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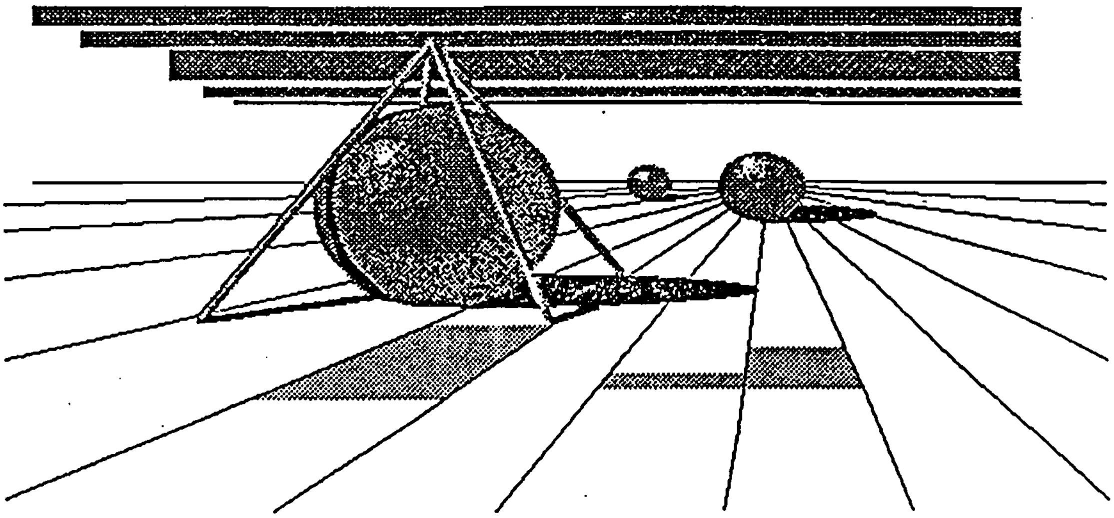

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DEVELOPMENT OF A GENERIC ANALYTICAL FRAMEWORK FOR ASSESSING IMPACT OF INEFFICIENCIES ON BUS OPERATION IN CAIRO

Dr. Khaled A. Abbas & Dr. Adel A. EL-Maksoud
Egyptian National Institute of Transport (ENIT)
P.O. Box 34 Abbassia - Nasr Road - Nasr City - Cairo - Egypt
Tel.: 202 2604901 - Fax: 202 2604121

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ABSTRACT

There is a tangible move, across cities of the world, towards achieving efficiency gains in the bus industry. The main bus transit system in Cairo is being provided by Cairo Transport Authority (CTA). The paper starts by reviewing some important indicators for buses operated by CTA. This research presents a classification of generic types of inefficiencies identified in public bus operation, namely; inefficiencies causing cost incurring, inefficiencies causing revenue loss, and inefficiencies causing cost incurring and revenue loss. The paper specifically identifies, categorizes and reviews those inefficiencies, which are reported in CTA annual statistical reports. These reports show losses in operation time being mainly attributed to four main causes, namely Engineering Failures, Operational Inefficiencies, Accidents' occurrence, and Force Majeure incidents. The main objective of this research is to develop a generic analytical framework for assessing the impact of these types of inefficiencies on public bus operation. In structuring this framework, several statistical relations, based on a priori causalities, are estimated. The paper concludes by presenting a demonstration of the utilization of the above relationships, within the developed analytical framework, for CTA. This takes the form of conducting sensitivity tests that are meant to explore the impact of potential inefficiencies in terms of time and revenue lost as a result of varying the extent of services provided by CTA.

يستهل هذا البحث بإستعراض لبعض المؤشرات الاساسية الدالة على أداء أتوبيسات هيئة النقل العام بمدينة القاهرة . ويقدم البحث تصنيفاً لعوامل عدم الكفاءة التى تحدث خلال عمليات تشغيل نقل الركاب بالاتوبيس حيث تتمثل فى تلك المؤدية الى حدوث زيادة فى التكاليف أو حدوث فاقد فى الايرادات أو تلك المؤدية الى حدوث كل من زيادة فى التكاليف وفاقد فى الايرادات. ويركز البحث فى إستعراضه على عوامل عدم الكفاءة اتى تضمنتها تقارير هيئة النقل العام بالنسبة لقطاع نقل الركاب بالاتوبيس وتتمثل فى أربعة أسباب رئيسية هى الاسباب الهندسية، الاسباب المتعلقة بالتشغيل، الحوادث والاحداث القهرية. ويتمثل الهدف الرئيسى لهذا البحث فى تطوير إطار تحليلى عام لأستخدامه فى تقييم تأثير تلك العوامل الاربع لعدم الكفاءة على تشغيل نقل الركاب بالاتوبيس. ويتكون الهيكل العام لهذا الاطار من عدة علاقات إحصائية تم بنائها أخذا فى الاعتبار منطقية تلك العلاقات. ويختتم البحث بإستعراض لكيفية إستخدام تلك العلاقات من خلال هذا الاطار التحليلى وذلك بإجراء: مجموعة من إختبارات الحساسية - حيث تهدف هذه الاختبارات الى إظهار تأثير عوامل عدم الكفاءة على فقدان أزمنة التشغيل ولفقدان الايردات وذلك كنتيجة للتغيرات فى مقدار خدمات نقل الركاب بالاتوبيس والمقدمة بواسطة الهيئة.

1. INTRODUCTION

Cairo, the capital of Egypt, is one of the largest and most densely populated cities in the World. This high population density is a common feature of the various districts that constitute the old and new city metropolitan areas as well as some of the newly developed suburban areas. In addition, the city have suffered during the past two decades from an unorganized urban sprawl from rural migrants. As a result of this high population densities and unorganized land use, several infrastructure and utilities systems are suffering from acute over-utilisation problems. A major problem that Cairo governorate faces on a daily basis is the traffic congestion as well as the inadequacy of provision of public transport modes to meet the required rising demands of accessibility and mobility of the urban population.

Public transport trips account for approximately 75-80% of all vehicular trips within Greater Cairo (Greater Cairo constitutes Cairo and a part of Giza and Qualibiya governorates). The public transport system in Cairo includes several modes, namely, buses, minibuses, trams, and Heliopolis metro, all being operated by the state-owned Cairo Transport Authority (CTA) and its subsidiary Greater Cairo Bus Company (GCBC). Both organizations are affiliated to the Cairo governorate. As a result of the inability of these state owned and operated modes to meet all of the required demand in terms of capacity and quality of service, a paratransit mode in the form of shared taxis has emerged in the public transport market to partially fill the gap, see Lashine et. al. (1987). These shared taxis are privately owned and operated. Until recently, very limited entry control was practiced in terms of their licensing and few restrictions were imposed on their operating practices.

Recently, two underground metro lines were opened. The first line was completed and opened for operation in 1989. This line is 43 km in length with a maximum capacity of 2 million passengers per day. The first and second stages of the second line were also opened recently with a total distance of 11 km. The total capacity of the second line after completion of all its stages is planned to reach 850 thousand passengers per day. The underground metro is operated by the Underground Metro Unit which is affiliated to the Egyptian Railway Authority and hence the Ministry of Transport.

Apart from the underground metro system, public transport services in Cairo can generally be characterized by low route capacity, low vehicular speeds, long delays, and overcrowding, see Cubukgil et. al. (1982). This can be mainly attributed to generic causes such as:

- Acute road congestion conditions. This traffic congestion problem is further aggravated by inadequate traffic management and control systems, illegal parking, poor law enforcement, aggressive driver behavior and general disregard for traffic regulations (i.e. operating environment related problems).
- Increasing demand levels for public transport services (i.e. demand related problems).
- Inefficiencies in operating these public transport services (i.e. supply related problems).

Despite of a recent fare increase, CTA is still suffering from a growing deficit resulting from the inefficient operation and the still relatively low fares imposed by the government. With an overall restriction on Government funding, it is considered unlikely that CTA will be able to accommodate any major expansion within the foreseeable future. Thus, increasingly more emphasis should be placed on reducing inefficiencies and achieving efficiency gains.

This research presents a classification of generic types of inefficiencies identified in public bus operation. It specifically identifies, categorizes and reviews those inefficiencies, which are reported in CTA annual statistical reports. These reports show losses in operation time being mainly attributed to four main causes, namely Engineering Failures both on the road and in garages, Operational Inefficiencies both on road and in garages, Accidents' occurrence on the roads, and finally Force Majeure incidents.

The main objective of this research is to develop an analytical framework for assessing the impact of these inefficiencies on public bus operation in Cairo. In structuring this framework, several statistical relations, based on a priori causalities, are estimated. Relations are first developed to assist in predicting the potential occurrence of these inefficiencies. The research attempts to produce monetary proxies for the potential time lost due to these inefficiencies. To achieve this, a statistical model relating operational revenue to bus-hours is estimated. Based on this model and the estimated amount of bus-hours lost due to each of the four types of inefficiencies, the research computes and compares the magnitude of possible revenue lost due to engineering failures versus operational inefficiencies versus accidents occurrences and finally versus Force Majeure incidents.

The paper concludes by demonstrating the utilization of the above relationships, within the developed analytical framework, to conduct sensitivity tests that are meant to explore the magnitude of potential inefficiencies in terms of revenue lost as a result of varying levels of bus service in terms of downsizing or expansion.

2. OPERATION OF BUS SYSTEM BY CTA

By far the largest share of public transport trips in Greater Cairo is made by CTA buses. The existing bus network provides a broad coverage of the Greater Cairo Metropolitan area. This is operated by 13 bus garages, which are geographically spread to cater for the extensive bus network provided by CTA. The available bus fleet is intensively used under extremely difficult operating conditions. Average speeds are low due to acute traffic congestion and no priority measures. However, because of the relative flexibility of individual buses to move in the stream of traffic, average bus speeds are still considerably higher than other CTA modes such as trams (average operating speed for buses is 18 km/hr versus 13 km/hr for CTA trams).

A time series comparison of the utilization of CTA buses (expressed as total number of passengers) during the last ten years from 1986 to 1996 is depicted in Figure (1). The figure shows a very significant increase of the number of ticket paying passengers using CTA buses during the early nineties, i.e. over 1100 million ticket passengers per year during 1991/92 and 1992/93. In 1995/96, the daily average number of operable buses reached 1784 buses. These carried 2.61 million ticket passengers a day, with an average of 1462 passengers per operable bus. These figures show that the demand dropped during 1995/96 to around 950 million ticket passengers. This significant decrease in CTA bus demand during the last few years could be mainly attributed to the opening of the underground metro and the substantial increase of the shared-taxi system and its extensive service coverage throughout Greater Cairo.

