OPERATIONS RESEARCH TECHNIQUE APPLIED IN REPLACEMENT OF STREET LIGHTS OF DHAKA CITY

BY

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BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

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A THESIS

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CERTIFICATE

THIS IS TO CERTIFY THAT THIS WORK HAS BEEN DONE BY ME AND IT WAS NOT SUBMITTED ELSEWHERE FOR THE AWARD OF ANY DEGREE OR DIPLOMA OR FOR ANY PUBLICATION.

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TO

MY BELOVED PARENTS

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ABSTRACT

Operation of the lighting system and its maintenance in the city is an extremely important service activity of the Dhaka Municipal Corporation. The level of performance of this lighting system depends more on the policy of replacement and its implementation than any other relevant factors. The level of performance in turn affects ' system cost' in terms of annual cost of replacement. Establishment of a clearcut relation between the level of performance and annual cost of replacement would require such considerations as,

(i) Use of mathematics and scientific methodology of Operations Research (OR) and Statistics.

(ii) Scientific approach of record keeping, storing and retrieval of basic data etc.

In the present work a study of the OR techniques and the methods applicable for the replacement of street light bulbs are discussed. The failure rates of the bulbs have been determined and fitted to the Weibull distribution which is a general type of theoretical distribution. On the basis of similarity of the failure patterns of existing 'WARDS' under the two 'Divisions', the system has been broken to four 'zones', so that failure patterns within each zone is similar. Thus four different replacement policies were suggested for the

four zones. These replacement policies could be designated as pure service replacement. The group replacement policy could not be recommended because bulk purchase discount advantage could not be obtained from the manufacturers of the light bulbs. With the proposed replacement policies characteristic curves in terms of (i) annual cost versus the percentage performance level and (ii) the percentage performance level versus frequency of service trips per week were developed for each zone. The performance could be measured as the ratio of actual number of light bulbs in operation to the total number of light bulbs in the zone at any period. The level of performance could be varied by varying the frequency of service trips per period (normally per week).

The replacement models were developed using one year's data as supplied by the Corporation. A computer programme in FORTRAN-IV language has been used in the IBM 370/115 computer. The parameters of the Weibull function were established using least squares method in the above programme. This programme along with other programmes for generation of the characteristic curves are stored in magnetic tapes which may be available from BUET computer centre on request to the Department of Industrial and Production Engineering.

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NOTATIONS

A	Acquisition cost
C	Annual cost
C_1	Unit cost of replacement in a group
C_2	Unit cost of individual replacement
$\hat{C}$	Average cost per mile
c.d.f	Cumulative distribution function
C_f	Failure replacement cost
C_g	Cost of replacing one item in group replacement
C_T	Cost per trip
C_{T_i}	Trip cost for zone i (i= 1,2,3,4)
C(t)	Average cost per period
$C(t_p)$	Total expected replacement cost per unit time for group replacement at time, t_p
D_T	Total milage covered during the year
D_0	Total road milage for the city lighting
F	Shape factor for different confidence values
F(t)	Cumulative distribution function at time, t
FC	Fuel cost
f	Actual number of light bulbs in operation
f(t)	Failure density function at time, t
f(x)	Number of failures in x th period
$H(t_p)$	Expected number of failure in interval $(0, t_p)$
h(t)	The hazard function at time, t

$K(t)$	Total cost from time of group installation until the end of t periods
$\frac{K(t)}{t}$	Average cost per period
MC	Maintenance cost
N	Total number of units in the group
NC_1	Cost of replacement of bulbs as a group (Group replacement cost of bulbs)
N_i	Number of items in zone i (i= 1,2,3,4)
N_o	Initial number of units in the group
N_t	Number of survivors through time t
N_{t-1}	Number of survivors through time t-1
n_i	Number of failures occuring in i th interval
p.d.f	Probability density function
P(n)	Present value of failure costs
P_R	Level of performance
$P_s(t)$	Survival probability in time t
P(t)	Probability of failure during the time period t
R(t)	The reliability function at time, t
T_i	Time of given read out
T_{i-1}	Time of previous read out
t	Age of replacement
t_i	Estimated time to first failure
w.r.t	with respect to
β	Weibull shape parameter or slope
η	Weibull scale parameter or characteristic life
γ	Weibull location parameter or minimum life

$\Gamma(n)$	Gamma function evaluated at n
μ	Mean life
σ	Standard deviation
β_u	Upper S- confidence limit
β_l	Lower S- confidence limit

CHAPTER 1

INTRODUCTION

The country is suffering in most situations both in strategic planning and execution due to lack of endeavours and efforts directed in line with Operation Research (OR) thinking. The industrial sector along with other vitally important sectors of the economy is reluctant to use mathematics in its decision making. The present study is thus devoted to find an application of OR in a problem which would be introduced in the following sections.

1.1. GENERAL INTRODUCTION

The term replacement is used with the widest applications. To the economist it does not mean that equipment will be duplicated at the end of its life; it does not imply like - to - like substitution. It occurs even if a manual process is superseded by a machine or if a group of machines is superseded by one large machine. To accountants replacements may be either assets or expenses, depending on how the asset unit is defined. The replacement of an entire asset results in the writing off of the old asset and the booking of the new. The replacement of a component part of an asset is the maintenance expense. To the engineers replacement is synonymous with displacement. Replacement then means that the present incumbent process will be displaced by a similar or more economic one. Recognizing the fact that all equipments, items, parts etc. have finite lives (stochastic in nature) and need replacement the all important fact remains with questions to be answered such as,

i) when and how frequently to replace?

and ii) which one to replace?

While answering these questions from the past, optimum replacement strategies had been evolved and new mathematics, heuristics developed. At this point mention may be made that optimum replacement strategy could not always be brought into operation in situations where key factors such as cash restrictions, import policy etc. are tight, as is the case in the country. Thus the experience of the writer suggests that most equipments of the country's installations are operating at levels far from optimum; one concrete example may be: continued operation of fleet of vehicles in the transport sector, where lives of most of them have passed economic points. This results in (i) increase in operating cost (including maintenance and repair costs) and (ii) inefficient production with decrease in output.

All replacement decisions criteria include such factor(s) as minimization of average operating cost and / or maximization of reliability of the system as a whole. In the later case standby optimum numbers of items are kept at hand so that system does not breakdown or the performance is maintained at predetermined level. The effort is then directed to evolve a policy so as to search for a method of replacement to minimize the cost and upkeep the predetermined level of performance. The present work is directed in achieving such an objective. It concerns a 'service' system of the city lighting. A preliminary study of the system revealed that scientific method(s) of replacement policy is absent resulting in unplanned replacement of the light bulbs of the system. This in turn results to high operating cost. The writer envisages that with the present rate of climbing cost of replacement, the overall operating cost of the system at an acceptable level of performance would be prohibitive resulting to possibly operating at lower level of performance. Thus the present work made in this context a study of the current status of the system as detailed in Chapter 3 and various limitations and shortcomings of the present system are analysed thus to suggest an improved method of replacement. The following articles are devoted to appraise the basic concepts of replacement strategy.

