on the budget and performance of a company, so that they can make more rational and informed planning decisions. A scenario can be composed of the user specification of certain relationships between model parameters, selection of policies and specification of values for key input parameters.

The applicability of the model as a tool that can support the planning and budgeting decisions of bus managers is fully demonstrated and evaluated using a case study. The selected case study is based on real data and information as related to route 48 connecting Misr AlGadida and Attaba in central Cairo and operated by Cairo Transport Authority (CTA). Such data was extracted from CTA annual statistical reports as well as from CTA budget plan. Unavailable required data was logically synthesized in an effort to fully demonstrate the applicability of the model. The required data is classified into geographical zoning and network structure data, fleet database, consumption and cost data, database for potential new buses, service description, and demand pattern. The life cycle depreciation function for buses is also specified. In addition fare and fleet replacement/addition policies are selected.

The model simulates the maintenance, operation, and procurement requirements and costs. This will take into account the expected increase in demand patterns and changes in service characteristics. Fares and subsidies are determined in accordance with the specified fare structure, policy and computed costs. Based on the simulation run, a budget skeleton is developed including a number of key

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indicators that are meant to assist in judging the expected performance of the bus transit system. The model is utilised in conducting sensitivity test that is meant to show the induced effects of increasing the fare level on the travel demand pattern, operational revenue and hence on the financial efficiency. Based on the simulated data, a power function model that relates changes in demand to fare changes is also calibrated. The framework of the proposed simulation model and its input data management system is outlined throughout figure 1. All components depicted in figure 1 will be discussed and demonstrated throughout the paper.

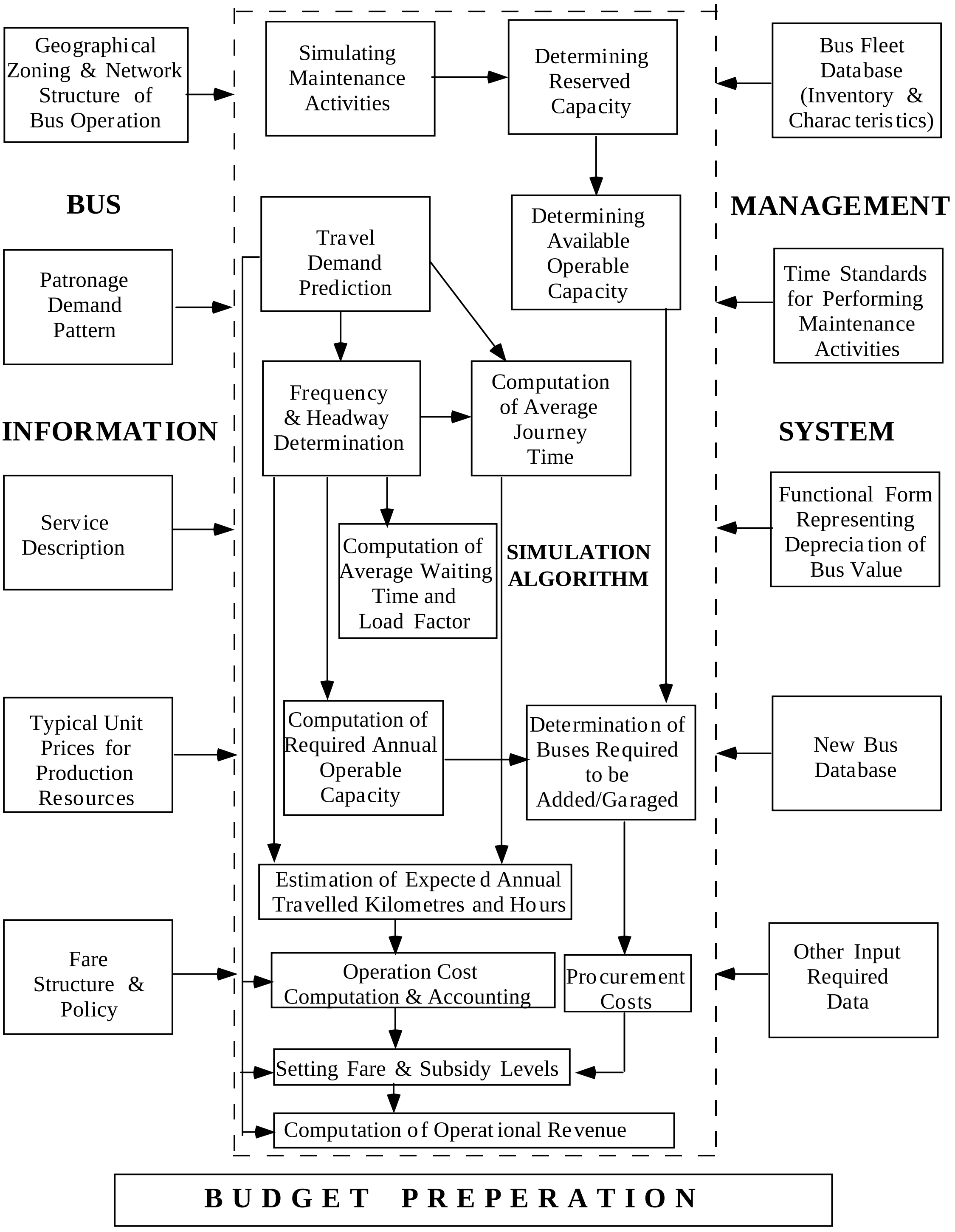

Figure 1: Framework of Proposed Simulation Model and Input Data Management System

2. DATA AND INFORMATION REQUIREMENT CONSTITUTING A BUS MANAGEMENT INFORMATION SYSTEM

In the next subsections, the data and information required by the model will be demonstrated by presenting a case study. This case study is based on real data and information as related to the operation of route 48 connecting Misr AlGadida and Attaba and operated by CTA. Such data was extracted from CTA annual statistical reports as well as from CTA budget plan. Unavailable required data was logically synthesized in an effort to fully demonstrate the applicability of the model.

2.1. Geographical Zoning and Network Structure of Bus Operation

The geographical zoning of bus operation shows how a bus company is divided in terms of geographical entities responsible for operation. Typically a company (CO) could be divided into a number of operating zones. Each of these zones is under the responsibility of a garage (G) operating a fleet of buses (B) on a number of routes (R). A network structure is composed of all of these routes. For each route the following basic information is required:

- Name of Route
- Distance from Garage/Depot to Origin Station (Terminal) (deadhead kilometers)
- Average operating speed between garage/depot and origin station (terminal)
- Number, name and location of main stations and intermediate stops. Based on the number of intermediate serviced stops, the number of origins/destinations can be determined as follows:

No. of Origins (i represents origin) = No. of Destinations (j represents destination) = No. of Intermediate Stops + 2

- Distance Matrix showing distances between the stations and stops on the designated route.

The CTA bus sector comprises 13 garages, geographically distributed throughout Greater Cairo metropolitan area. One of these garages is Gisr El Suez, which is responsible for operating around 200 buses of type Nasr serving 30 routes, including route 48. Route 48 runs from Al-Nozha Al-Gadida through Aziz AlMasry ending at Attaba. For simplicity, only one intermediate station will be considered in the structuring of route 48 distance, time and passenger matrices. In table 1, an approximate route 48 distance matrix is presented.

Table 1: Distance Matrix ($D_{CO,G,R,ij}$) for Route 48*

Destination Origin	Al-Nozha Al-Gadida	Aziz AlMasry	Attaba
Al-Nozha Al-Gadida	-	7 km	17 km
Aziz AlMasry	7.5 km	-	10 km
Attaba	18 km	10.5 km	-

(*) CO = CTA, G = Gisr Al Suez Garage, R = Route 48

For simplicity, variable subscripts (CO,G) are not repeated from here onwards except when needed

2.2. Bus Fleet Database

Buses are allocated to routes to provide the necessary capacity required to meet the expected demand. For each of the buses allocated to a particular route, several data items describing and representing characteristics for these buses are required. In the case of CTA route 48 , typically 3 buses are provided. For each of these 3 buses (B), table 2 shows a typical input of required inventory data.