The figures represent the average of the 13 bus garages operated by CTA, excluding the 4 garages operated by GCBC. For consistency purposes, these 4 garages were not included within the scope of this research because the bus routes operated by GCBC are characterized by being quite lengthy (interurban routes) compared with the other bus routes operated by CTA garages (being typically urban short routes).

The operable productivity of CTA garages expressed in terms of operable bus fleet, traveled bus-kilometers and operable bus-hours produced during the financial year 1995/96 is presented in Figures (2), (3) and (4) respectively. It is apparent from these three figures that the 13 bus garages have a considerable variation in their productivity. This can be mainly attributed to the variations in garage sizes and bus fleets available at each garage.

CTA bus fares are currently set at a 25 piastres[1] flat fare except for some lengthy bus routes which are charged either 40 or 50-piastres flat fare. Seasonal tickets (known as membership or travel cards) represented only 3% of the total revenue collected during 1995/96, while ticket revenue accounted for 97%. The average revenue per ticket passenger was 22.4 piastres compared with only 3.7 piastres per travel card holder passenger. The difference between the average revenue per ticket passenger and the flat 25-piastre fare could be attributed to the various concessionary fares offered by CTA, such as those offered to army and police personnel. The average ticket revenue per operable bus across the 13 garages during 1995/96 is illustrated in Figure (5). As shown in the figure, this is in the range of 80000 L.E. per year, reaching 102900 L.E. if travel card revenue was included.

3. CLASSIFICCATION OF INEFFICIENCIES IN PUBLIC TRANSPORT

Public transport organisations often have some multiple goals which may seem contradictory to the efficient provision of services. Typical of these goals are:

- securing jobs as a part of government employment policy;
- maximizing operational productivity in terms of bus-kms;
- coverage of a network of routes and services that includes profitable as well as non-profitable areas; and
- providing low cost services.

In most cases, such goals are imposed by governments through regulations. This leads to ignoring profit maximization, and a lack of cost minimization awareness in public transport enterprises and hence causing high inefficiencies. Adapted from Kranton (1990) & Wright (1990) root causes leading to inefficiencies in public transport enterprises can be identified as follows:

- Institutional & regulatory constraints on the operation of the public transport enterprise;
- Structure of the output market (being mainly monopolistic rather than competitive);
- Control mechanism between government and the enterprise (such as inadequate accountability, insufficient subsidy and budget allocations);
- Lack of managerial incentive structure and existence of several hierarchies of management and control;
- Poor conditions of labour employment specially in garages;
- Lack of managerial freedom signified with no power of hire/fire, and absence of incentives/penalties system related to work achievement;
- Administrative and clerical employees dominate staff and lack of highly skillful staff as well as lack of continuous training;
- Inadequate and poor transit equipment, and a shortage of supplies especially spare parts;
- Poor organisation, management and execution of transit operations; and
- Street congestion.

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[1] $ 1.0 ≅ 3.4 Egyptian Pounds L.E. (1 L.E. = 100 Piasters)

Discussion of such generic issues, their potential effects on efficiency and how these can be improved is beyond the scope of this paper. As an initial point, this paper classifies public transport inefficiencies into three different generic classes according to their impacts on cost and revenue. These three classes are presented in Figure (6) and discussed below.

3.1 Inefficiencies Causing Cost Incurring

This class of inefficiency results in the incurring of excessive costs. A generic example is the over-staffing characterizing most public transport enterprises, specially in developing countries. As previously discussed, this is usually imposed by governments through regulations. This is usually considered as the main reason for high operation costs in these enterprises.

3.2 Inefficiencies Causing Revenue Loss

An example of this class of inefficiency is the irregularities that characterize the fare collection system especially in public transport enterprises in developing countries. Although this type of inefficiency might not have an impact on costs, however it has a substantial impact on the amount of revenue levied.

3.3 Inefficiencies Causing Cost Incurring And Revenue Loss

This class of inefficiency arises from the day-to-day operation. As implied, it causes cost incurring as well as revenue loss. Four examples of this type of inefficiency are identified and reported in CTA annual reports, namely Accidents' Occurrence, Engineering Failures, Operation Inefficiencies, and Force Majeure incidents.

4. INEFFICIENCIES ENCONTERED BY CTA BUS OPERATION

This section sheds some useful light on the four types of inefficiency encountered by CTA in the process of operating its bus fleet. All statistics are based on CTA statistical report for the financial year 1995/96. As previously stated, these four types of inefficiency include:

- Accidents' Occurrence;
- Engineering Failures;
- Operation Inefficiencies; and
- Force Majeure incidents.

4.1 Accidents' Occurrence

An 'Accident' is defined by White et. al. (1995) as an event in which one or more passenger is killed or injured, or one vehicle or more is damaged. An accident could thus range from a major event such as high-speed coach on a motorway, in which many people are killed or injured, to a single passenger being slightly injured (or a single vehicle being damaged) in an event not involving any other people (or vehicle). Before highlighting the CTA bus accidents' statistics during 1995/96, it is worthwhile defining the following expressions:-

Fatalities were defined by Jacobs and Fouracre (1977) as the number of deaths occurring within 30 days of an accident. Some countries consider fatalities only if as a result of an accident a victim died on the spot, some if he/she died within 24 hours, some have a limit of 3 or 7 days.

Injuries can be defined as the reported number of persons seriously or slightly injured in road accidents.

Casualties are taken as the total number of fatalities and injuries resulting from road accidents. Collision represents accidents causing only damage to vehicles involved.

The statistics of bus accidents' occurrence as reported by CTA during the financial year 1995/96 are summarized in Table (1). The figures indicate that the annual number of bus related accidents in CTA is considerably high (1039 accidents per year which is equivalent to an average of 3 accidents per day). As expected in urban areas, collision type of accidents were dominant (51%). This is followed by collision accidents causing casualties (30%) and then followed by accidents resulting in casualties only (17%) and then followed by fire accidents (2%). The statistics also show that the number of passengers and pedestrian casualties is 464 casualties, of which 40 represent fatalities (9%), and 424 (91%) represent injuries with various degrees of severity. Three measures of accidents risk were computed, namely:

- No. of Accidents per 1000 operable buses
- No. of Accidents per 1000 000 bus-kms
- No. of Accidents per 1000 000 bus-hours

These could be transferred into probabilities of occurrence of a bus accident as follows:
Probability of an operable bus being involved in an accident during daily operation = $4*10^{-6}$
Probability an accident occurs as a result of operating a typical 10 km. bus trip = $5*10^{-5}$
Probability an accident occurs as a result of operating a typical half an hour bus trip = $5*10^{-5}$

According to Giannopoulos (1989), the most common indicators that can be used to express safety level of a certain bus transport operation is the total number of accidents per 100,000 vehicle-kilometers run. Values of 0.45 to 1.8 accidents per 100000 veh-km. (on a yearly basis) are usually considered as normal figures. On computing the same indicator for CTA bus operation, a value of 0.56 is obtained. This shows that in relative terms, CTA bus operation can be considered safe in terms of number of accidents. However, when comparing the above kilometer based fatality rate in CTA (0.21) with statistics obtained from India and Great Britain, it was found that for public bus operators in five Indian cities this rate was on average 0.65 fatalities/million bus-km. (based on 1978 statistics), see Jacobs and Downing (1982), while in four British cities this rate was on average 0.06 (based on 1979 statistics). This shows that CTA bus operation could be considered safer in relative terms than its counterparts in India. However, the reverse is true when compared with British cities.

4.2 Engineering Failures

According to Wright and Thiriez (1987), an indication of maintenance and driving standards is the proportion of buses that breakdown in service and require either assistance from a mobile repair unit or in the depot. A reasonably well maintained fleet would expect to have breakdowns at a rate of no more than 8-10% of operable buses.

Three generic groups of defaults causing engineering failures to buses are identified in CTA 95/96 statistical report. These are mainly mechanical, electrical and chassis related defaults. The numbers of defaults for the three types are illustrated in Table (2).

It is apparent from the table that the chassis related defaults accounts for around 69% of the total number of engineering failures. It can be also deduced that the total number of engineering failures seems high, with an average of over 343 defaults a day, which when related to operable fleet size indicates that around 19% of the fleet might be subject to at least one engineering failure per day. This is far beyond the above international standard of 8-10%. Three measures of engineering failure risk were computed, namely:

- No. of Engineering Failures per 1000 operable buses
- No. of Engineering Failures per 1000 000 bus-kms
- No. of Engineering Failures per 1000 000 bus-hours

These could be transferred into probabilities of occurrence of a bus engineering failure as follows:

Probability of an operable bus incurring an engineering failure during daily operation = $5*10^{-4}$
Probability an engineering failure occurs as a result of operating a typical 10 km bus trip=0.007
Probability an engineering failure occurs as a result of operating a typical half hour bus trip=0.006

4.3 Operational Inefficiencies

Operational Inefficiencies could be divided into three categories:-

Route-related inefficiencies: these could be due to off-schedule delays occurring while buses are traveling on their designated routes.

Garage-related inefficiencies: these could be due to the lack of time discipline to fulfill maintenance programs as scheduled. This increases the time buses spend in garages and reduces the availability ratios.

Crew-related inefficiencies: these could be attributed to the lack of adequate crew planning, hence leading sometimes to the unavailability of crew to operate buses.

Despite that CTA keeps a record of the total time lost due to operational inefficiencies, no statistics have been recorded concerning their total number of occurrence. The total time lost due to operational inefficiencies across the 13 bus garages operated by CTA during 1995/96 was reported at 495932 hours for route related inefficiencies and 138308 hours for garage related inefficiencies, see Table (3). The table shows that, excluding crew related inefficiencies, route related inefficiencies represent 78% of the total operational inefficiencies, while garage related inefficiencies constitute the rest (22%).

4.4 Force Majeure Incidents

Force Majeure incidents can be defined as unforeseen events such as bad weather conditions, road failure, ... etc. No statistics concerning the number of Force Majeure incidents have been reported in CTA 95/96 statistical year-book. However, the total time lost due to Force Majeure incidents during 1995/96 was recorded at 442,000 hours, see Table (4).