The street lights maintenance (excluding those of highways) is controlled by the Municipal Corporation of the city. The study of the existing system reveals that a strictly service replacement policy is adopted. The entire lighting system of the city is divided into two administrative divisions. These divisions constituted of a total of 56 wards, are administered separately. This division is made strictly on the basis of administrative point of view. Failure history for a period of one year has been collected and analysed initially to determine appropriate failure distributions for each ward. On the basis of similar failure patterns new 'Zones' have been proposed. Thus the existing two divisions may retain but it would be wise to bring the administrative jurisdiction to zonal concept. This would help maintain efficient maintenance policies and better control.

1.2 REPLACEMENT PROBLEMS

The replacement problems usually fall in two catagories such as:

i) replacement of items that deteriorate with time;

and ii) replacement of items that fail in service.

When equipment deteriorates, the decision to replace will depend upon the cost of new equipment and the cost of maintaining the efficiency of the old and also concerned with determining the optimum point in time at which the item should be replaced. The second one is related to circumstances in which the item breaks down or fail completely.

In the theory of item replacement it is customary to distinguish between two types of repair associated with item failure, each type of repair generating a particular replacement problem. The first type of repair results in the item being restored to a condition as good as new. This class of replacement policy is considered in the literature as age replacement policy. Under such a policy an operating item continuously in service is subject to failure, the item is replaced at failure or at a specified age which ever comes first. Assuming instantaneous repair and replacement the author shows that when the failure rate of the item is strictly increasing and differentiable or unique optimal replacement age exists which minimizes the long-run total expected cost per unit time. The second category of repair, the item age is not effected by repair following a failure, thus the item failure rate remains undisturbed. In the second type of failure there may be instances when items fail abruptly. Failures of light bulbs in a street lighting system is one such example. The life of an item, in this case is probabilistic in nature as mentioned earlier and thus follows a probability distribution. The cost of maintenance and operation of the system over a year is given by:-

$$\text{Cost} = \begin{bmatrix}\text{Cost of making a}\\ \text{single replacement}\end{bmatrix} \times \begin{bmatrix}\text{Probable number of}\\ \text{failures during year}\end{bmatrix}$$

The above expression contains two quantities. The first one is composed of other quantities such as item cost, and cost of replacement. Thus it is a strategic matter which decides the replacement policy. The second element could be ascertained from the probability of failure distribution of items.

1.3 REPLACEMENT METHOD FOR ITEMS COMPLETELY FAILED

The problem of replacement arises because of two factors; firstly, the existing unit or units may have out lived their effective lives and it may not be economical to allow them to continue operation; secondly, the existing unit or units may have completely failed. In each case operation research techniques are available. These frequently met with that of determining at what age the maintenance costs for old units will be off-set by new purchases. Various methods developed for solving these problems are given as follows:

a) actuarial methods

b) numerical methods

c) application of dynamic programming

d) statistical methods using simple algorithms

In the present work statistical methods have been used and various statistical probability distributions available and used in similar situations have been studied. Considering the generality in nature, the Weibull distribution has been used in the present work. A detailed study of failure charactristics of light bulbs for all the wards has been made and presented in Chapter 5. On the basis of similarity in failure charactristics in terms of the two parameters such as 'scale parameter' and 'shape parameter' of the Weibull distribution, the wards were pooled and thus four 'zones' were established. It is hypothesized that under the proposed zoning concept the overall performance of the entire system would be improved with corresponding reduction of replacement cost. This is because the service trips of maintenance crews could now be better planned. The total distance travelled by the service crews would be shortened as the present highly erratic and haphazard movements would be smoothened and thereby reduced.

1.4 OPERATIONS RESEARCH TECHNIQUES IN INDUSTRIAL PROBLEM SOLVING

Operations Research (OR) approach could be applied in decision making problems in strategic situations met within industry, agriculture and various field of economy. The oldest profession which has been involved in a sophisticated OR work is that of an actuary who has been applying life contigency, probability and various mathematics and other methods to enable the life offices to decide what the premium rates of various policies should be, how best profits could be distributed in case of with profit policies, etc. The problem in industry starts from procurement of raw materials up to the despatch of the finished product. In both developing and developed economics the OR approach is equally applicable. In developing ecbnomics there is a great scope of developing an OR approach towards planning. The basic problem in most of the developing countries in Asia & Africa is to weedout poverty and hunger as quickly as possible; there is a great scope for economists, statisticians, administrations, politicians, technicians work together to workout this problem with an OR approach.

The OR approach needs to be equally developed in various agricultural problems (Neverthlese, there have been successful applications of OR in industries in developed countries). The scientific approach aims at giving a quantitative analysis of the problems posed, in order to develop a mathematical model on the basis of which data are collected and numerical investigations are made.

The basic OR approach is

i) to formulate the problem as precisely as possible

ii) to device methods of attacking problems

iii) to undertake investigations on the basis of (ii) and draw conclusions.

In stage (ii) a model is to be devised and decision to be made what data should be collected and how they should be analysed. The stage (iii) is very often followed by a study of implementation of the recommendations.

Having specified OR way of attacking a problem various techniques are applied for the purpose of solving the problem and should not distort the problem to apply a particular technique.

Operations Research Techniques are continually being evolved indeed the OR worker must often avoid the pitfalls of existing techniques in maintaining his enquiring experimental attitude of mind. Certain techniques have, however, now been used in many situations so successfully with only minor modifications on each occasion that the responsible OR man must always consider these techniques first in the given situations because, after all, he is paid to produce results not to sàlary his own intelectual curiosity.

These techniques give a clear indication of just how OR workers and the results it has had. Many of these techniques are derived from mathematical statistics which is still one of the most powerful tools in the OR approach. This is necessary so because one common property of industrial systems is their variability and mathematical statistic is the method of handling the problem of variability. The other techniques are linear programming, queueing theory, simulation methods, stock and production control models, decision theory and game theory, operations gaming, information theory and evolutionary operation. These techniques do not ofcourse represent the limit of an OR team's capabilities, nor are they the sum total of existing OR techniques. Other methods which could have been mentioned are - search theory, symbolic logic, Boolean algebra and dynamic programming. Some techniques applied in OR are borrowed from other disciplines - actuarial theory and value theory for example. There are others being developed continually. Some are applicable in but a few rare cases, others acquire the powerful sweep of queueing theory or simulation.

In the present work an application of mathematical statistics of the OR is sought. The following section is devoted to identify the scope and objectives of the present work.

1.5 SCOPE AND OBJECTIVES OF THE PRESENT WORK

Scientific and systematic approaches applied to problem-solving areas and also in planning are almost absent in the country as a result poor performances become almost inevitable. In the Dhaka Municipal Corporation, it is no exception. The Corporation in addition to various activities is responsible for operating and management of the street lighting system, an important sector of the Corporation. The objective of the maintaining of lighting systems is to keep a satisfactory level of lighting performance as economically as possible and could be achieved through a carefully design plan and strategy. From the initial study of the existing system of replacement of the light bulbs it was mentioned that a purely service replacement is being used. The cost of replacement has been ascertained. The average variable cost of replacement has been determined. The inherent weaknesses of the existing policy of replacement have been studied While the city is expanding physically along with population growth, the pressure on expansion of the lighting network is becoming necessary. The high cost of replacement should be a pivotal factor in any redesigning of the system.