Table 2: Database Including Inventory & Characteristics for Buses Serving Route 48

Data Items (Units of Measurement)	**Bus**	**Bus**	**Bus**
$SNB_{R,B}$ = Serial No. of Bus[*]	01	02	03
$TB_{R,B}$ = Type of Bus	Nasr	Nasr	Nasr
$SCB_{R,B}$ = Seating Capacity of Bus	33 Seats	33 Seats	33 Seats
$STCB_{R,B}$ = Maximum Standing Capacity of Bus	33 Standee	30 Standee	30 Standee
$CAB_{R,B}$ = Current Age of Bus	5 Years	4 Years	3 Years
$TKB_{R,B}$=Travelled Kilometers of Bus	630000 km.	440000 km.	300000 km.
$PPB_{R,B}$=Procurement Price of Bus (L.E.)[**]	400000 L.E.	500000 L.E.	500000 L.E.
$SVB_{R,B}$ = Salvage Value of Bus	4000 L.E.	5000 L.E.	5000 L.E.
$ULB_{R,B}$ = Useful Life of Bus	8 Years	8 Years	8 Years
$ULBK_{R,B}$= Useful Life of Bus in Km	1000000 km	1000000 km	1000000 km
$LFR_{R,B}$ = License Fees Required	375 L.E.	375 L.E.	375 L.E.
$INSUR_{R,B}$ = Insurance Fees	1130 L.E.	1130 L.E.	1130 L.E.
$BCRM_{R,B}$= Bus Cost of Routine Maintenance	50 L.E.	50 L.E.	50 L.E.
$BCPM_{R,B}$= Bus Cost of Periodic Maintenance	150 L.E.	150 L.E.	150 L.E.
$BCEO_{R,B}$ = Bus Cost of Engine Overhaul	4000 L.E.	4000 L.E.	4000 L.E.
$BCBR_{R,B}$ = Bus Cost of Body Rebuild	5000 L.E.	5000 L.E.	5000 L.E.
$BCUM_R$ = Bus Cost of Unscheduled Maintenance	$\cong$ 500 L.E.		
FRM_{CO} =Frequency of Routine Maintenance	52 Times/year		
FPM_{CO} = Frequency of Periodic Maintenance	12 Times/year		
$TIEO_{R,B}$=Threshold Interval for Engine Overhaul	400000 km.	400000 km.	400000 km.
$TIBR_{R,B}$= Threshold Interval for Body Rebuild	600000 km.	600000 km.	600000 km.
$EOP_{R,B}$ = Engine Overhaul Performed	0	0	0
$BRP_{R,B}$ = Body Rebuild Performed	0	0	0
$ANWH_{R,B}$=Average Number of Working Hours	12 Hr./day	14 Hr./day	16 Hr./day
$BCRF_{R,B}$ = Bus Consumption Rate of Fuel[***]	12 Lit./hr.	12 Lit./hr.	12 Lit./hr.
$BCRO_{R,B}$= Bus Consumption Rate of Oil[***]	0.253 kg./hr.	0.253 kg./hr.	0.253 kg./hr.
$BCRL_{R,B}$= Bus Consumption Rate of Lubricants[***] (Kg/1000hr.)	6.27	6.27	6.27
$BCRT_{R,B}$=Bus Consumption Rate of Tires (Tires /Km)	4/30000	4/30000	4/30000
$BCRB_{R,B}$ = Bus Consumption Rate of Batteries (Battery/Km)	1/60000	1/60000	1/60000
$ARC_{R,B}$ = Average Road Calls (Times/year)	2	1	1
ASB_R = Average Staff per Bus (Employee/Bus)	10.3		

(*) B = 1,…3 (**) Currently 1US$≅6.0 Egyptian Pounds (L.E) & 1 L.E. = 100 piasters
(***) These rates are based on models reported by Abbas and Abd-Allah (1998).
Source: Compiled and Synthesized from CTA Reports.

The average time a bus stays in the maintenance workshop (hence not available for service) can be specified as an empirical formula. Such formula can represent effects of parameters, representing efficiency of workshop conditions, on the time required to perform maintenance. These parameters include parts not in stock and/or not locally obtainable, not enough technical personal to perform the work, insufficient shop space, and old or outdated maintenance equipment. If such formula is not calibrated, a deterministic specification can suffice. Alternatively a stochastic representation taking account of randomness and uncertainty can be used. In case of CTA, a deterministic specification is hypothesized and shown in table 3.

Table 3: Time Standards for Performing Maintenance Activities for Buses Operated by CTA

$ATBRM_{CO,G}$ = Average Time a Bus Stays in Routine Maintenance	Performed outside operation times
$ATBPM_{CO,G}$ = Average Time a Bus Stays in Periodic Maintenance	1 day
$ATBEO_{CO,G}$ = Average Time a Bus Stays in Engine Overhaul	5 days
$ATBBR_{CO,G}$ = Average Time a Bus Stays in Body Rebuild	7 days
$ATBUM_{CO,G}$ = Average Time a Bus Stays in Unscheduled Maintenance	2 days

The unit prices of operational material costs are then input. These include the unit prices for fuel, oil, lubricants, tires, and batteries. In addition information leading to the computation of labor costs is entered. It has to be noted that according to CTA, staff requirements is aggregated i.e. it is difficult to determine the requirements of each bus for management personal, drivers, conductors, maintenance personal, clerks and unskillful workers. Typically, the norm in transit operations is to pay drivers and technical staff an hourly based rate. However, in CTA salaries are monthly paid. Therefore, table 4 shows the typical average yearly earnings per CTA employee regardless of his/her rank or profession. These when combined with average staff per bus can provide the basis for computation of staff costs.

Table 4: Typical Unit Prices of Production Resources Used by CTA

UPF_{CO} = Unit Price of Fuel (Diesel/Solar)	0.4 L.E./liter
UPO_{CO} = Unit Price of Oil	3 L.E./Kg.
UPL_{CO} = Unit Price of Lubricants	3.5 L.E./Kg.
UPT_{CO} = Unit Price of Tire	720 L.E./Tire
UPB_{CO} = Unit Price of Battery	230 L.E./Battery
$AYEPE_{CO}$ = Average Yearly Earning per Employee	5000 L.E./Year

Source: Compiled and Synthesized from CTA Reports.

2.3. Patronage Demand

Transit demand is known to vary in relation to a number of parameters. Ridership, between an origin and a destination, can be disaggregated by route (R), period of traveling (P), service type (S) and type of passenger (TP). Such travel demand can be represented by collecting data to form several demand origin/destination matrices taking the following form $TD_{CO,G,R,P,S,TP,ij}$. This variation could be incorporated in the model. However, such formulation would require extensive and costly data collection effort of travel demand. In addition, it would seem impractical to implement time dependent timetables that would cause confusion to the passengers and might act as a discouragement factor for using the system. In this context, a travel demand matrix was synthesized for route 48 based on the average demand pattern spanning over a number of years. This is shown in table 5.

Table 5: Current Daily Travel Demand ($TD_{R,ij}^{Current}$) Matrix for Route 48

Destination Origin	Al-Nozha Al-Gadida	Aziz AlMasry	Attaba
Al-Nozha Al-Gadida	-	350	600
Aziz AlMasry	300	-	900
Attaba	580	870	-

2.4. Service Description

The bus service level can be described using a number of variables, namely average waiting time represented by headway, average in bus time, comfort represented by allowable load factor, convenience, safety and security. In this research, service description would include the first three variables, namely headway ($Headway_R$), average in bus travel time matrix ($AIBTT_{R,ij}$) and maximum allowable load factor ($LF_{R,B}$). CTA operates buses at a headway of 38 minutes for route 48 , i.e. a frequency ($Frequency_R$) of 1.58 buses/hour. The daily service is scheduled over a 20-hour period, denoted as DSP_R. The $AIBTT_{R,ij}$ is synthesized and shown in table 6. Most of CTA buses are operated with the back door opened to passengers alighting and boarding. In accordance with NCHRP (1975), the average boarding time (ABT_R) is taken as 6 sec/passenger, while average alighting time (AAT_R) is taken as 3 sec/passenger. Also an average layover time (ALT_R) at station/stops of around 30 sec/stop is assumed based on the review of Levinson (1992).

Table 6: Average In Bus Travel Time ($AIBTT_{R,ij}$) Between Main Stations of Route 48

Destination Origin	Al-Nozha Al-Gadida	Aziz AlMasry	Attaba
Al-Nozha Al-Gadida	-	17 minutes	55 minutes
Aziz AlMasry	21 minutes	-	38 minutes
Attaba	62 minutes	41 minutes	-

2.5. Fare Structure and Policy

The model allows the user to first determine the fare structure system to be followed. Two structures are available, namely flat fare based on unit passenger, or distance fare based on unit passenger.kilometre. The model then allows the user to choose one of the following fare policy options to be considered in computing the future unit fare level.