5. AN ANALYTICAL FRAMEWORK FOR ASSESSING THE IMPACT OF INEFFICIENCIES ON PUBLIC BUS OPERATION IN CAIRO

In this research a generic analytical framework was developed to be used to:

- Assess the impact of inefficiencies on existing bus service operation; and
- Act as a tool to explore the effect of inefficiencies on bus operation as a result of any potential service changes (i.e. expansion or downsizing).

It is worth noting from the outset that the framework developed in this paper is only concerned with the third class of inefficiencies, i.e. inefficiencies causing cost incurring and revenue lost. Furthermore, inefficiencies considered in this research, were mainly attributed to accidents' occurrence, engineering failures, operational inefficiencies both on roads and garages and finally to Force Majeure incidents.

In order to assess the impact of these causes of inefficiencies on public bus operation, these could be expressed as numbers of occurrences. However, the potential numbers of occurrences, on their own, are insufficient to reflect the extent of impact on bus operation. This is simply because the amount of time or money lost differs according to the type of default within each of the four considered types of inefficiency. Therefore, the impact of inefficiencies were expressed as lost time, which could be easily transferred to lost money (or in other words lost revenue). No attempt was made to estimate the amount of extra cost incurred due to the occurrence of these types of inefficiencies. This is mainly due to lack of CTA reported data on the potential amount of cost incurred as a result of the occurrence of each of these types of inefficiencies.

The developed framework could be divided into five main stages as illustrated in Figure (7).

- First Stage: Deciding on the amount of service change and predicting generic service change parameters;
- Second Stage: Predicting ticket passengers and ticket revenue;
- Third Stage: Predicting the number of occurrence of each potential type of inefficiency.
- Fourth Stage: Predicting lost time due to each potential type of inefficiency; and
- Fifth Stage: Valuation of lost time and estimating lost revenue due to potential inefficiencies and computing an aggregate measure of inefficiency.

The framework depicted in Figure (8) starts by deciding the amount of service change to be considered. This could include:

- service expansion, i.e. purchasing of additional fleet to serve new or existing routes, or intensification of existing service provision, or
- service downsizing, i.e. downsizing of existing fleet, or downsizing of existing service provision.

The decision of service expansion or downsizing is usually taken at a strategic level. Once this decision is taken, the annual traveled kilometers could be predicted based on the size of the new annual operable fleet. Additionally the annual operable hours could be predicted based on the predicted annual traveled kilometers.

The second stage of the analytical framework takes place in two successive steps. In the first step, the total number of passengers (representing expected demand levels) is estimated based on the annual operable buses, traveled kilometers, or operable hours (all acting as proxies of expected supply level). The second step predicts the total ticket revenue based on the expected total number of passengers obtained from the first step. As shown in Figure (8), the total ticket revenue is also directly related to the expected annual operable hours.

It should be noted that all predictive functions in the framework were estimated based on regression as well as on stochastic modeling techniques. Estimation of all models was completely guided by well thought a-priori causalities, which are mainly depicted in the detailed analytical framework in Figure (8). The next section will address the process involved in the estimation of these functions in greater detail.

The third stage is concerned with predicting the number of potential occurrence of the different types of inefficiencies, namely number of accidents, number of engineering failures, number of operational inefficiencies and number of Force Majeure incidents. Although some of these causes of inefficiencies, namely accidents and Force Majeure incidents, can be considered as random stochastic variables, these could be coarsely estimated using deterministic functions. In these deterministic functions the number of accidents and number of Force Majeure incidents could be related to annual traveled kilometers (a proxy for exposure), while the numbers of engineering failures and number of operational inefficiencies could be related to annual operated hours (a proxy of utilization). However, due to unavailability of empirical data on the number of operational inefficiencies and Force Majeure incidents, these two functions were not estimated.

Three different approaches were used in the forth stage concerning the prediction of time lost due to potential types of inefficiency. The first approach relates the time lost component of each type of inefficiency to its potential number of occurrence (predicted in the previous stage). Thus, neither the predictive function concerning the lost time due to operational inefficiencies nor that for Force Majeure incidents were estimated for the same reason mentioned above. The second approach relates the time lost component of each type of inefficiency to the generic operational explanatory variables i.e. operable buses, bus-kilometers and bus-hours. In the third approach, lost time due to engineering failures and operational inefficiencies were estimated based on the annual operated bus-hours, while lost time due to accidents and Force Majeure incidents were estimated based on the annual traveled bus-kilometers, see Figure (8). All the empirical data required for this approach were available in CTA statistical reports, thus the predictive functions for the four types of inefficiency were all developed.

The fifth and final stage is concerned with producing monetary proxies for the potential time lost due to different causes of inefficiency as well as to develop an aggregate measure of revenue inefficiency.

6. ESTIMATION OF STATISTICAL MODELS CONSTITUTING THE ANALYTICAL FRAMEWORK

The causes of different types of inefficiencies are expected to vary from one year to another as well as from one garage to another depending on the operational conditions. Thus, in estimating the statistical relations constituting the analytical framework, several trials were conducted to decide the acceptable data set that can give an acceptable representation of reality as well as to produce a best fit, in relative terms, between the variables involved in these statistical models. These trials are presented in Table (5). The best fit came as a result of using points representing the statistics of the 13 CTA bus garages averaged over the three financial years of 93/94, 94/95 and 95/96. This data set produced the lowest standard deviations (standard errors) and coefficients of variations. This data set is also considered representative both of the 13 garages operated by CTA as well as of the 3-years of operation where operating environment in each of the garages may have changed. Having decided on the data set, the different regression equations (predictive functions) were estimated.

6.1 Estimation of Statistical Models for Predicting Generic Service Change Parameters

As depicted in Figure (8), the analytical framework starts by predicting the three generic operational variables (parameters), namely operable fleet, bus-kilometers and bus-hours. The annual operable fleet is simply obtained by multiplying the total number of working buses (taking into consideration the downsizing or expansion decisions) by the annual working days (CTA buses are working 365 days per year). Annual traveled kilometers are related to the size of the new annual operable fleet. Once annual traveled kilometers is obtained, it is utilized to predict the annual operable hours. Each of these relations was estimated using linear, exponential and power functions. The function that produced the highest R^2-value (i.e. coefficient of determination) between the two variables was selected as the best fit relation, see Table (6). It is to be noted that the same procedure was followed throughout the estimation of all of the statistical regression models constituting the rest of the analytical framework.

6.2 Estimation of Statistical Models for Predicting Ticket Passengers and Ticket Revenue

In order to estimate the operational revenue resulting from selling tickets to passengers, the expected number of passengers should be first estimated. Ticket passengers (representing the demand for service) can be directly related to operable buses, operable kilometers, or operable hours (all acting as proxies for the amount of service supply), see Table (7). Another set of predictive functions relating ticket revenue to the three generic operational variables as well as to the predicted number of passengers was also estimated and summarized in Table (7) below.

Comparing R^2-values for all of the estimated functions in table (7), indicates that the predictive functions relating ticket revenue to operable fleet have the lowest values in relative terms. This seems acceptable since the other three variables are more plausibly related to ticket revenue. The framework depicted in Figure (8) shows only the predictive functions relating ticket revenue to the number of passengers and to the total bus-hours. The number of passengers was simply chosen because it is the most plausible variable in influencing the amount of revenue collected, while the bus-hours variable was chosen in order to assist in producing monetary proxies for the potential time lost attributed to the main four causes of inefficiency (as will be explained in section 6.7).

6.3. Estimation Of Statistical Models For Predicting The Number Of Occurrence For Each Potential Type Of Inefficiency

The logical way for predicting lost times due to different causes of inefficiency ought to be based on their numbers of occurrences, i.e. number of accidents, number of engineering failures, number of operational inefficiencies and number of Force Majeure incidents. Thus, this approach initially requires predicting the numbers of occurrences of these types of inefficiency.

For this purpose, the number of accidents was predicted based on bus-kms acting as an exposure measure, while the number of engineering failures was predicted based on bus-hours acting as a utilization measure. However, due to unavailability of CTA data concerning the number of operational inefficiencies and Force Majeure incidents, this approach could not be completely followed to predict the numbers of occurrences of these two other types of inefficiency. Table (8) summarizes the predicted functions estimated using this approach.

R^2-values in table (8) are around 0.45 and the highest value is 0.54 for the power function relating the number of engineering failures to bus-hours. These low R^2-values could be attributed to the randomness of occurrence of accidents and engineering failures.

6.4 Estimation of Statistical Models for Predicting Lost Times Due to Different Types of Inefficiency (Based on Number of Occurrences)

Both lost times due to accidents and due to engineering failures were predicted based on numbers of occurrences of accidents and engineering failures predicted using models presented in the previous sub-section. Table (9) presents the functions estimated using this approach.

R^2-values table (9) are around 0.5 and the highest value is 0.582 for the power function relating time lost due to accidents to number of accidents. These low R^2-values could be related to the randomness of occurrence of accidents as well as to the possible inaccuracy of procedures followed by CTA in estimating the time lost due to the occurrence of engineering failures.

6.5 Estimation of Statistical Models for Predicting Lost Times Due to Different Types of Inefficiency (Based on Operational Explanatory Variables)

Another way for predicting lost times due to different types of inefficiency is based on relating lost times to the three generic operational variables, namely operational buses, traveled kilometers and operated hours. Table (10) presents the functions estimated using this approach.

The table shows low R^2-values for most of the calibrated functions. Although lost time due to an inefficiency seems to be logically dependent on the three selected explanatory variables, the empirical data paradoxically indicate that these deterministic relations are weak except for the power function relating lost time due to accidents to bus-kms which shows a high R^2-values in relative terms.

These weak relations could mainly stem from the randomness of the occurrence of the different types of inefficiency (rather than from the plausibility of the selected variables). It could be also attributed to the possible inaccuracies of the procedures followed by CTA in estimating the time lost due to these types of inefficiency.

6.6 Predicting Lost Times Due to Different Types of Inefficiency as Random Rates

The weakness of the above predictive functions does not affect the soundness of the developed analytical framework since this is a generic framework which is not based on CTA empirical data. Still using such weak deterministic functions in predicting the impact of inefficiencies on CTA revenue would give misleading results. Thus, it would seem more appropriate to explore the random, possibly stochastic, nature of these parameters so as to adjust the results obtained from the analytical framework to approximately match the empirical data. In developing these stochastic functions, lost times due to engineering failures and operational inefficiencies were taken as rate values relative to operated bus-hours, while lost times due to accidents and Force Majeure incidents were taken as rate values relative to traveled bus-kilometers. These were plotted for the 13 garages operated by CTA over the three financial years 93/94, 94/95, and 95/96 (a total of 39 scatter points).