The objectives of the current research work are set as follows:

i) To study the failure patterns of light bulbs of the system and to ascertain the failure parameters

ii) To establish zones (sub-systems) of the system on the basis of similar failure characteristics.

iii) To evolve a prediction model to help predict number of failures per period which could be simulated at various strategies of replacement i.e. frequency of service trips of the crews per period

iv) To establish a relation between cost of replacement per year with system performance and with various strategies of replacement.

A preliminary investigation of the present study has indicated a positive pointer towards definite improvement of the present system. This could be achieved by using techniques of Operations Research (OR) such as Replacement - heuristic and thus formulating a clearcut policy of replacing light bulbs.

CHAPTER 2

LITERATURE SURVEY

The process of equipment replacement is a historical as well as a natural process. However new theories and strategies have been evolved and practised in many installations. Thus many literatures on this subject have been compiled uptil today. A theory of replacement is basically concerned with the prediction of replacement cost and then determination of the most economical replacement policy. In such a prediction process another stochastic factor (variable) and its effect is to be considered. This is the process of estimation of an item's finite life. Items in group also have finite lives which are probabilistic and thereby could best be predicted when their distributions are known. This prediction is further complicated when 'renewal' aspect for an item is in operation. This means that an item's original life could be extended by bringing maintenance and repair in operation to a point which is uncertain in terms of its location. Fortunately in such a situations the "Renewal Theory" and sophisticated mathematics are available, discussion of which is beyond the scope of the present work.

The earliest replacement policies mostly concerned the deterministic problems. McCall (1) published a survey on the subject and stressed upon the practical need for subtle and delicate maintenance policies. Contemporary work on replacement problems was also credited to Ghosal (2). A particular class of problems of replacement can be tackled by using the technique of Operational Research specially the dynamic programming technique that primarily strives to determine the state of affairs when an optimal policy is followed. Ghosal discussed how a problem in block replacement could be solved using Markov Chain. Crookes (3), Bartholomew (4), Nakagawa & Osaki (5), Sivazlian (6), Shamblin & Stevens (7) all have contributed towards problems and theories of equipment replacements. An optimum replacement of forklift trucks has been described by Eilon, King and Hutchinson (8). Jardine (9) and Sivazlian & Stanfel (10) have also developed various types of deterministic replacement models. West(11) compared the methods for alternative replacement policy identifying certain cost relationship partinent to the minimization of costs and developing the methods for predicting costs based on probability distribution of life spans. Many important methods have been applied to various maintenance models; the first of which is the class of preparedness of models where the equipment fails stochastically and alternative maintenance action for such equipment include inspection and replacement. Preventive maintenance models possess the second class of maintenance models.

Ackoff & Sasieni (12) suggested a method to determine the optimal life of an equipment when increased age reduces its efficiency and average cost per period for individual replacement. Ackoff & Sasieni also suggested a probabilistic model to predict expected number of failed items per period in a system. It has been demonstrated that group replacement has positive advantage over service replacement under normal cost situations. Wild (13) considered the effects on different costs of both random replacement and age replacement policies.

Age replacement for an infinite time span has received attraction. When such an optimal interval exists, Morse (14) has suggested a method for determination of this replacement interval minimizing the expected cost per unit time. But in case of finite time span the optimal age replacement interval is not easy to find out. Sasieni, Yaspan and Friedman (15) presented a procedure for computing the economic life of a machine that assume the purchase only a single item. They illustrated the procedures for determinig the policies in replacing bulbs, airline stewardesses, given the present failure age distribution and survival distribution. They also determined the optimum adjustment interval for a machine with a specified linear operating cost. A dynamic programming model for equipment replacement has been constructed by Bellman (16). He considered two possible courses of action whether a machine should be kept on for another period or it should be replaced by a purchased machine.

Dean (17) summarized the replacement models developed by other authors (such as Terborgh, Orenstein, Claphan, Smith, Bellman, Rifas, Rutenberg, Pennycuick, Senju) and setup some replacement decision rules. Several problems in the optimal control of dynamic systems were investigated by Dermann (18). A system is classifiable into one of a finite of states and controlled by making one of a finite number of decisions. This stochastic process is dependent upon the sequence of decisions, in that the decision determines the probability laws. Using the methods due to Dermann for sequencial decisions problems involving average cost per unit time criteria. Klien (19) generalized his model and formulated the problem of finding optimal policies whose deterioration can be expressed as a Markov Chain in linear programming terms. It has been assumed that the time until the next inspection is variable and it is determined at each inspection.

McCall (20) determined some of the operations characteristics of opportunistic replacement and inspection policies which makes the replacement of a single inspected part conditional on the state of one or more continuously inspected parts. Weiss (21) presented a derivation of the asymptotic results from the theory of Semi-Markov process. The derivations found are not completely rigorous. Handlarski (22) analysed preventive maintenance scheme for improving machine utilization. He has introduced a new model integrating the availability and the cost function into one profit function which has been done by adding a new parameter, revenue gained per unit operation time of the machine. An interested reader is referred to Roll & Naor (23), Parsons (24), Wyder (25) for some of the works in preventive maintenance policy and replacement theory.

Kaufmann (26) constructed an equipment survival curve taking a classic example of light bulbs to show the relation between the number of surviving bulbs at any given moment and the number of bulbs originally placed in service. The probability of failure is an important characteristic to measure the risk involved to keep in service an item of equipment that has been in operation for a particular time.

From the above survey of available literatures the works of Kaufmann and Ackoff & Sasieni are devoted to replacement of items whose lives end after failure. The failure distribution used in their models was the negative exponential. Moreover input cost parameters for both individual item cost and group item cost are such that a strategy for group replacement (failed and unfailed) may become a possible optimum policy. But such defferential costs and cost advantage of one over other does not exist in the present study. Thus the methods available could not be used in the present work.

A modified service replacement policy has been suggested in the present work. Although the negative exponential distribution is accepted to be a very close approximation of real life situation, it lacks generality. Thus the weibull distribution is proposed in the present work.

CHAPTER 3

STUDY OF THE EXISTING SYSTEM OF STREET LIGHTS OF DHAKA CITY - A CASE STUDY

3.1 HISTORICAL BACKGROUND OF DHAKA MUNICIPALITY CORPORATION

Early in the nineteenth century the city of Dhaka was a mere wreck of its once-splendid self and civic facet of its overall milico. A Europian chronicler who visited Dhaka in 1824 recorded that two-thirds of the vast area of the city were filled with ruins in which the bulk of its estimated 3,00,000 citizens (29)

A Committee of Improvement existed in the city as early as in 1823. It confined itself to a modest range in two spheres of public works, viz., sanitation and transport, specifically its function were defined to be the improvement of Bazar Street, the construction of bridges and roads, the filling of unsanitary pools and ditches. The Committee was an official body and its fund was sanctioned by the Government. In 1840 Government created a Dhaka Committee with wider range of functions. The functions of the Committee were to look after the conservancy drains, tanks and general cleanliness of the town, to guard against any encroachment on the roads. A relevant thing to be noted during the period 1840-64 is the degree of public participation in civic function like watering of the main Bazar Street.