1. Specification of a percentage of operational costs that operational revenues (i.e. fare box revenues) ought to cover, $POCC_{CO}$
2. Operational revenue to break even with operational costs
3. Operational revenue to cover operational costs and to achieve a specified financial efficiency ratio, FER_{CO}
4. Operational revenue to cover operational costs and to achieve a specified rate of return, RRC_{CO} on invested capital (mainly bus procurement capital)

The policy of the Egyptian government is still to subsidize the urban public transport for the Egyptian masses in Greater Cairo. Thus, CTA can only specify a percentage of operational costs that operational revenues (i.e. fare box revenues) ought to cover. This is currently taken to be in the range of 45%. The fare structure adopted by CTA is a form of route based flat fare structure i.e. fares are slightly differentiated from one route to another to express minor service or distance differences. Ticketed fare is currently in the range of 25 piasters/passenger, see White et al. (1999).

2.6. Functional Form Representing Depreciation of Bus Value

“Depreciation is the loss in value of the vehicle during the time it is owned due to passage of time, wear and tear, miles it is driven.” (Dolce, 1992). The depreciation curve (sometimes referred to as life-cycle deterioration curves) could be selected to take any of the following functional forms:

1. Linear depreciation
2. Accelerated depreciation being higher during first years compared to remaining years
3. Parabolic i.e. depreciation is different from one year to another
4. Formula representing transformation of capital sum of bus procurement and future sum of salvage value into uniform annual amounts taking into consideration time preference over the life cycle of buses by using an appropriate discount rate.

The practice followed by CTA is to consider a linear depreciation of bus value spanning over the expected useful lifetime of buses. The official book value representing useful lifetime of buses is currently set at 4 years. However, more than 50% of CTA buses have exceeded 8 years and are still being used for operation. To represent such reality, a useful life of 6 years will be considered.

2.7. New Bus Database

The new bus database includes inventory data on a number of bus types that are considered as potentials for future procurement. For each bus type in the new bus database many of the data items listed in table 1 are provided. In addition, the model allows the flexibility of selecting the payment alternative available by bus suppliers for procuring buses. These include:

1. Lump sum payment, (LSP_B)
2. Annual installments, where the model requires the user to provide four pieces of information: namely the lump sum cost (LSC_B), initial procurement percentage (IPP), supplier installment period (SIP) and the supplier installment fee (SIF).

2.8. Other Input Data Required

Some other data items are required to initiate the simulation run. The first is the annual number of operating days, (AOD_{CO}). CTA operates a full calendar year, which is considered as 365 days. This remains constant throughout the simulation period. The model can also cater for the effect of inflation by allowing the user to enter values representing inflation rates (IR). Additionally, the model requires the user to enter values for the discount rate (DR) in case a financial analysis is performed within the simulation.

3. THE ROUTE BASED SIMULATION MODEL

The developed model contains the principal structural relationships that exist among the various components involved in the overall management of a bus transit company. The user enters the basic data, values for key parameters and selects the policies to be simulated. The model utilizes all these inputs through its mathematical formulations and algorithms and traces the requirements and provision, in physical and financial terms, of the major activities/components of the bus transit system. It considers the effects that these activities/components have on each other as well as on the overall performance of the bus transit system. In developing the model formulations and algorithms the research was partly guided by the review of previous efforts including TCRP (1999), Peng et al. (1997), USDOT (1990, 1987, 1984a & 1984b) as well as Banasiak and Wilson (1985). The following subsections describe the mathematical formulations and algorithms used by the model as well as demonstrate the model applicability in simulating a base scenario for the considered case study i.e. route 48 operated by CTA.

3.1. Simulating Maintenance Activities and Determining Reserved Capacity

The life cycle of a bus progresses through time from an initial state of being in an excellent condition, passing through various states (very good, good, fair, poor), and terminating at a state where it should be scrapped (retired) i.e. where the bus is almost unusable due to radical deterioration. Sufficient appropriate maintenance is vital throughout the life of a bus to keep it in a satisfactory condition. Maintenance activities included in the model are categorized as follows:

(1) Scheduled Preventive Maintenance including routine and periodic maintenance activities as well as engine overhaul and body rebuild activities. According to Dolce (1994), planned intervals for inspecting and conducting preventive maintenance programs should be first determined based on manufactures' recommended intervals and secondly considering the effect of the service operating environment. There are two main objectives for the preventive maintenance activities.

- Maximize the availability of safe high quality buses.
- Minimize the overall maintenance cost by reducing the frequency of occurrence of road calls and hence unexpected maintenance that has very high costs as well as harming the reputation and image of a company. This may be perceived by passengers as a degradation in offered levels of service and might deter them from using the system in the future.

Scheduling of maintenance measures are based mainly on manufacturers frequencies and kilometer thresholds. A kilometer threshold can be described as the number of traveled kilometers at which the condition of a bus changes from one state to another, thus identifying a need for intervention by applying a maintenance treatment. However, it should be noted that manufacturers' frequencies and threshold intervals for performing scheduled inspection and maintenance activities should be modified in accordance with norms based on need, experience and operating environment conditions. Excessive preventive maintenance could affect costs as negatively as too little will.

(2) Unscheduled Maintenance is work resulting from surprise breakdowns which may necessitate road calls. Road calls would probably require a bus to be either fixed on the road or towed to the nearest maintenance workshop. In both cases this represents an expensive operation that has undesirable effects. Frequency of breakdowns and hence road calls can be minimized by adopting timeliness scheduled preventive inspection and maintenance programs.

Maintenance requirements (physical and financial) should be traced on a bus by bus bases taking into account the exclusion of buses that are scheduled for retirement due to reaching the end of their useful life. The mathematical formulations and algorithms as related to the determination of the annual maintenance activities and expected bus capacity reserved in maintenance are displayed in table 7. The last column in the table presents the numerical output resulting of the application of these formulations to route 48. It is to be noted that routine maintenance activities can be performed without affecting operation period and hence not included in formulation of expected bus days in scheduled maintenance.

3.2. Available Operable Capacity

The model goes on to determine the annual bus capacity that is available for utilization and hence operation. Two important ratios are computed, namely the capacity availability ratio representing the percentage of capacity available after subtracting those capacities expected to be reserved for performing scheduled maintenance. The other ratio known as capacity spare ratio represents those capacities that ought to be reserved as contingency in case of road calls, hence buses hooked up in unscheduled maintenance needing swift replacement to continue and maintain normal operation. The mathematical formulations and algorithms as related to the determination of the annual available operable capacity are displayed in table 8. The last column in the table presents the numerical output resulting of the application of these formulations to route 48 .

3.3. Travel Demand Prediction

Several methods can be utilized in forecasting transit patronage. The choice of a method depends on the purpose of the analysis. If major transport system changes are proposed, then bus passengers should be predicted using the traditional four stage modelling, where a disaggregate, logit based, mode choice model is utilized. Such model takes the following form:

$P_B = e^{GC_B} / \sum_m e^{GC_m}$ where: P_B = Probability of choosing bus as a travelling mode
e = base of natural logarithms GC_B = Generalized Cost for travelling by Bus
m = Considered alternative modes
GC_m = Generalized Cost for travelling by considered mode m

Another alternative method is to forecast patronage as a function of demand and supply related factors. An example of such method is proposed by Hensher (1992), where a log linear demand equation is calibrated. This equation includes factors representing fare, vehicle kilometers, income and cost of alternative modes such as automobile. The following represents the formulation of such model.

$$\ln TD = K_0 + K_f \ln (\text{fare}) + K_{los} \ln (\text{vkm}) + K_y \ln (\text{income}) + K_a (\text{auto cost})$$

Table 7: Mathematical Formulations & Algorithms Simulating Bus Maintenance Activities and Determination of Capacity Reserved