The dispersion patterns obtained did not follow any of the well known stochastic distributions. This confirms that the rates of lost times per bus-hours or per bus-kilometers for the different types of inefficiency are fully random variables. Therefore, three different scenarios (low, medium and high scenarios) have been suggested for predicting the rates of lost time per bus-hour or per bus-kilometers for different types of inefficiency at CTA. Medium scenario corresponds to the mean value, while high and low scenarios correspond to the mean value plus and minus the value of the standard deviation respectively. Table (11) summarizes the mean values and standard deviations of the rate of lost times for the four main types of inefficiency for the 13 garages over the three financial years 93/94, 94/95 and 95/96.

The percentages of coefficients of variation (i.e. percentages of standard deviations divided by mean values) indicate that there are substantial variations in predicting the values of these variables. The percentages of deviation from the mean are in the range of 67% to 70% for the rates of lost times per bus-kilometers due to accidents' occurrence, and the rates of lost times per bus-hours for engineering failures and operational inefficiencies. On the other hand, predicting the rate of lost time per bus-kilometers due to Force Majeure incident produced the lowest variation in relative terms (i.e. around 38%).

6.7 Estimation of Potential Lost Revenue Due to Types of Inefficiency

With reference to the previously estimated relations, it would be possible to obtain values representing the total revenue expected from service changes as well as the potential lost revenue due to each of the four considered types of inefficiency. This is simply done by utilizing the calibrated predictive function relating the total ticket revenue to the annual operated hours. This function was initially estimated to predict how much revenue could be raised from the operation of a unit bus-hour. It is used here to predict how much revenue could be lost due to the loss of a unit bus-hour as a result of different types of inefficiency.

Table (12) summarizes the results of the estimated revenue lost due to inefficiencies during the financial year 1995/96 versus CTA actual data for the same year. Alternative combinations of predictive functions were tested with the intention of selecting the best combination of predictive functions. Tested combinations are as follows:

- Combination (1) represents lost time due to accidents and engineering failures being predicted based on the number of occurrence, while lost time due to operational inefficiencies and Force Majeure incidents being predicted as random variables related to bus-hours and bus-km respectively.
- Combination (2) represents lost time due to accidents and Force Majeure incidents being predicted as random variables related to bus-km, while engineering failures and operational inefficiencies being predicted as random variables related to bus-hours.
- Combination (3) represents lost time due to each type of inefficiency being predicted from regression functions shown in Table (10), where accidents and Force Majeure incidents were related to bus-km, while engineering failures and operational inefficiencies were related to bus-hours.
- Combination (4) represents lost time due to accidents and engineering failures being predicted based on the number of occurrence, while lost time due to operational inefficiencies and Force Majeure incidents being predicted from regression functions as in Combination (3).
- Combination (5) represents lost time due to each type of inefficiency being selected from the above four combinations to best fit the CTA data for 1995/96.

In all of the above predictive combinations, the impacts of the main four causes of inefficiency on CTA revenue are aggregated in a single percentage referred to as the aggregate measure of inefficiency and defined as follows:

Measure of Inefficiency = 1 - (TR / (TR+TRL))

Where: **TR** is the ticket revenue arising from the service; and
TRL is the total revenue lost due to different inefficiency causes.

Comparing with the total revenue collected, it is apparent that the amount of revenue lost based on CTA actual data during 1995/96 is very substantial (i.e. the lost revenue was 22.1823 million L.E. versus a total revenue of 183.6338 million L.E.). This value represents around 12% of the total revenue collected during this year. It is also apparent that lost revenue due to accidents accounts for less than 1% of the total revenue lost, while operational inefficiencies, Force Majeure incidents, and engineering failures have very high shares (40%, 36%, and 23% respectively). Thus, both engineering and operational inefficiencies account for 63% of the total revenue lost, which could reflect the inefficiency of the fleet in terms of: technical conditions and ages; operational and engineering staff; and management system.

Based on CTA 95/96 statistical data, the overall inefficiency expressed by the measure of revenue inefficiency is estimated as 10.78%. It is apparent that in all of the considered predictive combinations, the total predicted revenue was only underestimated by about 0.2%, see Table (12). As for the prediction of total lost revenues due to the four causes of inefficiencies, it is obvious from the table that predictive combination (1) or (4) produced the best results for lost revenue due to accidents, predictive combination (2) produced the best results for lost revenue due to engineering failures, operation inefficiencies as well as due Force Majeure incidents. On the other hand, predictive combination (3) produced inaccurate predictions of lost revenue.

Predictive combination (5) represents lost time due to each type of inefficiency being selected as the best predicted from the other combinations. This produced a total lost revenue of 22.597 million L.E. which is an over-prediction by about 1.87%. This discrepancy could be mainly attributed to weaknesses in some of the predictive functions. Furthermore, this combination produced a measure of revenue inefficiency of 11.15%, which is an over-prediction by 3.4%.

7. POTENTIAL APPLICABILITY OF THE DEVELOPED FRAMEWORK FOR CTA

In this section, a demonstration of the utilization of the above relationships, within the developed analytical framework, will be shown for CTA. This will take the form of conducting sensitivity tests that are meant to explore the impact of potential inefficiencies in terms of revenue lost as a result of varying the extent of services provided by CTA.

Various downsizing and expansion of services provided by CTA were proposed. These were expressed in terms of annual traveled bus-kilometers. For each of these service levels, the framework models were utilized so as to obtain the expected equivalent values of total revenue, lost revenue and net revenue, see Figure (9). In addition for each of these service levels, the equivalent measure of revenue inefficiency was computed, see Figure (10). Two important linear equations were obtained, the first representing the sensitivity of Ticket Revenue (TR) obtained by CTA to varying degrees of services represented by Bus-Kilometers (BK). The second equation represents the sensitivity of the Total Revenue Lost (TRL) by CTA in relation to varying degrees of services also represented by BK. These two equations are as follows:

$$\mathrm{TR} = 0.9556\,\mathrm{BK} + 2.67 \qquad \text{(TR \& BK are in million)}$$

$$\mathrm{TRL} = 0.125\,\mathrm{BK} - 0.59 \qquad \text{(TRL \& BK are in million)}$$

8. CONCLUSION

Apart from the underground metro system, public transport services in Cairo, operated by CTA, can be generally characterized by low route capacity, low vehicular speeds, long delays, and overcrowding. This can be mainly attributed to generic causes such as acute road congestion, inadequate traffic management and control systems, illegal parking, poor law enforcement, aggressive driver behavior and general disregard for traffic regulations, increasing demand levels for public transport services, and inefficiencies in operating these public transport services.

This research presented a classification of generic types of inefficiencies identified in public bus operation. Inefficiencies are classified into three generic classes according to their impacts on cost and revenue, namely; inefficiencies causing cost incurring, inefficiencies causing revenue loss, and inefficiencies causing cost incurring and revenue loss. The paper specifically identifies, categorizes and reviews those inefficiencies, which are reported in CTA annual statistical reports. These reports show losses in operation time being mainly attributed to four main causes, namely Engineering Failures, Operational Inefficiencies, Accidents' occurrence, and finally Force Majeure incidents. The following conclusions were obtained as a result of examining 95/96 data concerning these four types of inefficiency:

- The annual number of bus related accidents in CTA is considerably high (1039 accidents per year which is equivalent to an average of 3 accidents per day).
- As expected in urban areas, collision type of accidents were dominant (51%). This is followed by collision accidents causing casualties (30%) and then followed by accidents resulting in casualties only (17%) and then followed by fire accidents (2%).
- The statistics also show that the number of passengers and pedestrian casualties is 464, of which 40 are fatalities (9%), and 424 (91%) are injuries with various degrees of severity.
- Values of 0.45 to 1.8 accidents per 100000 veh-km. (on a yearly basis) are usually considered as normal figures. On computing the same indicator for CTA bus operation, a value of 0.56 was obtained. This shows that, in relative terms, CTA bus operation can be considered safe in terms of number of accidents.
- On comparing the kilometer based fatality rate in CTA (0.21) with statistics obtained from India and Great Britain, it was found that for public bus operators in five Indian cities this rate was on average 0.65 fatalities/million bus-km., while in four British cities this rate was on average 0.06. This shows that CTA bus operation could be considered safer in relative terms than its counterparts in India. However, the reverse is true when compared with British cities.
- Three generic groups of defaults causing engineering failures to buses were identified in CTA 95/96 statistical report, namely mechanical, electrical and chassis related defaults. The chassis related defaults accounted for around 69% of the total number of engineering failures.
- It was also deduced that the total number of engineering failures seems high, with an average of over 343 defaults a day, which when related to operable fleet size indicates that around 19% of the fleet might be subject to at least one engineering failure per day. This is far beyond the above international standard of 8-10%.
- Operational inefficiencies could be divided into route-related inefficiencies, garage-related inefficiencies, and crew-related inefficiencies. CTA statistics on lost time indicate that, excluding crew related inefficiencies, route related inefficiencies represent 78% of the total operational inefficiencies, while garage related inefficiencies constitute the rest (22%).
- No statistics concerning the number of Force Majeure incidents have been reported in CTA 95/96 statistical year-book. However, the total time lost due to Force Majeure incidents during 95/96 was recorded at 442,000 hours.
- Comparing with the total revenue collected, it is apparent that the amount of revenue lost, estimated based on CTA actual data during 1995/96, is very substantial (i.e. lost revenue was

computed at 22.1823 million L.E. versus a total revenue of 183.6338 million L.E.). This value represents around 12% of the total revenue collected during this year. The proposed measure of revenue inefficiency is estimated as 10.78%.

- It is also apparent that the estimated lost revenue due to accidents accounts for less than 1% of the total revenue lost, while operational inefficiencies, Force Majeure incidents and engineering failures have very high shares (40%, 36% and 23% respectively). Thus, both engineering and operational inefficiencies account for 63% of the total revenue lost, which could reflect the inefficiency of: the fleet in terms of technical conditions and aging, the operational and engineering staff as well as of the management system.