Formally established on the 1st of August, 1864, Dhaka Municipality has its prototypes through retrospective decades, though they were germinal and fell far short of a full-fledged Municipal body with a corporate entity of its own. Municipal Act was published in 1884 and that period Magistrate was the Chairman of the Paurashava. Government abolished Dhaka Paurashava at the end of the year 1947 and at that time the functions of the Paurashava was run by the Government selected body. In 1960 Government established the Municipal Ordinance. In the month of October, 1978 the Government converted the Dhaka Paurashava into Dhaka Municipal Corporation by an Ordinance.

3.2 FUNCTIONS OF DHAKA MUNICIPAL CORPORATION

The existing functions of Dhaka Municipal Corporation are deposed as under.

Public Health

The Corporatioh is reponsible for the sanitation of the city, control of environmental pollution and removal of refuse from all public streets, public latrines, urinals, drains, and all building and land vested in the Corporation and for the collection and proper disposal of such a refuse. The Corporation keeps records of births, deaths and marriages within the limits of the city and adopts preventive measures for infectious diseases by vaccination. Mosquito control scheme is now executed by the Corporation.

Water Supply and Drainage

The function of DMC is to look after, construct, maintain and clean of surface drains only of the city. The water supply and other drainage system, swerage system has been maintained by WASA and the storm swerage drainage is now maintained by Public Health Engineering. The Corporation maintains the portion when handed over by Public Health Engineering to Dhaka Municipal Corporation.

Articles of Food and Drink

The Corporation prohibits the manufacture, sale or preparation or the exposure for sale of any specified article of food or drink in any place unless licensed by them. The Corporation also prohibits the import of such articles for sale without the license. The Corporation is authorized for seizure and disposal of any animal, poultry or fish intended for food which is diseased, or any food or drink which is noxious. The Corporation has also the function to establish and maintain public markets and secure the proper management and sanitation of such markets.

Culture and Social Welfare

The Corporation provides and maintains public hall and community centres and also provides for the reception of distinguish visitors, arranges on the occasion of any fairs, shows or public festival within the city. It maintains burial grounds and burning ghats.

Trees, Parks and Gardens

The Corporation plants trees on the public streets and public places and takes care for the plantation and protection of trees. The Corporation takes care of the parks namely Victoria Park, Gulistan Park, Narinda Park and Shishu Park. They also maintain public gardens.

Engineering Works

Development and maintenance of roads and some times project offered to DMC by Government, e.g. bus terminal scheme (Jatrabari, Tejgoan and Mirpur Inter-district bus terminals) are the functions of civil engineering. Office buildings of the Corporation are to be constructed by them. Street lighting, Street watering, trafic control are the main functions of electrical engineering section. Development and maintenance of road carpeting by asphalt plant, slaughter house, decomposed plants are the mechanical engineering functions of the Corporation.

The above functions and responsibilities and the personnel are depicted in an organization chart. The objective is to identify and locate the position of the lighting system management function in the chart. The organization chart is shown in Fig. 3.1. It can be observed that the organization is classical line-staff type. The scope of the current discussion is restricted upto showing the organization of the Corporation.

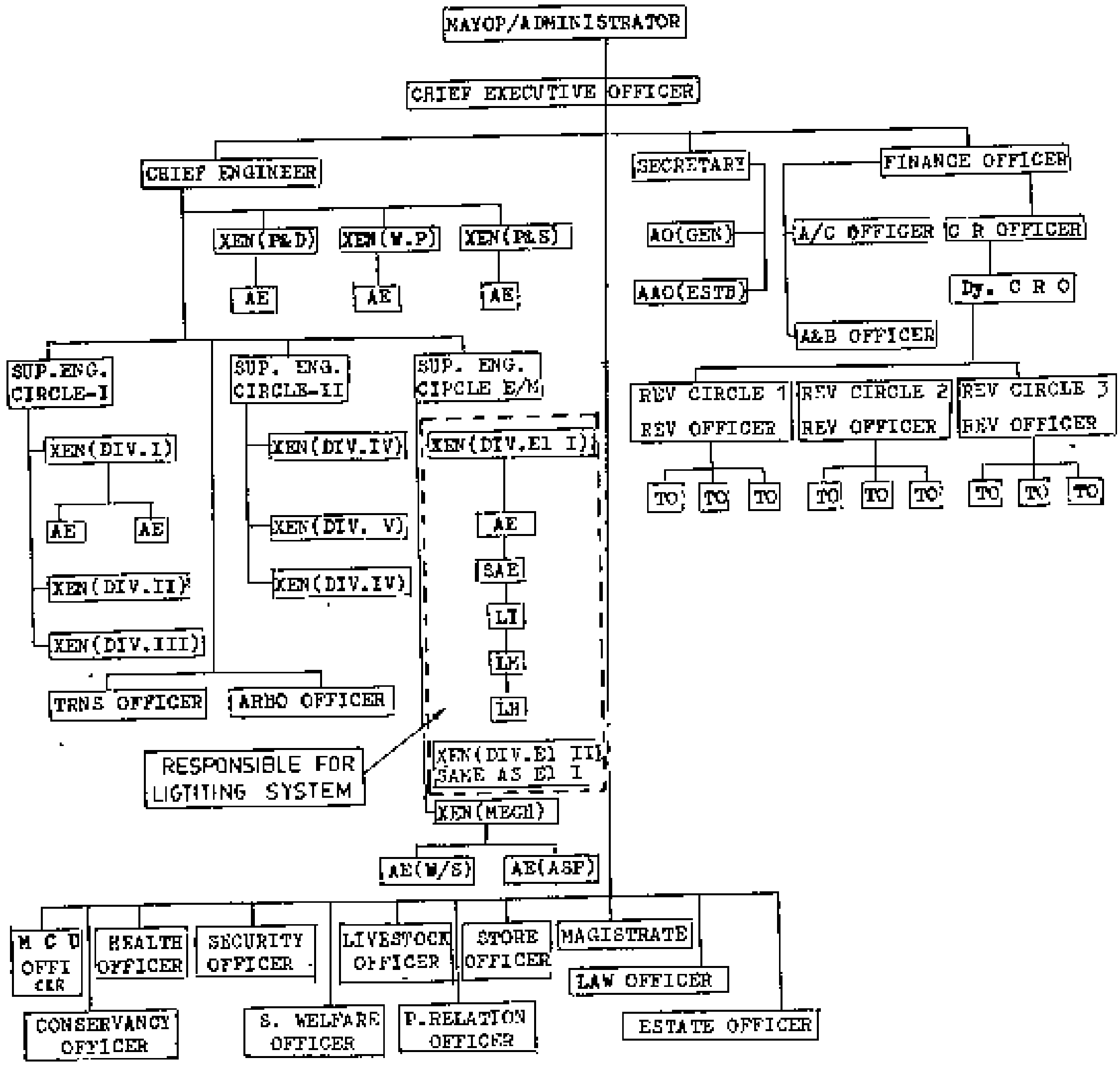


FIG 3.1 ORGANISATION CHART OF DMC

3.3 STRENGTH OF MANPOWER AND VEHICLE RESOURCES

The total number of employees of the Corporation is 8090 and among them 4491 are serving on day-basis on hire. Statement below shows the distribution of staffs.