Mathematical Formulations & Algorithms	Variable Definitions	Route 48 Output
$BSR_R = \sum_{B \forall B \in R \in G \in CO} BSR_B$ (*) $BSR_B = \begin{cases} 1.00 \text{ if } CAB_{R,B} \geq ULB_{R,B,} \ \& \ TKB_{R,B} \geq ULBK_{R,B} \\ 0.00 \end{cases}$	BSR = Buses Scheduled for Retirement due to reaching end of their useful life B = Buses Allocated for Route	0 buses
$B_R = B_R^{Existing} - BSR_R$	From this point onwards, any reference to allocated buses would exclude those buses scheduled for retirement.	3 buses
$RMA_R = \sum_B FRM_{R,B}$	RMA = Routine Maintenance Activities	156 times
$PMA_R = \sum_B FPM_{R,B}$	PMA = Periodic Maintenance Activities	36 times
$EOA_R = \sum_B EOA_B$ $EOA_B = \begin{cases} 1.00 \text{ if } TKB_{R,B} \geq TIEO_{R,B,} \ \& \ TKB_{R,B} < TIBR_{R,B,} \ \& \ EOP_{R,B} = 0.00 \\ 0.00 \end{cases}$	EOA = Engine Overhaul Activities	1 time
$BRA_R = \sum_B BRA_B$ $BRA_B = \begin{cases} 1.00 \text{ if } TKB_{R,B} \geq TIBR_{R,B} \ \& \ BRP_{R,B} = 0.00 \\ 0.00 \end{cases}$	BRA = Body Rebuild Activities	1 time
$UMA_R = \sum_B ARC_{R,B}$	UMA = Unscheduled Maintenance Activities	4 times
$EBDSM_R = (PMA_R * ATBPM_{CO,G}) + (EOA_R * ATBEO_{CO,G}) + (BRA_R * ATBBR_{CO,G})$	EBDSM = Expected Bus Days in Scheduled Maintenance	48 days
$EBHSM_R = \sum_B \{(FPM_{R,B} * ATBPM_{CO,G}) + (EOA_{R,B} * ATBEO_{CO,G}) + (BRA_{R,B} * ATBBR_{CO,G,})\} * ANWH_{R,B}$	EBHSM = Expected Bus Hours in Scheduled Maintenance	658 hours
$EBSSM_R = \sum_B \{(FPM_{R,B} * ATBPM_{CO,G,R}) + (EOA_{R,B} * ATBEO_{CO,G,R}) + (BRA_{R,B} * ATBBR_{CO,G,R})\} * ANWH_{R,B} * SCB_{R,B}$	EBSSM = Expected Bus Seated Capacity in Scheduled Maintenance	21714 seats
$EBSSTSM_R = \sum_B \{(FPM_{R,B} * ATBPM_{CO,G,R}) + (EOA_{R,B} * ATBEO_{CO,G,R}) + (BRA_{R,B} * ATBBR_{CO,G,R})\} * ANWH_{R,B} * (SCB_{R,B} + STCB_{R,B})$	EBSSTSM = Expected Bus Seated and Standing Capacity in Scheduled Maintenance	42138 seated & standing
$EBDUM_R = \sum_B ARC_{R,B} * ATBUM_{CO,G}$	EBDUM = Expected Bus Days in Un-scheduled Maintenance	8 days
$EBHUM_R = \sum_B (ARC_{R,B} * ATBUM_{CO,G}) * ANWH_{R,B}$	EBHUM = Expected Bus Hours in Un-scheduled Maintenance	108 hours
$EBSUM_R = \sum_B (ARC_{R,B} * ATBUM_{CO,G}) * ANWH_{R,B} * SCB_{R,B}$	EBSUM = Expected Bus Seated Capacity in Un-scheduled Maintenance	3564 seated
$EBSSTUM_R = \sum_B (ARC_{R,B} * ATBUM_{CO,G}) * ANWH_{R,B} * (SCB_{R,B} + STCB_{R,B})$	EBSSTUM = Expected Bus Seated and Standing Capacity in Un-scheduled Maintenance	6948 seated & standing

(*) For simplicity, subscripts following summation notations i.e. ($\sum_{B \forall B \in R \in G \in CO}$) are not repeated from here onwards

Table 8: Mathematical Formulations & Algorithms for Determining Annual Available Operable Capacity

Mathematical Formulations & Algorithms	Variable Definitions	Route 48 Output
$MPAC_R = AOD_{CO} * \sum_B ANWH_{R,B} * (SCB_{R,B} + STCB_{R,B})$	MPAC = Maximum Possible Annual Capacity	978930 seated and standing
$CAR_R = 1 - (EBSSTSM_R / MPAC_R)$	CAR = Capacity Availability Ratio	0.96 (Dimensionless)
$AAC_R = MPAC_R * CAR_R$	AAC = Available Annual Capacity	936792 seated and standing
$CSR_R = EBSSTUM_R / AAC_R$	CSR = Capacity Spare Ratio	0.007 (Dimensionless)
$AOC_R = AAC_R * (1 - CSR_R)$	AOC = Available Operable Capacity	929844 seated and standing

The third method that can be used for forecasting patronage is the elasticity formulation. This is the most widely utilized method by transit operators. It measures the responsiveness of demand to changes in supply variables such as fares, waiting time, travel time, etc. normalized by the current level of demand and the variable under question. In the case of route 48 operated by CTA, a base realistic scenario is assumed, where no significant changes in fare or in service characteristics are expected to occur. Also, in the case of CTA in general and route 48 in particular, patronage data have been historically fluctuating up and down over the years. Thus, a simple time series model to represent the expected demand pattern for route 48 was calibrated as follows:

$Y = -659.66Ln(x) + 4359.7$ where $R^2 = 0.5678$
Y = Annual number of ticket passengers using route 48
X = No. of years considering 87/88 as base year

Applying this model, produces a predicted level of demand of approximately 2990 ticket passengers/day on route 48. Such demand is distributed among the route 48 O/D matrix cells in accordance with the current average weight of each cell, and as shown in table 9.

Table 9: Expected Daily Travel Demand Matrix ($TD_{R,ij}^{Expected}$) for Route 48 (Base Scenario)

Destination Origin	Al-Nozha Al-Gadida	Aziz AlMasry	Attaba
Al-Nozha Al-Gadida	-	291	498
Aziz AlMasry	249	-	747
Attaba	482	723	-

3.4. Frequency and Headway Determination

According to Cedar and Wilson (1986), the process of developing an operation plan consists of five steps, namely network design, frequency setting, timetable development, bus scheduling, and driver scheduling. In this research, we are mainly concerned with frequency determination. The required frequency is a function of two parameters representing demand and supply. In order to obtain the frequencies of bus operations that are meant to meet expected travel demand and to achieve a desirable level of service, one has to go through several steps. First the 24 hour O/D matrix is multiplied by an hourly peak factor (PHF_R). According to American Highway Capacity Manual, see HCM (2000), the average value of peak hour factor for traffic flows in urban conditions is about 11% with a range from 7% to 18%. Previous traffic studies in Cairo indicated that such factor is in the range of 7% of AADT. Such low value can be attributed to the phenomenon known as peak spreading which is very significant in the city of Cairo. This value can be adopted to compute peak demand for CTA route 48 . Based on this factor, an expected peak hour patronage matrix was estimated using the following formulation. Also, a simple algorithm, depicted in table 11, was also developed to compute the maximum point load shown in table 10.

$PHTD_{R,ij}^{Expected} = PHF_R * TD_{R,ij}^{Expected}$ where: PHTD = Peak Hour Travel Demand

Table 10: Expected Peak Hour Travel Demand Matrix ($PHTD_{R,ij}$) & Maximum Point Load (MPL_R) for Route 48

				Maximum Point Load (MPL) (Direction)	Maximum Point Load (MPL) (Direction)
Destination Origin	Al-Nozha Al-Gadida	Aziz AlMasry	Attaba	↓	↑
Al-Nozha Al-Gadida	-	21	35	56	
Aziz AlMasry	18	-	53	**MPL_R = 88**	52
Attaba	34	51	-		85

In addition a representative bus capacity has to be computed. This is done by averaging the seated and standing capacities of each bus in service. Finally frequency and headway can be computed using the formulations depicted in table 11 and applied for route 48.

Table 11: Mathematical Formulations & Algorithms Simulating Frequency and Headway Determination

Mathematical Formulations & Algorithms	Variable Definitions	Route 48 Output
$MPL_R = Max. [Max.(\sum_i PHTD_{R,ij}), Max.(\sum_j PHTD_{R,ij})]$	MPL = Maximum Point Load in Peak Hour Demand	88 passengers
$ABC_R = (\sum_B SCB_{R,B} + STCB_{R,B}) / B$	ABC = Average Bus Capacity	64 seated & standing
$Frequency_R = MPL_R / ABC_R$	Frequency measured as bus journeys required within a certain demand period*	1.36 buses/hour
$Headway_R = (1/Frequency_R) * 60$	Headway = Headway of bus services measured as time between each bus service	44 minutes

(*) Usually taken as the peak hour in urban services

The current frequency representing available supply is compared with the computed frequency representing required supply. The case study shows the situation where required supply is less than current supply. In this case a value can be recommended in terms of a reduction of frequency and hence an increase in headway. This would eventually cause an increase in average waiting time per passenger and a degradation in the level of service. This might lead to more passengers leaving the current bus service and being attracted to alternative competitive modes i.e. a ridership reduction. Another solution is to keep the current frequency levels thus improving the level of service through a reduction of the current load factor. In this base run, the first solution is adopted.

3.5. Computation of Average Waiting Time and Load Factor

Once frequency and headway are determined, average waiting time can be computed using the following general formulation.

$WT_R = \{(Headway_R)^2 + \sigma^2\} / 2 * Headway_R$ where WT = Waiting Time

According to Ortuzar and Willumsen (1994), σ is the standard deviation of the headway. If the service is perfectly regular, σ = 0, then the expected waiting time is half of the headway. It is known, however, that if the frequency of the service is low, passengers will try to arrive just a few minutes before the next departure, thus setting an upper limit to the expected waiting time. Based on the computed headway, it is expected that average waiting time for route 48 would be in the range of 22 minutes.