The main objective of this research was to develop an analytical generic framework for assessing the impact of these types of inefficiencies on public bus operation as well as to act as a tool to explore the effect of inefficiencies on bus operation as a result of any potential service changes (i.e. expansion or downsizing). In structuring this framework, several statistical relations (regression as well as stochastic), based on a priori causalities, were estimated. Alternative combinations of predictive functions were tested with the intention of selecting the best combination. The paper concluded by presenting a demonstration of the utilization of these relationships, within the developed analytical framework for CTA. This took the form of conducting sensitivity tests that were meant to explore the impact of potential inefficiencies in terms of revenue lost as a result of varying the extent of services provided by CTA.

Various scenarios for downsizing and expansion of services provided by CTA were proposed. These were expressed in terms of annual traveled bus-kilometers. For each of these service levels, the framework models were utilized so as to obtain the expected equivalent values of total revenue, total revenue lost and net revenue. In addition for each of these service levels, the equivalent measure of revenue inefficiency was computed. Two important linear equations were obtained, the first representing the sensitivity of Ticket Revenue (TR) obtained by CTA to varying degrees of services represented by Bus-Kilometers (BK). The second equation represents the sensitivity of the Total Revenue Lost (TRL) by CTA in relation to varying degrees of services represented by BK.

It is obvious from the above discussions concerning sources of inefficiency at CTA that operational and engineering related inefficiencies are dominant. These two types of inefficiency are very much endogenous in their nature i.e. can be better managed and reduced by CTA. On the other hand, accidents and Force Majeure incidents can be considered as random occurrence incidents. The occurrence of such incidents can be partially reduced by CTA, (specially accidents), while mainly being attributed to other exogenous factors which are beyond the control and management of CTA. Focusing to reduce one source of inefficiency in isolation to the others could lead to piecemeal improvements, if other sources of inefficiency were not addressed in parallel. It is beyond the scope of this research to suggest ways and means targeted towards reducing the identified inefficiencies and hence achieving efficiency gains. Publications dealing specifically with these types of inefficiency were reported, see USDOT (1985) for the Wisconson Bus Safety Manual, see Foerster et. al. (1984) and Schiavone (1994) for traditional and innovative ways and means to improve maintenance efficiency, see Smerk et. al. (1988) for the handbook on mass transit management including methods to achieve an efficient maintenance and operations of transit fleets and see Volinski (1997) for one of the most recent studies conducted for the U.S. DOT on transit efficiencies. It is also worth noting that a few studies have looked into ways and means for improving public transport operation in Cairo, see for example Wyatt (1980), Cubukgil et al. (1982), and Gakenheimer and Meyer (1990).

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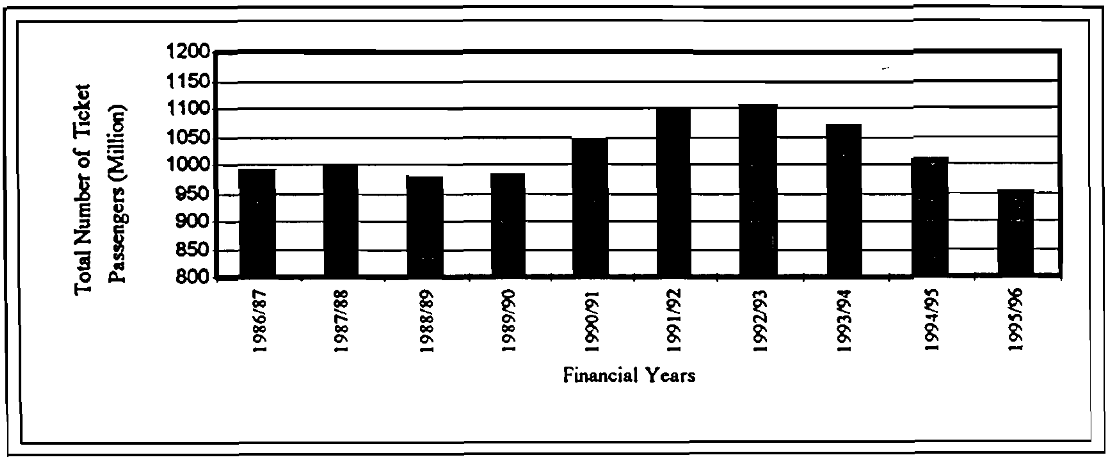

Figure 1: Ticket Passengers Carried by CTA Buses Over a 10-year Period (1986/87 Throughout 1995/96) (Source: CTA Statistical Report of Operational Achievements for Financial Year 1995/96)

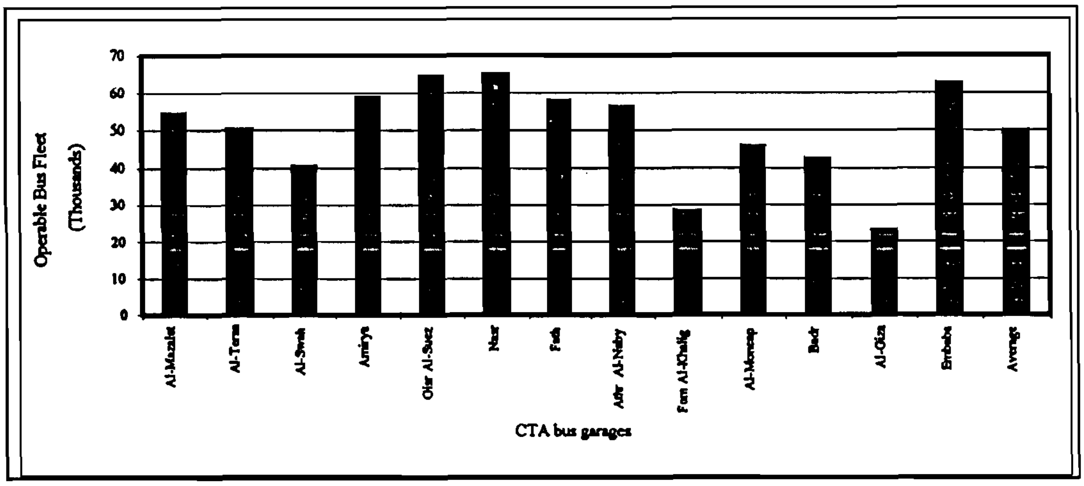

Figure 2: Operable Bus Fleet Operated by the 13 CTA Bus Garages During 1995/96

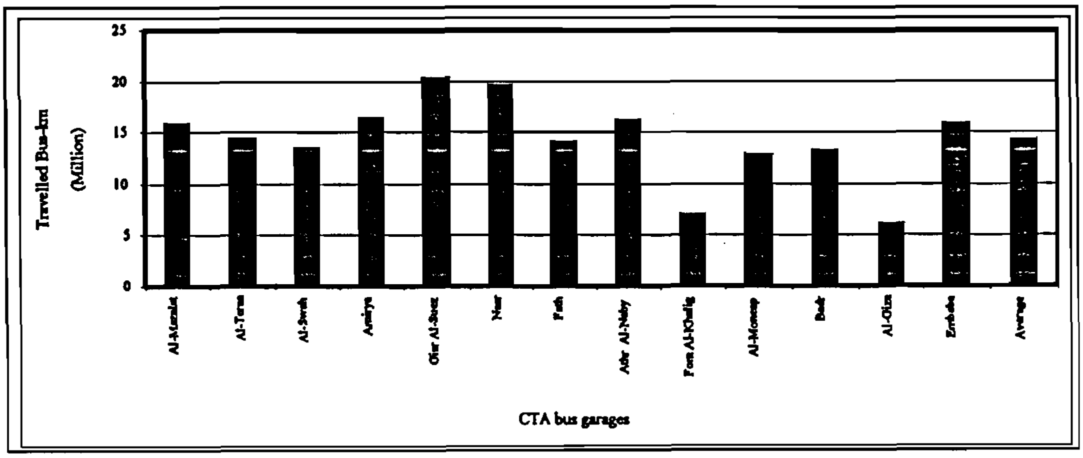

Figure 3: Traveled Bus-Kms. Produced by the 13 CTA Bus Garages During 1995/96

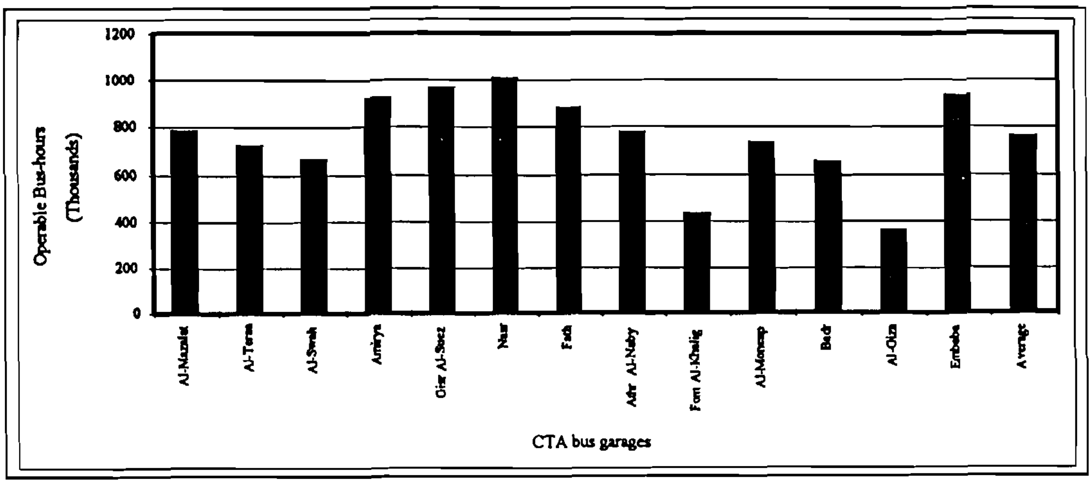

Figure 4: Operable Bus-Hours Produced by the 13 CTA Bus Garages During 1995/96 (Source: CTA Statistical Report of Operational Achievements for Financial Year 1995/96)