Statement showing distribution of staff Department/Section wise

Department/Section	Number of Employee	
	Regular	Day-basis
Administrative Department	95	3
Establishment Section	29	-
Administrator Cell	28	1
Public Relation Officer	7	1
Security Section	146	2
Law Section	7	-
Social Welfare Section	245	25
Arboriculture	188	89
Finance Department	70	-
Revenue Department	680	-
Estate Department	28	43
Health Sanitation	153	3,927
Health Department	613	128
Livestock & Veterinary Hospital	71	15
Engineering Department	854	257
Education Department	14	-
Store Section	16	-

Department/Section		Number of Employee Regular	Number of Employee Day-basis
Transport Section		309	-
Outfall Works		46	-
	Total	3,599	4,491

Engineering Department (Electrical) is responsible for the maintenance of street lighting system of Dhaka city. This Division is subdivided into two divisions namely, Engg. Div. (Elc.)-I and Engg. Div. (Elc.)-II. These divisions are set up from the administrative point of view. The total number of employees of these two divisions are 119 and 158 respectively. It has already been shown the place and responsibility of these two division in the organization chart in art 3.2 . It may be useful to note that there are total of 377 (119 + 158) staffs under these two divisions responsible in operating the lighting system. Incidentally the ratio of this number with the total strength in the department is 0.34.

Strength of Vehicles

A total strength of 276 number of vehicles are being used by the Corporation. There are twelve vehicles used for street light maintenance work. The vehicles are of three types:

i) Hydraulic Ladder carrier engaged for quick repair maintenance of street lights

ii) Trucks over which bamboo ladders are carried and vehicles are engaged in the areas having wide roads

iii) Push trolly is used in medium or small lane/bylane where trucks, ladder carriers are not accessible to the point.

The total strength of vehicles is listed in table 3.1.

Table 3.1 Total strength of vehicles.

Name of Vehicle	No. of Vehicles used for lighting	Total No. of Vehicles of D M C
Truck	3	123
Hydraulic Ladder	7	7
Pick-Up	-	2
Mini Truck	-	52
Tractor	-	1
Water Tanker	-	5
Bus	-	1
Micro Bus	-	2
Jeep	-	13
Car	2	15
Motor Cycle	-	55
Total	12	276

3.4 TREND OF ANNUAL CONSUMPTION AND EXPENDITURES OF LIGHT BULBS OF DHAKA CITY

Generally four types of bulbs are used by Dhaka Municipal Corporation for street lighting of Dhaka City - incandascent lamp bulbs, flurescent tubes, mercury bulbs and sodium lamps. Mercury and sodium lamps are rarely used due to high cost. Though these two types of bulbs are extensively used in all developed countries, flurescent tubes of 40 watts are commonly used in the city. Incandascent bulbs still exist in many places of Dhaka city and future scheme of DMC to replace all the incandascent lamps by 1985.

The total consumption of flurescent tubes and incandascent bulbs are shown year-wise for the last three years in table 3.2.

Table 3.2 Year-wise consumption of tube and light bulbs.

Year	No. of flurescent tubes	No. of incandascent bulbs
1980 - 81	34,000	18,000
1981 - 82	45,000	14,000
1982 - 83	52,000	8,000
1983 - 84(estimated)	66,000	6,000

Source:- DMC file preserved by the XEN of Elc. Div.II

From the above it is observed that the use of flurescent tubes are gradually increasing with the decreasing of incandascent lamps and total consumption is also increasing. With this increasing trend in consumption the overall expenses per year has an increasing trend. This is given in the following section.

Expenses Year-wise

The annual expenses of street light bulbs & materials, maintenance of street lighting and the salary of street lighting staff were retrieved from the corporation files and are listed in table 3.3.

Table 3.3 Expenses for bulbs & materials, maintenance & salary cost

Year	Bulbs and Materials Taka	Maintenance of lighting Taka	Salary of street lighting staff for 8 months(up to Feb) Taka
1974 - 75	-	20,06,915	2,32,046
1975 - 76	-	14,38,832	2,62,049
1976 - 77	-	22,27,216	3,23,779
1977 - 78	-	23,66,537	5,08,996
1978 - 79	17,03,378	25,30,548	5,70,343
1979 - 80	20,57,365	25,17,088	7,69,159
1980 - 81	56,14,286	49,98,697	6,65,602
1981 - 82	39,10,166	13,23,149	-
1982 - 83	27,49,538 (up to Feb'83)	37,04,210 (up to Feb'83)	11,31,910

3.5 EXISTING REPLACEMENT POLICY

The entire street lighting system of Dhaka City is under the management of the Municipal Corporation of the City (DMC). The management follows the service replacement policy for the replacement of street light. In service replacement the unit is replaced after its complete failure i.e. replacing an individual item that has failed. This existing system of replacement process is the most conventional one. It consists of one regular field trip of the system everyday. Thus any failed bulb located in the system is replaced by a new item. This is the normal replacement. There is another service replacement based on specific complaint received from the user point of view.

Normal Replacement Process

In the normal replacement the service crews who are called Maintenance Gang makes at least one trip of the system (wardwise) to detect any failed item. One Gang consists of one lineman and two helpers. Each gang is assigned for one large ward or two smaller wards. The gangs function from 1-30 p.m to 9-00 p.m. for all the wards other than the VIP roads. The normal duty for those VIP roads is from 1-30 p.m. to 11-30 p.m. Gangs for VIP roads are provided with modern radio communicating devices such as wireless sets. Sufficient materials are given in advance to those gangs so as to replace failed item within short time. For other wards materials are procured from the stores following necessary formal paper works.

Normally a fixed amount of fuel oil is issued for maintenance of vehicles on the basis of daily consumption of past records which is relaxable in the case of emergency and extra works. In some wards the working gangs use push trollies. In case of emergency such as after storm and high winds the supervisors make an emergency trip and assess the situation and instruct accordingly.

Service Replacement on Request/Complaint

Under this system of service, complaints/requests are received and accordingly these are met on first-come-first-serve basis. These complaints regarding any failure of any light-bulb in the system, are made by one of the following ways:

a) Complaint received from the public either by telephone or by written application. These complaints are received by the Corporation by one of the following control points:

i) Complaint received by the wireless control room

ii) Complaint received by the complaint centre of DMC

iii) Complaint received by different offices such as Chief Engineer's Office, Superintendent Engineer's Office and others.

b) Complaint received by the maintenance mobile gang. The maintenance gangs on duty travel in the wards and detect the failed bulbs in the system. Moreover, any defects in the accessories, problems in the line etc. are replaced by them. The failed bulbs are replaced immediately. These crews are also capable to detect any failures on the bulbs due to uneven fluctuations of voltages. For any snaping of wire if detected, written information is given to the relevant office for further necessary actions.

c) Each ward Committee is headed by a chairman with few members. This committee is also responsible to inform concerned electrical divisions if any irregularities in the performance of the street lighting system are detected.