Another important indicator of service level is the maximum allowable load factor ($LF_{R,B}$). Load factor can represent the comfort level inside the bus. It is expressed as the ratio of the maximum capacity (seating and standing) in relation to the standard seating capacity of the bus. This can be computed for each bus allocated for route 48 and averaged across the operating fleet, thus producing a figure of 1.94. This is considered as extremely high load factor, which is typical of bus services, operated by CTA in Cairo.

$LF_{R,B} = [(\sum_B SCB_{R,B} + STCB_{R,B}) / B] / [(\sum_B SCB_{R,B}) / B]$

3.6. Average Journey Time

A route round trip time is composed of three main components:

1. In Bus Round Trip Travel Time ($IBRTTT_R$) including outbound and inbound journeys
2. Boarding and alighting times for passengers
3. Layover time representing the elapsed period after boarding and alighting of passengers at a terminus and the bus departure time from the terminus

The mathematical formulations and algorithms as related to the determination of average journey time is displayed in table 12. The last column in the table presents the numerical output resulting of the application of these formulations to route 48.

Table 12: Mathematical Formulations & Algorithms Simulating Determination of Average Journey Time

Mathematical Formulations & Algorithms	Variable Definitions	Route 48 Output
$OD_R = \sum_i OD_{R,ij\forall j=i+1}$	OD = Outbound Distance	17 km
$ID_R = \sum_j ID_{R\ ij\forall I=j+1}$	ID = Inbound Distance	18 km
$RTD_R = OD_R + ID_R$	RTD = Round Trip Distance	35 km
$OIBTT_R = \sum_i OTT_{R,ij\forall j=i+1}$	OIBTT = Outbound In Bus Travel Time	55 minutes
$IIBTT_R = \sum_j ITT_{R\ ij\forall I=j+1}$	IIBTT = Inbound In Bus Travel Time	62 minutes
$IBRTTT_R = OIBTT_R + IIBTT_R$	IBRTTT = In Bus Round Trip Travel Time	117 minutes
$RTAS_R = [(RTD_R) * 60]/ RTTT_R$	RTAS = Round Trip Average Speed	17.9 km/hr
$PHTD_R = \sum_{ij} PHTD_{R,ij}$	PHTD = Peak Hour Travel Demand	209 passengers
$RTT_R = (RTD_R / RTAS_R) + [(PHTD_R / Frequency_R) * (ABT_R + AAT_R)]/(60*60) + (ALT_R * i)/(60*60)$	RTT = Round Trip Time	2.36 hours

3.7. Required Annual Operable Capacity

The model goes on to determine the bus capacity i.e. the number of bus units required to satisfy the determined service values. The mathematical formulations and algorithms as related to the determination of the required operable capacity are displayed in table 13. The last column in the table presents the numerical output resulting of the application of these formulations to route 48 .

Table 13: Mathematical Formulations & Algorithms Used for Determining Required Operable Capacity

Mathematical Formulations & Algorithms	Variable Definitions	Route 48 Output
$NBUR_R = RTD_R * 60 / (RTAS_R * Headway_R)$	NBUR = Number of Bus Units Required	2.66 buses
$AANWH_R = (\sum_B ANWH_{R,B}) / B$	AANWH = Average of Average Number of Working Hours	14 hours/day
$RAOC_R = NBUR_R * ABC_R * AANWH_R * AOD_{CO}$	RAOC = Required Annual Operable Capacity	869629 seated & standing

3.8. Determination of Buses required to be Added/Garaged-Reallocated

New buses are procured for two reasons:

1. Replacement of existing buses that have reached the end of their useful lives
2. Addition of new buses to cater for the insufficiency of supply required to meet expected travel demand.

The fleet replacement/addition policy to be followed is determined in light of the availability of capital in the actual budget. An annual fleet procurement policy could take any of the following forms:

- Replace buses in accordance with predetermined fleet replacement criteria, regardless of demand considerations.
- Purchase new buses to cover the insufficiency in supply so as to meet the expected increase in travel demand.
- Extend bus usage beyond replacement criteria
- Purchase and extend

The determination of buses required to be added starts by comparing the required annual operable capacity with the available annual operable capacity. Three outcomes are possible of such comparison. The first is the do nothing scenario where both capacities are equal. The second scenario is where available capacity is greater than or equal to required capacity. In such situation, either the service continues with an oversupply which can lead to an improvement in level of service and hence attraction of more passengers demand or alternatively such oversupply is reallocated and utilized by some other routes or garages or eventually garaged to save operational and maintenance costs.

The third scenario is where available capacity is less than required capacity. In such situation, either the service continues with an undersupply, which can lead to degradation in level of service, and hence passengers shifting to other modes or alternatively such gap is filled by the purchase of new buses. The total new buses required to be added through procurement or reallocation among routes include those buses required to be added to meet the increase in travel demand as well as those buses required to replace buses reaching retirement. The mathematical formulations and algorithms required to test and compute the number of buses required to be added or garaged are displayed in table 14. The last column in the table presents the numerical output resulting of the application of these formulations to route 48 .

3.9. Estimation of Expected Annual Travelled Kilometers and Hours

Estimation of expected annual travelled kilometers and hours act as the basis for computation of operational costs. The mathematical formulations required to estimate expected annual travelled kilometers and hours are displayed in table 15. The last column in table presents the numerical output resulting of application of these formulations to route 48.

Table 14: Mathematical Formulations & Algorithms Used for Determining Required Operable Capacity

Mathematical Formulations & Algorithms	Variable Definitions	Route 48 Output
$CD_R = AOC_R - RAOC_R$	CD = Capacity Discrepancy	60214 seated & standing
if $CD_R > 1.0$ Then $CD_R / (ABC_R * AANWH_R * AOD_{CO})$ BRG_B={ Else 0.00	BRG = Buses Required to be Garaged or Reallocated	0.18 buses
if $CD_R < 1.00$ Then $\lvert CD_R \rvert / (ABC_R * AANWH_R * AOD_{CO})$ BRA_B={ Else 0.00	BRA = Buses Required to be Added	0 buses
$EB_R = B_R + BRA_R - BRG_R$	EB = Expected No. of buses*	2.8 truncated to 3 buses

(*) Assuming no budget or re-allocation constraints are encountered

Table 15: Mathematical Formulations Used for Estimating Expected Travelled Km. & Hours

Mathematical Formulations & Algorithms	Variable Definitions	Route 48 Output
$ETK_R = Frequency_R * RTD_R * DSP_R * AOD_{CO}$	ETK = Expected Travelled Kilometers	348409 km/year
$ETH_R = (Frequency_R * IBRTTT_R * DSP_R * AOD_{CO})/60$	ETH = Expected Travelled Hours	19411 hours/year

3.10. Operation Costs Computation and Accounting

The total operation costs, sometimes referred to as running costs is computed as the summation of maintenance, production, staff, depreciation as well as other non production costs. Maintenance costs include costs of all types of scheduled as well as unscheduled maintenance activities. Production costs include five main types of consumables, namely fuel, oil, lubricants, tires and batteries.

Staff costs is usually disaggregated in accordance with different types of labour such as drivers, conductors, mechanics, engineers, clerical staff and finally managerial staff. Some of these labour types are paid on an hourly basis, others are paid on a salary basis. However, CTA treats all labour types on a salary basis in addition to various productivity related incentives and bonuses. Such detailed data on a bus by bus basis is not available. In this context, labour costs per bus is computed as the average number of workers per bus multiplied by the average salary . Such values are averaged based on CTA data for the whole bus sector.

Annual depreciation cost (ADC_R) of buses can be either based on adopting a linear depreciation function or alternatively estimating depreciation cost of buses taking time preference into consideration. The mathematical formulations and algorithms as related to the computation of operation costs are displayed in table 16. The last column in the table presents the numerical output resulting of the application of these formulations to route 48 .

3.11. Procurement Costs

If new buses are to be procured by paying the procurement price as a lump sum, then the procurement costs is equal to the procurement price per bus multiplied by the number of buses required to be added. Alternatively, buses can be purchased by first paying an initial procurement percentage and paying the rest of the purchase price as installments with an installment fee over a period of time specified by the supplier. The mathematical formulations and algorithms as related to the computation of procurement costs are displayed in table 17. The last column in the table presents the numerical output resulting of the application of these formulations to route 48.