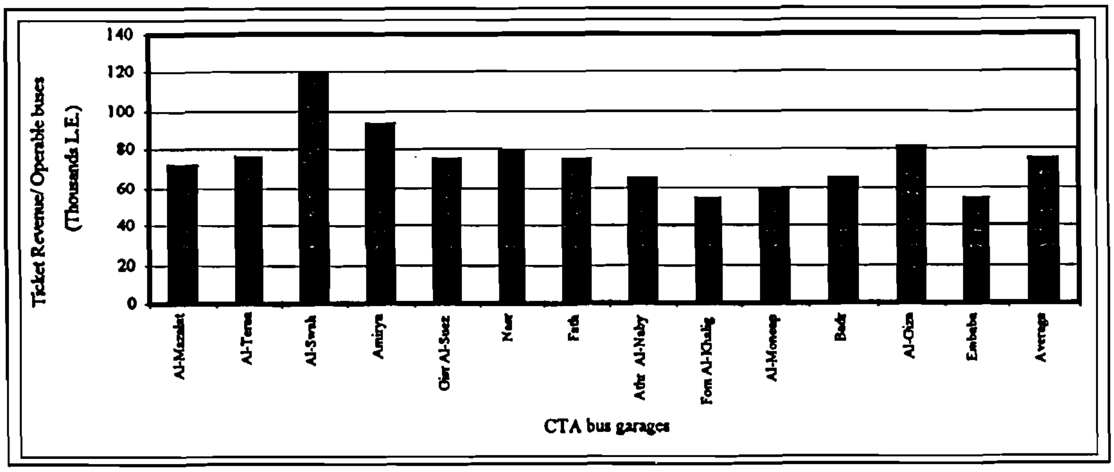

Figure 5: Average Ticket Revenue per Operable Bus for the 13 CTA Bus Garages During 1995/96 (Source: CTA Statistical Report of Operational Achievements for Financial Year 1995/96)