In some cases other agencies such as the Electric Supply Agency (Dhaka Electric Supply) of the Power Development Board reports to the DMC, of any failures of light bulbs dected during their own servicing and operational activities.

These above complaints are attended to on priority basis. The normal replacement as mentioned earlier along with these service replacement constitutes the existing replacement policy of the Corporation. The actual replacement process is now described below.

Replacement Process

a) Complaint received from the public are attended by the concerned maintenance gang posted in the complaining area. In case of any major fault they investigate the matter and prepare a list of materials. Appropriate supervisory personnel such as SAE/AE in some cases the higher supervisory personnel such the Executive Engineer investigate the complaint and endorse the replacement process.

b) Complaint received from the mobile gang and necessary materials are issued after proper scrutiny. After the replacement the working gang submit a list of work (address, nature of replacement etc. to the office with area). Supervisory level Officer occusionally investigates and takes some on the spot verification.

c) Complaint received from the ward Committee are carried out by working gang receiving necessary materials from the office. After replacement/repair of street lights the working gang takes signature from the ward Chairman or Member and produce it to the office for proper record.

Complaint given by other agencies are also attended and after proper action the concerned agency is reported back of the action taken.

Exceptional Replacement

There are few very important lines needing special attention . Any complaints from such special lines are immediately attended to on top priority. As such sufficient reserved materials are given to the gangs in this jurisdiction to carry out the maintenance work. This gang generally submits work lists to the office everyday.

3.6 DEFECTS & LIMITATIONS OF THE EXISTING PROCESS OF REPLACEMENTS

The existing system of replacement is rather unscientific where systematic procedure is almost absent. The defects of the existing system of replacement are listed below:

i) Eratic movements of the gang may be comparable to spaghetti which is formed due to unplanned and uneconomic trips. As service replacement policy exists, the crew attends any complaint as first-come-first-serve basis. This ignores the application of techniques of OR such as travelling salesman problem, branch and bound, network analysis etc.

ii) Primary data of the failure characteristics of the items in the present system are not available. Thus decisions in terms of planned level of performance at various costs could not be made. Thus proper replacement strategy could not be established.

iii) The existence of a centralized system of management hinders the promptness of the process of replacements. The procurement of necessary materials from the central stores has the following disadvantages:

  a) lengthy paper work and bureaucratic imposition
  b) increase the cost of acquisition as the crews at the furthest wards have to travel back to the store to collect their stores.

iv) The existing two electrical divisions which are responsible for street light maintenance were set up arbitrarily based entirely on administrative ease. This resulted in dissimilar wards interms of their failure patterns, being brought under a division. Thus no single replacement policy could be adopted.

v) There is no provision for recording the daily movement of the crews. Thus the trips of the crews could not be planned.

vi) Most of the replacements are made when attending the complaints previously made. In the process the crews make survey of the system to detect any normal failures. As a result normal replacement could not be accomplished satisfactorily.

vii) The present record keeping system is defective. Thus any installation of new item is not recorded according to 'pole' identification, a holding number of the light posts. As a result estimation of the actual performances of the light bulbs could not be made.

The proposed replacement policy would remove few of the above defects of the existing system. But a final word regarding the management of the lighting system, may be that a carefully planned reorganization is necessary giving more autonomy and decentralization of authority.

CHAPTER 4

DEVELOPMENT OF METHODOLOGY FOR ESTAHLISHMENT OF A REPLACEMENT POLICY FOR LIGHT BULBS IN THE CITY

A study of lighting system of the city was made in chapter 3. The study revealed that the existing system of replacement policy had few inherent weaknesses. Thus to overcome these weaknesses, a method has been proposed. The methodology used for the proposed method has been established in the present chapter.

4.1 DISTRIBUTION OF FAILURE PATTERNS

Exponential distribution is generally used for failures of light bulbs. But the exponential and hyper-exponential distributions are found to be typical for failures of many electronic components, electronic computers, bus-motors etc. These distributions are widely used for reliability prediction. But these should not be used indiscreminately rather be used cautiously depending on situations and their typicality. The hazard function for exponential density function is constant which is applicable of the density function.in life testing. The other probability distribution namely the hypergeometric should be used in a situation where the failure is increasing. The exponential distribution is a special case of both Gamma and Weibull distribution. This is characterized by a constant hazard function which is also the parameter of the distribution, i.e, if a system has survived for a particular period, the probability of survival for the next increament of the period is the same as if it has just been placed into service neglecting degradation failures. The weibull distribution is probably the most widely used distribution for life testing applications. The weibull distribution was known to statsticians as the Fisher - Tippett Type III distribution of smallest values or as the third asymptotic distribution of smallest extreme values. In case of hyper - exponential distribution the failure rate decreases with increase in time.

The Poisson distribution is applicable when a random failure exists, practical examples of this type of failure distribution can be found in the failure of lamps and vehicle engines. Due to paramount importance of this distribution in statistical practice, tables of random normal variates have been established. Lives of various machinery items and biological species follow exponential distribution; the inter-arrival time of ships in a port or of customers at a shop counter may approximate to exponential distribution. This type of distribution is expected to be used often to describe service time in queuing problems.

Gamma distributions are characterized by two parameters - shape parameter and scale parameter; possess increasing failure rate in the case when shape parameter is greater than unity. This distribution can also be used to model the time to the failure of a system if the underlying failure distribution is exponential. The problem from a practical stand point is the selection of a distribution model. Unless one has considerable test data it is difficult to determine whether the proper model is, for instance, Weibull or Gamma. Distribution models such as these will generally 'fit' well in the 'middle' of the range of the random variable. There are certain values of skewness and kurtosis which are indicative of the shape of a distribution that the weibull can not attain which the log normal or gamma distribution can attain (27). Fortunately, in most engineering application the Weibull is usually close enough to provide reasonable guidance; when the shape parameter is approximately one, the Weibull distribution takes an exponential shape whereas it approximates normal distribution when the shape parameter is approximately 3.5.

The parameters of weibull distribution, shape, scale & location indicate the weibull slope, characteristic life and the minimum life respectively. The two-parameter weibull has a minimum life of zero and the three-parameter distribution can always be converted to the two-parameter distribution by a simple linear transformation. The hazard function decreases in time when shape parameter is less than one, increases when greater than one and constant in case of unity value. Location parameter of a weibull distribution is usually assumed to be zero and its value less than zero could indicate failure in storage (27). Its reliability is not easy to find out directly as in the case of exponential distribution. One of the main feature of this distribution is its ability to generate a family of curves with different shapes of the failure-rate functions.