3.12. Setting Fare and Subsidy Levels and Estimating Operational Revenue

The first step in the fare determination procedure is to decide on the fare structure whether it is flat fare or distance based fare. Based on this, the total operation cost per unit demand is computed, where the unit demand in the flat fare structure is simply the number of passengers, while that for distance based fare is the passengers.kilometres. Passenger.kilometres is one of the most representative measures of the extent of bus usage. A passenger.kilometer value is meant to act as a unit base for fare specification as well as for cost and revenue comparisons. Passenger.kilometres matrices are computed by multiplying the demand origin/destination matrix by the distance origin/destination matrix.

It is obvious that an increase in travel demand would cause a decrease in the operational cost per unit demand and hence a decrease in required unit fare. Computing the required fare level can be done by selecting an appropriate formulation in accordance with the selected fare structure and fare policy. This is followed by determining the subsidy level in accordance with the selected fare policy.

Operational revenue is then computed as the multiplication of the unit fare by the number of passengers (in case of flat fare structure) or by the number of passenger.kilometres (in case of distance based fare). The operational financial surplus/deficit is then computed by subtracting the operational costs from operational revenue. This is an extremely important financial indicator that can help in the assessment of the financial performance status of a bus company. It is also very important as it is considered as one of the sources of financial funds to be pumped into the following years budgets. The mathematical formulations and algorithms, as related to the setting of fare structure, computation of fare and estimation of subsidy level in accordance with selected fare policy, are displayed in table 18. The last column in the table presents the numerical output resulting of the application of these formulations to route 48.

Table 16: Mathematical Formulations Used for Estimating Expected Operation Costs

Mathematical Formulations & Algorithms	Variable Definitions	Route 48 Output
$RMC_R = (EB_R * FRM) * \{(\sum_B BCRM_B)/B\}$	RMC = Routine Maintenance Cost	7800 L.E.
$PMC_R = (EB_R * FPM) * \{(\sum_B BCPM_B)/B\}$	PMC = Periodic Maintenance Cost	5400 L.E.
$EOC_R = EOA_R * \{(\sum_B BCEO_B)/B\}$	EOC = Engine Overhaul Cost	4000 L.E.
$BRC_R = BRA_R * \{(\sum_B BCBR_B)/B\}$	BRC = Body Rebuild Cost	5000 L.E.
$SMC_R = RMC_R + PMC_R + EOC_R + BRC_R$	SMC = Scheduled Maintenance Cost	22200 L.E.
$UMC_R = UMA_R * BCUM_{R,B}$	UMC = Unscheduled Maintenance Cost	2000 L.E.
$SUMC_R = SMC_R + UMC_R$	SUMC = Scheduled and Unscheduled Maintenance Cost	24200 L.E.
$FC_R = [ETH_R * \{(\sum_B BCRF_{R,B})/B\}] * UPF_{CO}$	FC = Fuel Costs	93174 L.E.
$OC_R = [ETH_R * \{(\sum_B BCRO_{R,B})/B\}] * UPO_{CO}$	OC = Oil Costs	14733 L.E.
$LC_R = [ETH_R * \{(\sum_B BCRL_{R,B})/(B*1000)\}] * UPL_{CO}$	LC = Lubricant Costs	426 L.E.
$TC_R = [ETK_R / \{(\sum_B BCRT_{R,B})/B\}] * 4 * UPT_{CO}$	TC = Tire Costs	33447 L.E.
$BC_R = [ETK_R / \{(\sum_B BCRB_{R,B})/B\}] * UPB$	BC = Battery Costs	1335 L.E.
$PC_R = FC_R + OC_R + LC_R + TC_R + BC_R$	PC = Production Costs	143116 L.E.
$SC_R = EB_R * ASB_R * AYEPE_{CO}$	SC = Staff Costs	154500 L.E.
$LF_R = EB_R * \{(\sum_B LFR_{R,B})/B\}$	LF = License Fees	1125 L.E.
$IF_R = EB_R * \{(\sum_B (INSUR_{R,B})/B\}$	IF = Insurance Fees	3390 L.E.
$ONPC_R = LF_R + IF_R$	ONPC = Other Non Production Costs	4515 L.E.
$ADCL_R = \sum_B (PPB_{R,B} - SVB_{R,B}) / ULB_{R,B}$	ADCL = Annual Bus Depreciation Cost in Case of Linear Depreciation	231000 L.E.
$ADCT_R = \sum_B (PPB_{R,B} * CRF_{R,B}) – (SVB_{R,B} * SFF_{R,B})$ $CRF_{R,B} = \{(DF/100)\,(1+DF/100)^{ULB}{}_{R,B}\} / \{(1+DF/100)^{ULB}{}_{R,B} - 1\}$ $SFF_{R,B} = (DF/100) / \{(1+DF/100)^{ULB}{}_{R,B} - 1\}$	ADCT = Annual Depreciation Cost of Bus in Case Time Preference is Taken into Consideration CRF = Capital Recovery Factor SFF = Sinking Fund Factor DF = Discount Factor	Not Applicable to Base Scenario
$TOC_R = SUMC_R + PC_R + SC_R + ADCL_R + ONPC_R$	TOC = Total Operation Costs	557331 L.E.

Table 17: Mathematical Formulations/Algorithms for Computing Procurement Costs

Mathematical Formulations & Algorithms	Variable Definitions	Route 48 Output
BRA_R * PLSP In case of Lump Sum Payment PC_R ={ (BRA_R * PLSP * IPP * CRF) + [BRA_R*PLSP*(1-IPP)*SIF*CRF] In case of Installment Procurement	PLSP = Procurement Lump Sum Price IPP = Initial Procurement Percentage SIF=Supplier Installment Fee PC = Procurement Cost	0 L.E.

Table 18: Mathematical Formulations for Computing Fare and Estimating Subsidy

Mathematical Formulations & Algorithms	Variable Definitions	Route 48 Output
$APass_R = (TD_R * AOD_{CO})$	APass = Annual Passengers	1091350
$APassKm_R = \sum_{ij} (TD_{R,ij} * D_{R,ij})$	$APassKm_R$ = Annual Passenger.Kilometres	13170660 pass.km
$TOC_R / APass_R$ in case of flat fare $TOCUD_R$ ={ $TOC_R / APassKm_R$ in case of distance based fare structure	TOCUD = Total operational cost per unit demand	0.51 L.E.
$TOCUD_R * POCC_{co}$ in case of % coverage $Fare_R$ = {or $TOCUD_R$ in case of breakeven coverage* $Fare_R$ = {or $TOCUD_R * FER_{co}$ In case of achieving a targeted financial efficiency ratio* $Fare_R$ = {or In case of flat fare & achieving rate of return on capital* $[(TOC_R + PC_R) / APass_R] * RRC_{CO}$ $Fare_R$ = {or $[(TOC_R + PC_R) / APassKm_R] * RRC_{CO}$ In case of distance based fare & rate of return on capital*	POCC = Percentage of operational costs that operational revenues ought to cover FER = Financial efficiency ratio to be achieved RRC = Specified rate of return on invested capital (mainly bus procurement capital) Fare = Fare Level (Fare per Passenger)	0.23 L.E./pass.
$TOCUD_R - Fare_R$ in case of percentage coverage $Subsidy_R$={ 0.00 in all other cases	Subsidy = Subsidy Level (Subsidy per Passenger or per Passenger.Km)	0.28 L.E./pass.
$Fare_R * APass_R$ in case of flat fare OR_R ={ $Fare_R * APassKm_R$ In case of distance based fare	OR = Operational Revenue	250840 L.E.
$TOCUD_R * (1-POCC_{co})$ in case of percentage coverage $FORS_R$={ 0.00 in all other cases	FORS = Foregone Operational Revenue Used as Subsidy	306532 L.E.
$OD\text{-}S_R = OR_R - OC_R$	OD-S = Operational Deficit-Surplus	-306491 L.E.
$OFF_R = OR_R / OC_R$	OFF = Operational Financial Efficiency	0.45

(*) In all these cases, the effect of fare increase on travel demand is not taken into account.