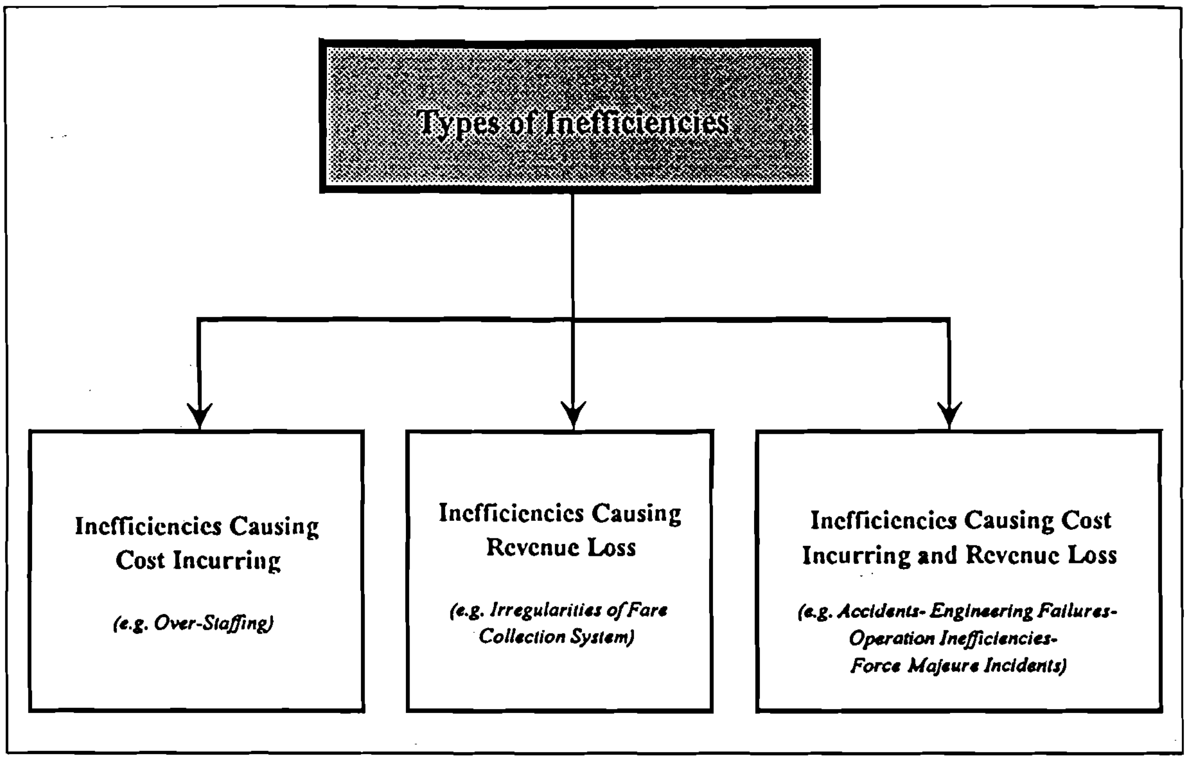

Figure 6: Generic Classification of Public Transport Inefficiencies

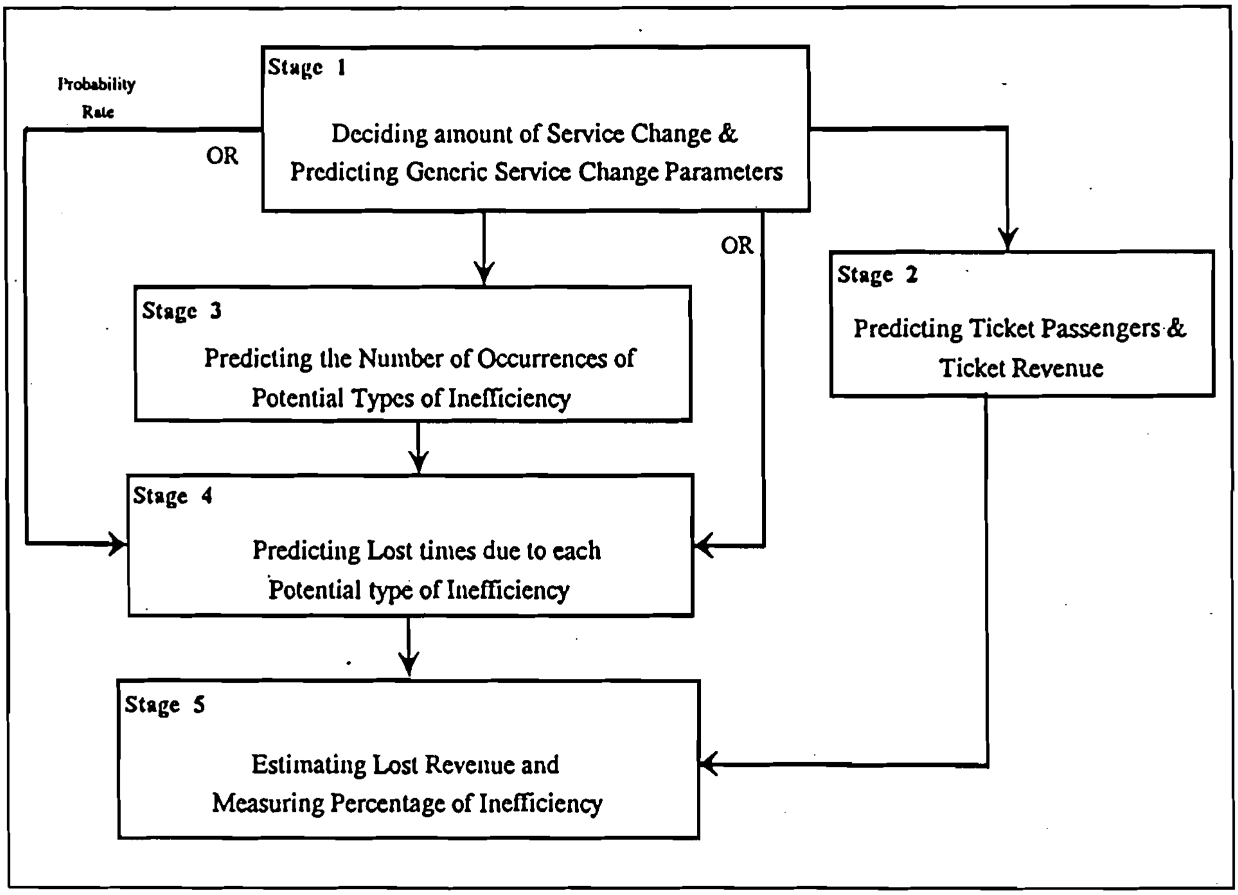

Figure 7: Main Stages Constituting the Developed Analytical Framework

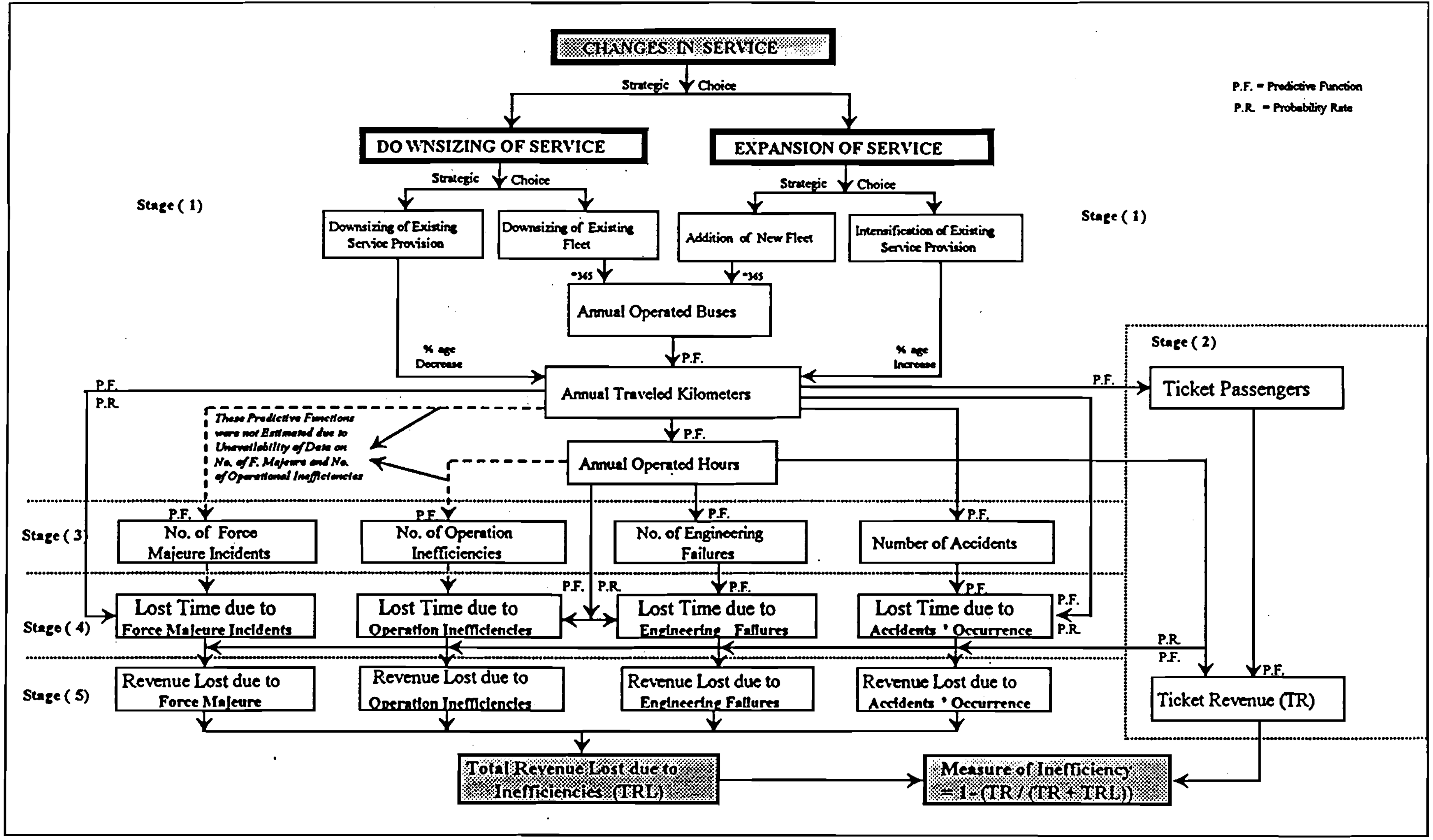

Figure 8: An Analytical Generic Framework for Assessing the Impact of Inefficiencies of Public Bus Operation

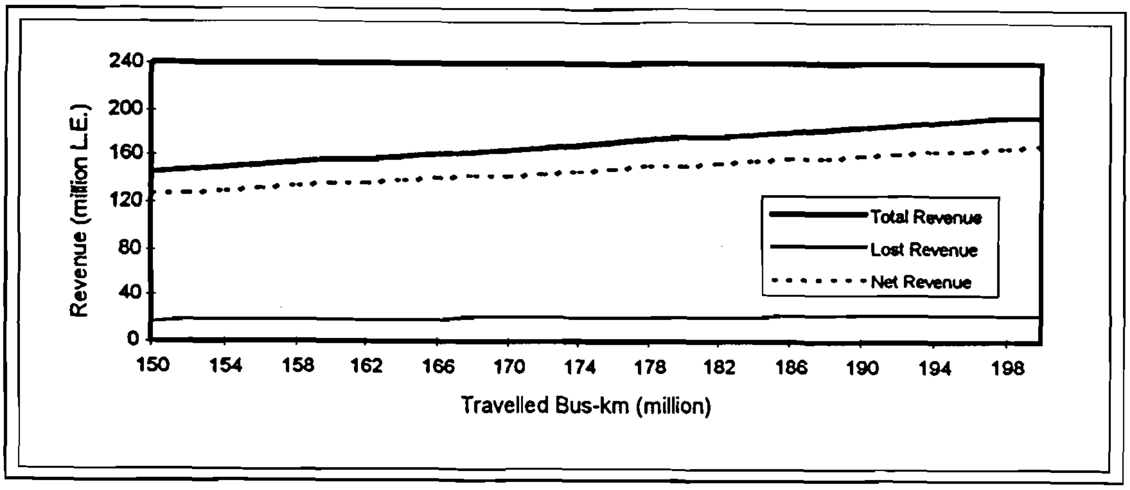

Figure 9: Total Revenue, Total Revenue Lost and Net Revenue Resulting From Downsizing or expansion of Traveled Bus-Kilometers Operated by CTA

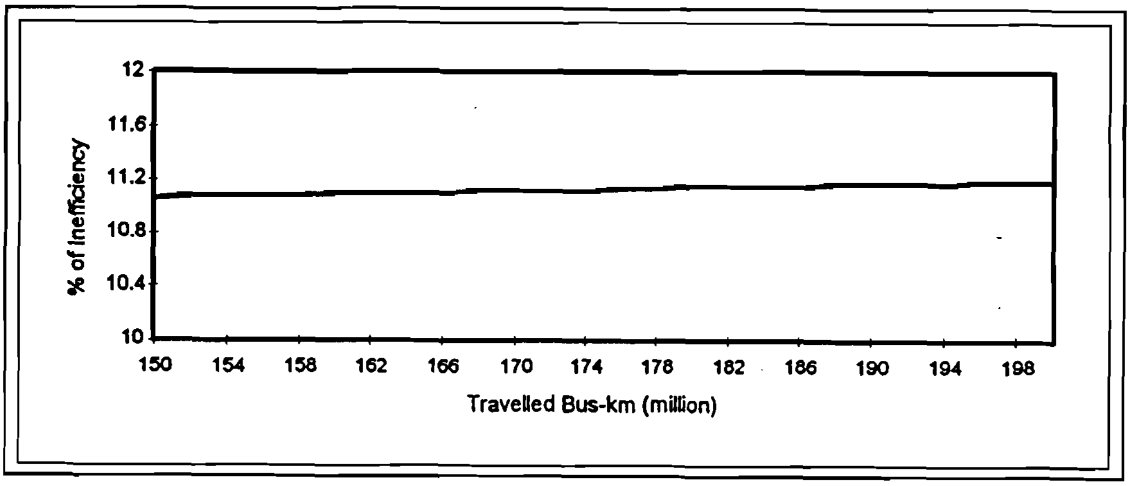

Figure 10: Revenue Inefficiency Resulting From Downsizing or Expansion of Traveled Bus-Kilometers Operated by CTA

Table 1: Bus Related Accidents As Reported In CTA 95/96 Statistics

Statistics & Rates	Bus Related Accidents							
	Types of Accidents					Passengers & Pedestrian Casualties		
	Collision Only	Collision & Casualties	Casualties Only	Fire	Total	Fatalities	Injuries	Total
Number of Accidents (%)	536 (51.6 %)	309 (29.7%)	174 (16.7%)	20 (2 %)	1039 (100 %)	40 (8.6 %)	424 (91.4%)	464 (100 %)
No. of Accidents per 1000 operable buses	0.823	0.474	0.267	0.031	1.595	0.061	0.651	0.712
No. of Accidents per 1000 000 bus-kms.	2.89	1.66	0.94	0.11	5.6	0.21	2.29	2.5
No. of Accidents per 1000 000 bus-hours	54.37	31.34	17.65	2.03	105.39	4.06	43.01	47.07

Table 2: Engineering Failures As Reported In CTA 95/96 Statistics

Types of Defaults Statistics & Rates	Mechanical Defaults	Electrical Defaults	Chassis-Related Defaults	Total Defaults
Number of Defaults (%)	26374 (21.1%)	12556 (10%)	86408 (68.9%)	125338 (100%)
No. of Defaults per 1000 operable buses	40.49	19.27	132.64	192.40
No. of Defaults per 1000 000 bus-km	142.15	67.67	465.71	675.53
No. of Defaults per 1000 000 bus-hour	2675.26	1273.63	8764.85	12713.74

Table 3: Lost Time Due To Operational Inefficiencies As Reported In CTA 95/96 Statistics

Lost Time due to Operational Inefficiencies (in hours) Statistics & Rates	Route-related inefficiencies	Garage-related inefficiencies	Crew-related inefficiencies	Total Excluding Crew Related
Lost Time (%)	495932 (78.2%)	138308 (21.8%)	N.A.	634240 (100%)
Lost Time per 1000 operable buses	761.29	212.31	N.A.	973.6
Lost Time per 1000 000 bus-km	2672.893	745.430	N.A.	3418.323
Lost Time per 1000 000 bus-hour	50305.16	14029.36	N.A.	64334.52

N.A. = Not Available

Table 4: Lost Time Due To Force Majeure Incidents As Reported In CTA 95/96 Statistics

Lost Time due to Force Majeure Incidents (in hours) (%)	442,000 (100%)
Lost Time per 1000 operable buses	678.50
Lost Time per 1000 000 bus-km	2.3812
Lost Time per 1000 000 bus-hour	44.835

Table 5: Trials For Deciding On Data Set To Be Used For Estimation Of Statistical Models Constituting The Analytical Framework

Period	CTA Garages	GCBC Garages	Total Points
95/96	13	4	17
95/96	13	-	13
94/95	13	4	17
94/95	13	-	13
93/94	13	4	17
93/94	13	-	13
93/94 to 95/96	13	4	17*3 = 51
93/94 to 95/96	13	-	13*3 = 39
Average 93/94 to 95/96	13	4	17
Average 93/94 to 95/96	13	-	13

Table 6: Estimation of Statistical Models for Predicting Generic Operational Parameters

Dependent Variables	Independent Variables	Relation Type	Predictive Functions
Annual Operable Buses (OB) (in thousand buses)	Bus Fleet after Service Changes (BF) (in thousand buses)	Linear	*$OB = BF \times 365$*
Annual Bus-Kilometers (BK) (in million)	Annual Operable Buses (OB) (in thousand)	Linear	$BK = 0.2907 (OB)$ (0.9135)[*]
		Power	*$BK = 0.1947 (OB)^{1.1003}$* *(0.9415)*
		Exponential	$BK = 3.7176\, e^{0.0262 (OB)}$ (0.9037)
Annual Bus-Hours (BH) (in thousand)	Annual Bus-Kilometers (BK) (in million)	Linear	$BH = 52.309 (BK)$ (0.9076)
		Power	*$BH = 79.513 (BK)^{0.8481}$* *(0.9578)*
		Exponential	$BH = 258.93\, e^{0.072 (BK)}$ (0.9184)

[*] Values between brackets under each equation represent coefficients of determination (i.e. R^2-values)
Predictive functions written in italic are selected as the best fit relations in the subsequent scenarios.