The writer has chosen the weibull distribution for the analysis of failure characteristics of light bulbs considering its generality and ease in handling. The failure density function, reliability function, cumulative distribution function and hazard function of weibull distribution may be stated as follows:

$$f(t) = \frac{\beta (t - \gamma)^{\beta - 1}}{\eta^{\beta}} \exp\left[-\left(\frac{t - \gamma}{\eta}\right)^{\beta}\right] \quad (4.1)$$

where, f(t) = Failure density function

Cumulative distribution function could be obtained by integrating f(t) with respect to t

Thus, $$F(t) = 1 - \exp\left[-\left(\frac{t - \gamma}{\eta}\right)^{\beta}\right] \quad (4.2)$$

where, F(t) = Cumulative distribution function

The Reliability function is given by,

$$R(t) = \exp\left[-\left(\frac{t - \gamma}{\eta}\right)^{\beta}\right]$$

The Hazard function is given by,

$$h(t) = \frac{f(t)}{R(t)} = \frac{\beta (t - \gamma)^{\beta - 1}}{\eta^{\beta}}$$

where, β = Shape parameter

η = Scale parameter

γ = Location parameter

t = Time period

The expression of above functions for other types of distribution failure are available in standard text books.

Estimation of the Parameters of Weibull Distribution

For the estimation of the weibull parameters of group data, the following methods can be used;

i) Least Squares Method,

ii) Maximum Likelihood Method,

and iii) Minimized Chi-Squares Method.

The Least Squares method has been used for the estimation of the parameters by Kabir (28) and computer programme in complete in FORTRAN IV language was available. In the present work, the above package has been used with some necessary modifications. This method is based on the inversion and double logarithmic transformation of the equation for the cumulative distribution function, F(t) is given earlier in equation 4.2. For convenience it is rewritten as follows,

$$F(t) = 1 - \exp\left[-\left(\frac{t - \gamma}{\eta}\right)^{\beta}\right]$$

which on transformation becomes,

$$\log_e \log_e \frac{1}{1 - F(t)} = \beta \log_e(t - \gamma) - \beta \log_e \eta$$

This is a linear equation of the standard form,

$$Y = mX - C,$$

where, $Y = \log_e \log_e \left[\frac{1}{1 - F(t)}\right]$

$m = \beta$

$X = \log_e (t - \gamma)$

$C = \beta \log_e \eta$

Shape parameter can be estimated using weibull probability paper and least squares fit. In the present work these calculations are carried out by a computer subroutine.

Location parameter has been estimated from the following equation,

$$\hat{t}_i = T_{i-1} + \frac{n_i T_{i-1} + T_i}{n_i + 1}$$

where, $\hat{t}_i$ is the estimated time to first failure

n_i is the number of failures occuring ith interval

T_i is the time of given read out

T_{i-1} is the time of a previous read out when >0.

Then, the original data is adjusted by substracting $\hat{t}_1$ from t_i's in group data. In the present work, location parameter is estimated as t_{i-1} where t_i is the class interval when first failure has occured.

Although the Least Square method does not guarantee to give the 'best' fit of the raw failure data yet it has been used for its simplicity in applications. The second method is best applicable when the data is originally in grouped form and inspection periods are long. The third is the best from the stand point of Chi-Square criterion for goodness of fit.

4.2 REPLACEMENT MODELS

Replacement models fall into two categories, depending upon the life pattern of the equipment under study. The first of which deals with models for replacing equipment that deteriorates with time. The other category presents replacement models that may be used to establish replacement policy for equipment that does not deteriorate with time, but fails instantaneously and completely. Replacement model for items that fail requires the use of probabilistic concepts and the statistics of failure data. The models for these replacement policies are well developed now a days and available in all reliability and Operations Research text books. The present work has dealt with service replacement. Light bulbs exibit the characteristic of instentaneous and complete failure and they are presented as follows:-

Analysis of failure data.

Failure data would be collected and recorded within discrete time of interval. The survivor bulbs function properly at the end of each time period. The probability of failure during the time period and that of survival are calculated from basic data using equations (4.12), (4.13), and (4.14).

The number of replacement per period

If x_t denotes the number of replacements made at the end of the t th period, the number of replacement at the end of each period would be

$$x_o = x_o$$
$$x_1 = x_o \quad P(1)$$
$$x_2 = x_o \quad P(2) \quad + x_1 \quad P(1)$$
$$x_3 = x_o \quad P(3) \quad + x_1 \quad P(2) \quad + x_2 \quad P(1)$$

and so forth.

A general expression for x_t would be

$$x_t = N_o \left[P(t) + \sum_{j=1}^{t-1} P(j)P(t-j) + \sum_{b=2}^{t-1} \left\{ \sum_{j=1}^{b-1} P(j)P(b-j) \right\} P(t-b) + \ldots \right] \tag{4.3}$$

The average life of the units under consideration is given by the expression

$$\sum_{t=0}^{n} t \left[P(t) \right] \tag{4.4}$$

This equation may be compared with equation (4.15)

Cost of group replacement

The cost of a replacing failure involves item cost, labour cost, production cost, material damage cost etc., the sum of these costs may not be costant for each failure. It depends on the number of failures in each period. Group replacing may cost less than replacements of failures by virtue of labour savings, volume discounts on materials or for other resource. This group replacement policy is applicable where the item cost is low and labour cost is high. To develop an equation for the cost of maintaining a system as a function of the control variable t, the number of period in group replacements let us assume K(t) as the total cost from time of group installation until the end of t periods. If the entire group is replaced at intervals of length t periods, then

$$\frac{K(t)}{t} = \text{average cost per period of time}$$

Further more, let

C_1 = unit cost of replacement in a group

C_2 = unit cost of individual replacement after failure

$f(x)$ = number of failures in the x th period

N = number of units in the group

Then, the total cost K(t) will be given by

$$K(t) = NC_1 + C_2 \sum_{x=1}^{t-1} f(x) \qquad (4.5)$$

in which NC_1 is the cost of replacing the bulbs as a group, and

$C_2\sum_{x=1}^{t-1} f(x)$ is the cost of replacing the individual failures at the end of each t-1 periods before the group is again replaced. Therefore, the cost per period is given by

$$\frac{K(t)}{t} = \frac{NC_1}{t} + \frac{C_2}{t}\sum_{x=1}^{t-1} f(x) \qquad (4.6)$$

The above scheme of ascertaining of group replacement cost was proposed by Churchman (11). A similar method was arrived at from a different approach as proposed by Jardine (9). This will be presented later.