4. BUDGET PREPARATION

Based on all of the previous mathematical formulations and algorithms used to compute the various demand and supply parameters for operation of a fleet of buses on a specific route, a budget summary can be produced as shown in table 19. The summation of such budgets on a route by route basis followed by a garage by garage basis can eventually produce a wholesome budget for the bus operator as shown in the following formulation.

$$\mathrm{Budget}_{CO} = \sum_{G} \sum_{R} \mathrm{Budget}_{G,R}$$

Finances available in the budget come mainly from accumulative operational earnings, retained depreciation costs, subsidy compensation, loans, grants, bank deposits, etc. Available budget can:

1. Cover all the necessary operational cost and capital requirements or
2. Cover all necessary operational cost requirements and a part of capital requirements or
3. Cover all necessary operational cost requirements but not the capital requirements or
4. Cover a part of operational cost requirements & unable of covering capital requirements

Table 19: Budget Layout for Route 48

Expected Patronage	Production & Service Parameters	Costs (Operational & Capital)	Fare, Subsidy & Operation Revenue	Performance Indicators
2990 pass./day	Production Parameters	Routine Maintenance Costs = 7800 L.E.	Fare Structure = Passenger Based	Financial Indicators
209 pass./ peak hour	Buses Continuing Service = 3 buses	Periodic Maintenance Costs = 5400 L.E.	Fare Policy = 45% Coverage of Operational Costs	Operational Deficit/Surplus = -306491 L.E.
Maximum Point Load =88 pass/hr.	Buses Scheduled for Retirement = 0	Engine Overhaul Costs = 4000 L.E.	Fare Level = 0.23 L.E./passenger	Operational Financial Efficiency= 0.45
	Buses Scheduled for Procurement = 0	Body Rebuild Costs = 5000 L.E.	Operational Revenue = 250840 L.E.	Level of Service Indicators
	Operable Buses = 3 buses	Scheduled Maintenance Costs = 22200 L.E.	Subsidy	Waiting Time = 22 minutes
	Service Parameters	Unscheduled Maintenance costs = 2000 L.E.	Subsidy Level = 0.281 L.E./Pass.	Travel Time = 2.36 hours/round trip
	Frequency = 1.36 buses/hour	Sub- Total Maintenance Costs = 24200 L.E.	Forgone Operational Revenue = 306532 L.E.	Load Factor = 1.94
	Headway = 44 minutes	Fuel Costs = 93174 L.E.		Maintenance Indicators
	Annual Travelled Kilometers = 348409 km/year	Oil Costs = 14733 L.E.		Capacity Availability Ratio = 0.96
	Annual Hours in Service = 19411 hours/year	Lubricant Costs = 426 L.E.		Capacity Spare Ratio = 0.007
		Tires Costs = 33447 L.E.		
		Batteries Costs = 1335 L.E.		
		Sub-Total Production Costs = 143116 L.E.		
		Staff Costs = 154500 L.E.		
		Licensing Costs = 1125 L.E.		
		Insurance Costs = 3390 L.E.		
		Sub-Total Other Non-Production Costs = 4515 L.E.		
		Depreciation Costs = 231000 L.E.		
		Procurement Costs = 0 L.E.		
		Total = 557331 L.E.		

5. SENSITIVITY OF FINANCIAL PERFORMANCE OF CTA ROUTE 48 TO INCREASES IN FARE LEVEL

A recent report noted that “CTA fares are subject to hyper-regulation, apparently as a matter of social policy. Fares are not simply regulated, they are frozen”, see World Bank (2000). The main objective of CTA should be shifted from being a social welfare organisation to profit making organisation. A recommendation by CREATS (2002) was to restructure the public transport fare system as one of the basis for ensuring a sustainable financial mechanism. CREATS survey revealed that public transport users in Cairo are willing to pay an additional 24 piasters on average given better service.

It is widely acknowledged that any changes in the fare level of public transport would induce changes in the expected demand pattern. According to Hobbs and Wright (1995), elasticities should be used to determine the change in ridership resulting from changes in service quality or fares. A commonly used measure of elasticity is the midpoint elasticity, see Levinson (1992), that is defined as:

$e = (R_2 – R_1) (F_1 + F_2) / (F_2 – F_1) (R_1 + R_2)$
where: R_1 = Initial Ridership, R_2 = Ridership after Change
F_1 = Initial Attribute such as fares, travel times, headways, F_2 = New Attribute

Using the above equation, a mid point elasticity value of approximately –0.65 was computed for CTA bus riders based on the data available for the years 1994 and 1996 shown in table 20. The table shows the drop in patronage due to the fare increase from an average fare of approximately 0.19 L.E./passenger to an average fare of 0.23 L.E./passenger. A fare elasticity value of –0.4 was derived by White et al. (1999) in a recent study of the metro lines in Cairo. Such value is not too far from the reached value in this research taking into consideration that the income levels of CTA bus riders is perceived to be less than metro lines’ passengers and hence the effect of fare increases is more significant.

Table 20: CTA Revenue and Patronage Statistics for Bus Operation

Year	Ticket Passenger Revenues	Number of Ticket Passengers	Average Fare/Passenger
1994	210515645 L.E.	1113699000 pass.	0.19 L.E./passenger
1996	225779372 L.E.	977279000 pass.	0.23 L.E./passenger

(Source: CTA 95/96)

The above elasticity value was used to test the effect of changes in fare level on the travel demand pattern and hence on the operational financial efficiency of route 48. Results of this type of sensitivity analysis are shown in figures 2 throughout 4. In figure 2, the expected changes in demand pattern as a result of fare increase is shown. A power function model was calibrated to describe the relation between annual travel demand and fare levels for route 48. The model took the following form:

$\text{Annual Number of Passengers}_R = 581301 (\text{Fare}_R)^{-0.521}$, where $R^2 = 0.9931$

The effect of changes in fare level on operational costs, revenue and hence on operational deficit/surplus are shown in figure 3. The figure shows that at a fare value of approximately 0.9 L.E./pass. (i.e. 4 times increase from current base fare of 0.23 L.E./pass.), annual travel demand is expected to reach 576700 passengers (i.e. a patronage reduction of approximately 46%). However, despite of this expected patronage reduction, a breakeven status is reached between operational costs and revenues, i.e. no subsidies are provided. This is due to the expected increase in operational revenue, i.e. a 75% increase. From this point onwards, the figure shows that further increases in fare level will still induce marginal operational profits. As previously stated, financial performance can be also represented by the operational efficiency ratio. In this context, figure 4 shows the pattern of increase in operational efficiency with respect to changes in fare level. It has to be noted that such increases in fare levels have to be supported by improvements in service levels. The expected decrease in patronage would eventually ease the in bus congestion and improve comfort levels. This. has to be supported by improvements in regularity and punctuality of bus services, see USDOT (1985), for discussing ways to tradeoff fares, service levels and capital budgets for transit operation

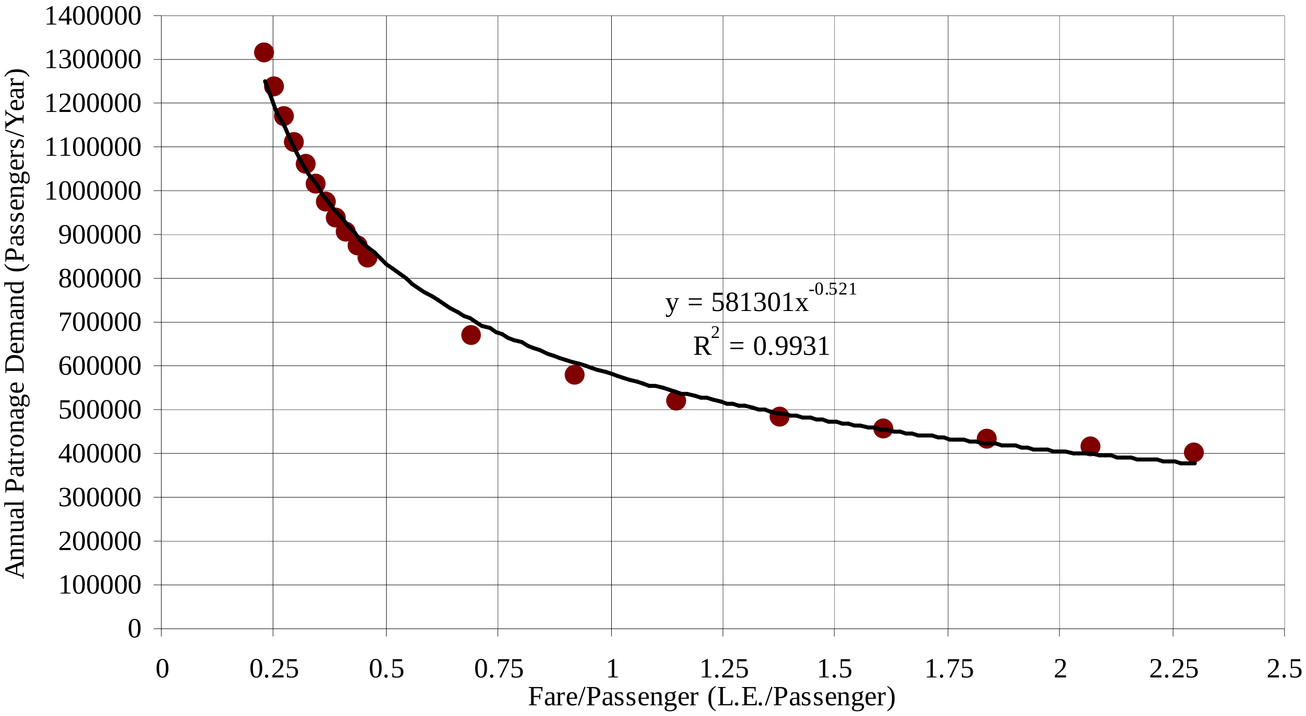

Figure 2: Effect of Fare Level on Annual Patronage Demand for Route 48 Operated by CTA