Table 7: Ticket Passengers and Ticket Revenue in Relation to Generic Operational Variables

Dependent Variables	Generic	Operational	Explanatory	Variables
	No. of Passengers (NP) (in million)	Operable Buses (OB) (in thousands)	Bus-Km (BK) (in million)	Bus-Hours (BH) (in thousands)
No. of Passengers (NP) (in million)	N.A.	$NP = 1.3427 (OB)$ (0.8197) $NP = 0.8219 (OB)^{1.1214}$ (0.8934) $NP = 16.478\ e^{0.0269(OB)}$ (0.8674)	$NP = 4.5915 (BK)$ (0.7634) $NP = 4.827 (BK)^{0.9797}$ (0.877) $NP = 19.075\ e^{0.0824\ (BK)}$ (0.8263)	$NP = 0.088 (BH)$ (0.8961) *$NP = 0.0269 (BH)^{1.1759}$* (0.9488) $NP = 15.257\ e^{0.0019\ (BH)}$ (0.9374)
Ticket Revenue (TR) (in million)	$TR = 0.213 (NP)$ (0.8099)* *$TR = 0.2258 (NP)^{0.9866}$* (0.8881) $TR = 4.1024\ e^{0.018\ (NP)}$ (0.8114)	$TR = 0.2574 (OB) + 0.414$ (0.6806) $TR = 0.2088 (OB)^{1.058}$ (0.7851) $TR = 3.5839\ e^{0.0251\ (OB)}$ (0.745)	$TR = 0.877 (BK) + 0.57$ (0.7991) $TR = 0.937 (BK)^{0.9891}$ (0.8824) $TR = 3.7297\ e^{0.0837\ (BK)}$ (0.8397)	$TR = 0.018(BH) - 0.678$ (0.7748) $TR = 0.0075 (BH)^{1.1241}$ (0.8559) $TR = 3.2913\ e^{0.0017\ (BH)}$ (0.8217)

N.A. = Not Applicable

* Values between brackets under each equation represent coefficients of determination (i.e. R^2-values)

Predictive Functions written in *italic* are selected as the best fit relations in the subsequent scenarios

Table 8: Predictive Functions Relating Number Of Occurrence Of Types Of Inefficiency To Generic Operational Variables

Dependent Variables	Independent Variables	Relation Type	Predictive Functions
Number of Accidents (NA) (Accidents/year)	Bus-km (BK) (in million)	Linear Power Exponential	$NA = 5.7642 (BK) + 9.6492$ (0.3753)* *$NA = 8.761(BK)^{0.8656}$* *(0.4596)* $NA = 29.026\ e^{0.074\ (BK)}$ (0.4466)
Number of Engineering Failures (NF) (1000 failures/year)	Bus-hours (BH) (in thousands)	Linear Power Exponential	$NF = 0.0117 (BH) + 1.5666$ (0.3955) *$NF = 0.0117(BH)^{1.0204}$* *(0.5387)* $NF = 3.023\ e^{0.0015\ (BH)}$ (0.4854)

* Values between brackets under each equation represent coefficients of determination (i.e. R^2-values)

Predictive functions written in italic are selected as the best fit relations in the subsequent scenarios.

Table 9: Predictive Functions Relating Lost Time To Number Of Occurrence Of Types Of Inefficiency

Dependent Variables	Independent Variables	Relation Type	Predictive Functions
Lost time due to Accidents (LT_{Ac}) (1000 hrs/year)	No. of Accidents (NA)	Linear	$LT_{Ac} = 6.2245 (NA) + 63.993$ (0.3581)
		Power	*$LT_{Ac} = 0.8558 (NA)^{1.4305}$* *(0.582)*
		Exponential	$LT_{Ac} = 121.82 e^{0.0149 (NA)}$ (0.4577)
Lost time due to Engineering Failures (LT_{EF}) (1000 hrs/year)	No of Engineering Failures (NF) (in thousands)	Linear	$LT_{EF} = 2.9114 (NF) - 2.1962$ (0.4257)
		Power	$LT_{EF} = 3.3239 (NF)^{0.8755}$ (0.465)
		Exponential	*$LT_{EF} = 8.0876 e^{0.105 (NF)}$* *(0.4793)*

* Values between brackets under each equation represent coefficients of determination (i.e. R^2-values)
Predictive functions written in italic are selected as the best fit relations in the subsequent scenarios.

Table 10: Predictive Functions Relating Different Types Of Inefficiencies Expressed As Lost Time To Generic Operational Variables

Dependent Variables	Generic Explanatory Variables		
	Operable Bus (OB) (in thousands)	Bus-Km (BK) (in million)	Bus-Hour (BH) (in thousands)
Lost Time due to Accidents' Occurrence (LT_{AO}) (in thousands hours)	$LT_{AO} = 15.128 (OB) - 109.64$ (0.2364) $LT_{AO} = 0.2758 (OB)^{1.9358}$ (0.5083) $LT_{AO} = 56.865 e^{0.0433 (OB)}$ (0.4298)	$LT_{AO} = 40.025 (BK) + 64.675$ (0.1672) *$LT_{AO} = 5.405 (BK)^{1.7222}$* *(0.5174)* $LT_{AO} = 73.822 e^{0.1311 (BK)}$ (0.3986)	$LT_{AO} = 1.0764 (BH) - 176.86$ (0.2711)* $LT_{AO} = 0.0006 (BH)^{2.0653}$ (0.5588) $LT_{AO} = 47.887 e^{0.0031 (BH)}$ (0.4843)
Lost Time due to Engineering Failures (LT_{EF}) (in thousands hours)	$LT_{EF} = 0.1086 (OB) + 22.875$ (0.0075) $LT_{EF} = 4.7803 (OB)^{0.421}$ (0.0576) $LT_{EF} = 17.068 e^{0.0071 (OB)}$ (0.0278)	$LT_{EF} = 0.2596 (BK) + 24.523$ (0.0043) $LT_{EF} = 10.229 (BK)^{0.331}$ (0.0458) $LT_{EF} = 18.696 e^{0.0182 (BK)}$ (0.0184)	$LT_{EF} = 0.0041 (BH) + 25.146$ (0.0024) *$LT_{EF} = 2.3775 (BH)^{0.3525}$* *(0.039)* $LT_{EF} = 19.094 e^{0.0003 (BH)}$ (0.0124)
Lost Time due to Operation Inefficiencies (LT_{OI}) (in thousands hours)	$LT_{OI} = 0.8322(OB) - 0.8954$ (0.1576) $LT_{OI} = 0.3957 (OB)^{1.138}$ (0.2638) $LT_{OI} = 8.4062 e^{0.027 (OB)}$ (0.251)	$LT_{OI} = 1.9316 (BK) + 12.565$ (0.0858) $LT_{OI} = 3.1766 (BK)^{0.8844}$ (0.2049) $LT_{OI} = 11.638 e^{0.0704 (BK)}$ (0.1726)	$LT_{OI} = 0.0485 (BH) + 3.5536$ (0.121) *$LT_{OI} = 0.0308 (BH)^{1.0537}$* *(0.2184)* $LT_{OI} = 9.6218 e^{0.0016 (BH)}$ (0.1957)
Lost Time due to Force Majeure Incidents (LT_{FM}) (in thousands hours)	$LT_{FM} = 0.3622 (OB) + 10.87$ (0.2263) $LT_{FM} = 2.6832 (OB)^{0.6013}$ (0.344) $LT_{FM} = 13.901 e^{0.0136 (OB)}$ (0.2999)	$LT_{FM} = 0.7928 (BK) + 17.414$ (0.1096) *$LT_{FM} = 8.2363 (BK)^{0.4593}$* *(0.2581)* $LT_{FM} = 16.992 e^{0.0331 (BK)}$ (0.178)	$LT_{FM} = 0.0224 (BH) + 11.829$ (0.1957) $LT_{FM} = 0.5453 (BH)^{0.5939}$ (0.3241) $LT_{FM} = 14.153 e^{0.0009 (BH)}$ (0.2743)

* Values between brackets under each equation represent coefficients of determination (i.e. R^2-values)
Predictive functions written in italic are selected as the best fit relations in the subsequent scenarios.

Table 11: Mean Values And Standard Deviations Of Rates of Time Lost Due To The Four Types Of Inefficiency In CTA

Rate of Time Lost Due to	Mean	Standard Deviation	Coefficient of Variation (%)	Low Scenario	Medium Scenario	High Scenario
Accidents (hours/ 1000000 Bus-km)	43.37	30.225	69.69	43.37	43.37	73.595
Engineering Failures (hours/ 1000 Bus-hours)	39.685	27.8645	70.21	11.8205	39.685	67.5495
Operational Inefficiencies (hours/ 1000 Bus-hours)	52.868	35.4271	67.01	17.4409	52.868	88.2951
Force Majeure Incidents (hours/ 1000000 Bus-km)	2125.424	817.039	38.44	1308.385	2125.424	2942.463

Table 12: Impact Of Inefficiencies On CTA Revenue (All Values Are In Million L.E.)

Basis for Prediction of Lost Time	Suggested Scenario of Randomness	Total Revenue (TR)*	Revenue Lost due to				Total Revenue Lost (TRL)	Measure of Inefficiency (%)
			Accidents	Engineering Failures	Operation Inefficiencies	Force Majeure Incidents		
CTA Data	1995/96	183.633	0.1436**	5.1191**	8.9446**	7.9752**	22.1825	10.78
Combination (1)	Low	179.994	0.1259	0.9569	3.0397	6.3406	10.4631	5.49
	Medium	179.994	0.1259	0.9569	9.2140	10.3000	20.5969	10.27
	High	179.994	0.1259	0.9569	15.3884	14.2595	30.7307	14.58
Combination (2)	Low	179.994	0.0637	2.0602	3.0397	6.3406	11.5041	6.01
	Medium	179.994	0.2102	6.9165	9.2140	10.3000	26.6407	12.89
	High	179.994	0.3566	11.7728	15.3884	14.2595	41.7773	18.84
Combination (3)	Not Applicable	179.994	0.5224	0.6505	5.0791	1.1902	7.4423	3.97
Combination (4)	Not Applicable	179.994	0.1259	0.9569	5.0791	1.1902	7.3522	3.92
Combination (5)	Not Applicable	179.994	0.1259	6.9165	9.2140	6.3406	22.597	11.15

(*) These values include travel card revenue, which was roughly estimated based on the same percentage of travel card revenue to ticket revenue collected at CTA during 1995/96 (i.e. travel card revenue / ticket revenue = 3.27678%).

(**) These values were simply computed by multiplying the amount of time lost due to each cause of inefficiency by 18.036 L.E. which is the rate of revenue per unit operable bus-hour. This rate was roughly computed by dividing the total ticket revenue by the total bus-hours during 1995/96.