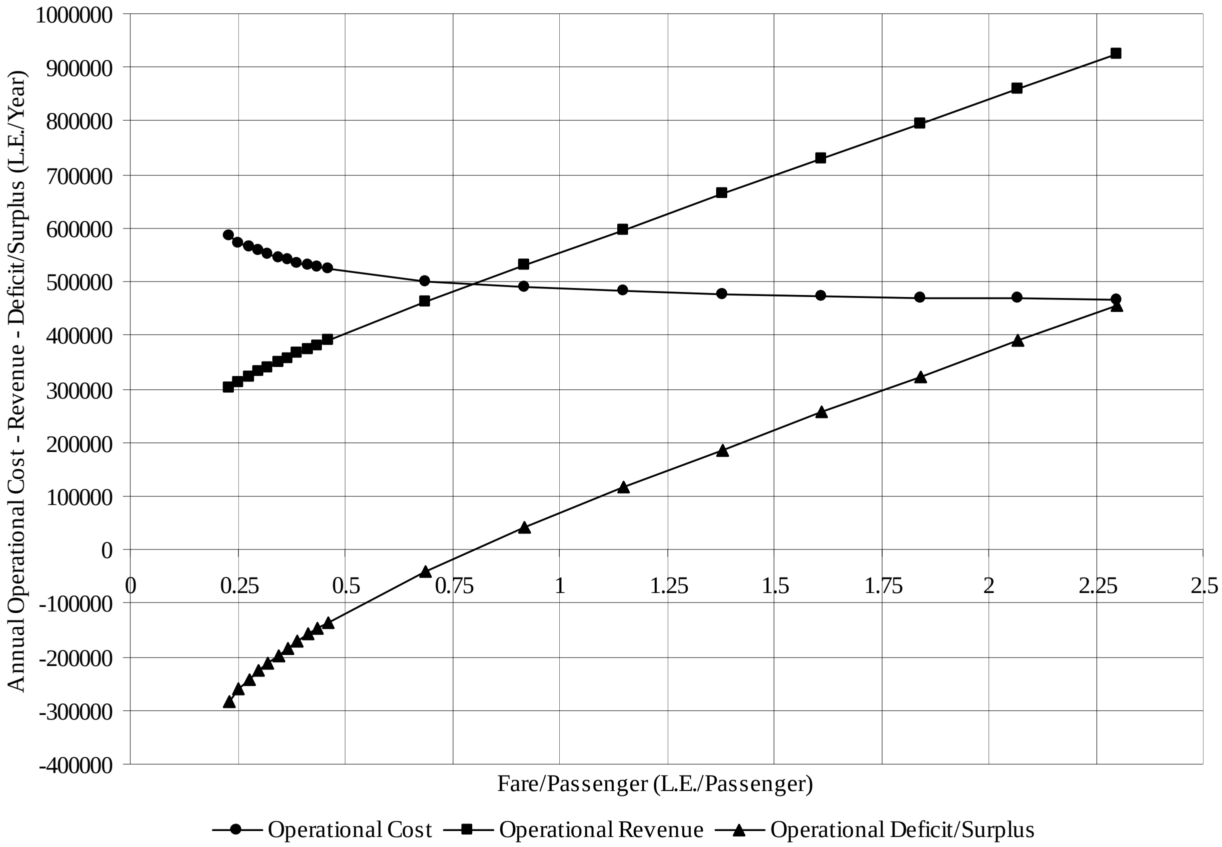

Figure 3: Effect of Fare Level on Annual Operational Cost, Revenue, Deficit/Surplus for Route 48 Operated by CTA

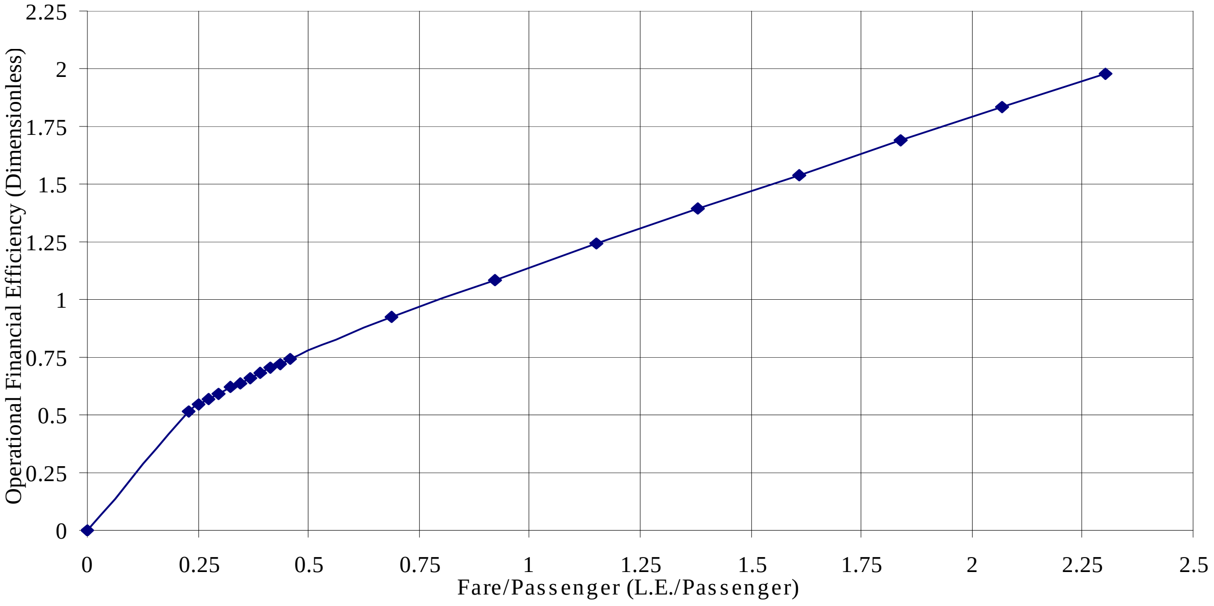

Figure 4: Effect of Fare Level on Operational Financial Efficiency of Route 48 Operated by CTA

6. CONCLUSION

The conceptual basis, and the general structure of a route based model developed for simulating bus operation parameters was presented in this paper. The model furnishes a logical, systematic, and detailed representation of the complex large scale bus transit system with its various components involved in the maintenance, operation, procurement (replacements and additions), costing, fare determination, travel demand prediction, performance evaluation, budgeting and the overall management of a bus transit company. However, several bus transit aspects were not covered in this research. These include the problem of route path determination, selection of stop locations along the route, timetable construction, fleet and drivers' scheduling.

A case study of route 48 operated by CTA was selected in an effort to demonstrate the applicability, practicality and usefulness of the model in preparing budgets. The case study helped in showing the main input parameters, specifications of the model as well as the applicability of the model mathematical formulations and algorithms. As a result of the model application, a budget skeleton was reached for route 48 . The budget layout is composed of five main headings, namely expected patronage, production and service parameters, operational and capital costs, fare and subsidy levels and operational revenue and finally various types of performance indicators.

The paper reports on the application of the model in conducting a sensitivity test that is meant to show the induced effects of increasing the fare level of route 48 on the travel demand pattern, operational revenue and hence on the financial efficiency. In the course of conducting such tests, a mid point elasticity value of approximately –0.65 was computed for CTA bus riders. Based on the simulated data, a power function model that relates changes in demand to fare changes was calibrated for route 48. The model shows that at a fare value of approximately 0.9 L.E./pass, a patronage reduction of approximately 46% is expected to occur. However, despite of this expected patronage reduction, a breakeven status is reached between operational costs and revenues, i.e. no subsidies are provided.

It is envisaged that there are three types of potential users for the developed model. The first is transit managers who have a long experience with the bus transit system and would like to explore the possible effects that may result from changes in policies, key input parameters, and other rules of thumb. The second is new transit employees who would like to get an insight and understanding of the bus transit system in a relatively short time (i.e. a training tool). The third is researchers who would like to use the model to investigate the effect of different combinations of scenarios on the performance of the bus transit system as well as to test the sensitivity of key output performance indices to changes in key input parameters.

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