Group Replacement of Items Subject to Failure

When the equipment replacement is required by the failure of the original unit or units having negligible salvage value the problem is one of determining whether it should be replaced individually or in group. The development of group replacement model needs to determine the optimal interval between group replacements for minimizing the total expected cost per unit time. The model developed for this problem is based on the assumption

i) the replacement policy is to perform group replacements at fixed interval of time

ii) with failure replacements occuring as necessary

The following scheme was developed by Jardine;

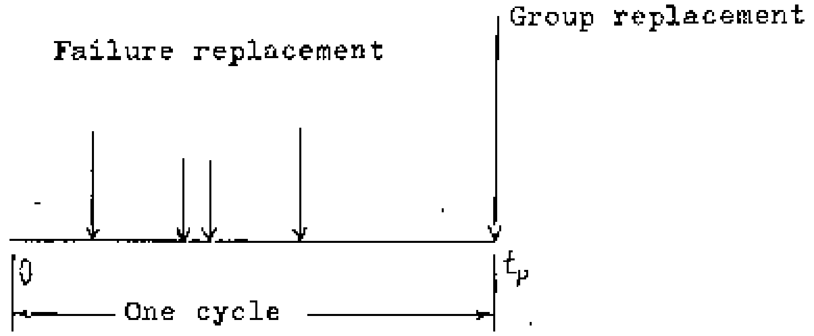
Let, C_g be the cost of replacing one item in group replacement

C_f be the failure replacement cost

$f(t)$ be the probability density function of the failure time of items

N be the total number of items in the group

The policy is illustrated below



The total expected replacement cost per unit time for group replacement at time t_p is given by the relation

$$C(t_p) = \frac{\text{Total expected cost in interval } (0, t_p)}{\text{Interval length}}$$

$$= \frac{\text{Cost of group replacement at time } t_p + \text{Expected cost of failure replacements in that interval}}{\text{Interval length}}$$

Thus, $$C(t_p) = \frac{NC_g + NH(t_p)\, C_f}{t_p} \qquad (4.7)$$

Eqn. (4.5) is used for group relacement problem relating replacement interval t_p to total cost.

To compare the model for determining optimal interval between preventive replacements of equipment subject to breakdown with the aforesaid model Jardine (9) developed a model assuming the performance of preventive replacements at constant intervals.

The total expected cost per unit time for preventive replacement at time, t_p, is

$$C(t_p) = \frac{\text{Total expected cost in interval } (0,\ t_p)}{\text{Length of interval}}$$

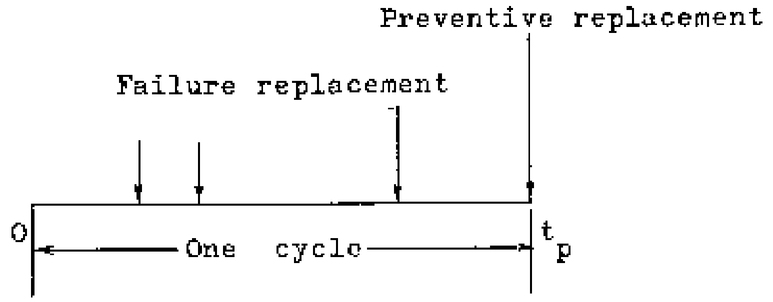
$$= \frac{\text{Cost of preventive replacement + Expected cost of failure replacements}}{\text{Length of interval}}$$

$$\text{Thus, } C(t_p) = \frac{C_p + C_f H(t_p)}{t_p} \qquad (4.8)$$

where, C_f = Cost of a failure replacement

$H(t_p)$ = Expected number of failure in interval $(0,\ t_p)$

C_p = Cost of preventive replacement



This is the model relating replacement interval t_p to total cost, $C(t_p)$.

The model for group replacement policy and that of service replacement policy have been discussed after Ackoff & Sasieni, Jardine, Fabricky and Churchman. In contrast of the above models the computational procedure of Sasieni, Yaspan & Friedman has now been summarised for general interest.

Computational Procedure for Age Replacement

Sasieni, Yaspan and Friedman presented a procedure for computing the economic life of a machine that assumes the purchase of only a single item. The present value of failure costs expressed as

$$P(n) = A + \sum_{i=1}^{n} C_i X^{i-1} \qquad (4.9)$$

where, $X = \frac{1}{1 + r}$

for periods of equal duration, $i = 1, 2, \ldots$, operating costs, $C_1, C_2, \ldots$, acquisition cost, A, and a replacement interval of n periods, annual rate of return on capital, r.

Since $P(n)$ increases as n increases, the company is considered to set up an annual amount y in the form of an annuity such that

$$P(n) = y + yX + yX^2 + \ldots + yX^{n-1} = \frac{y(1 - X^n)}{1 - X} \tag{4.10}$$

The optimal value of the replacement interval n is that which minimizes y, or which minimizes, $F_0(n)$

$$F_0(n) = \frac{P(n)(1 - X)}{1 - X^n}$$

$$F(n) = \frac{P(n)}{1 - X^n} \tag{4.11}$$

Since $1 - X$ is a constant. An iterative method is presented which yields the economic life based on the condition that $F(n)$ be a minimum,

$$\Delta F(n - 1) < 0 < \Delta F(n)$$

where, $\Delta F(n)$ is the difference operator,

$$\Delta F(n) = F(n+1) - F(n).$$

They have considered a number of illustrative replacement problems in industry and illustrated the procedure to determine the hiring policies in replacing Airline stewardesses, given the present age distribution and survival distribution.

4.3 PROPOSED METHODOLOGY

Assuming the distribution pattern as Weibull family of distributions the different parameters namely shape parameter, scale parameter & location parameter have been calculated. The probability density function for failure times and cumulative density function for the individual ward of the city are found out. The mean life and standard deviation are also determined. The probability of new bulbs that fail in successive weeks are computed. The number of replacement due to failure in successive weeks, under a policy of service replacement can be computed. The development of replacement policy for units that fail must be replaced by an analysis of failure data. The probability of a bulb failing within each time period can be calculated by

$$P(t) = \frac{N_{t-1} - N_t}{N_o} \tag{4.12}$$

where,

$P(t)$ = Probability of failure during the time period t

N_o = The initial number of units in the group

N_t = The number of survivors through time t

N_{t-1} = The number of survivors through time t-1

The probability that a bulb having survived to an age t-1, will fail during the interval t-1 to t can be calculated from

$$P_c(t) = \frac{N_{t-1} - N_t}{N_{t-1}} \tag{4.13}$$

The survival probability may be calculated from

$$P_s(t) = \frac{N_t}{N_o} \tag{4.14}$$

The assumptions taken to find the number of replacement per period are as follows:

a) The failures are detected only at the end of a time period

b) If failed items are replaced, the replaced items will evantually fail and must be replaced. These will also fail and require replacement, thus giving rise to the replacement of the replaced.

To compute the cost of individual replacement, the limit n tending to infinity of f_n and assuming that limit which is equal to f, the survivers f from the inserted f replacements for a long time are just replaced.

Then $(1 - P_o)f$ survivors from insertions at time t previously; $(1 - P_o - P_1)f$ survivors from time 2t ago; $(1 - P_o - P_1 - P_2)f$ from 3t ago, and so on. Because the survivors must total N, the number in the system,

$$\begin{aligned} N &= f\left[1 + (1 - P_o) + (1 - P_o - P_1) + (1 - P_o - P_1 - P_2) + \cdots\right] \\ &= f[P_o + P_1 + P_2 + \cdots \\ &\qquad + P_1 + P_2 + \cdots \\ &\qquad\qquad + P_2 + \cdots \\ &\qquad\qquad\qquad + \cdots \\ &\qquad\qquad\qquad .] \\ &= f\left[P_o + 2P_1 + 3P_2 + \cdots\right] \end{aligned} \tag{4.15}$$

The expression in brackets is the average life, assuming that the failures in the interval K_t to $(K+1)t$ occur at time $(K+1)t$.

The equation (4.15) is the all important equation based on which the proposed method of replacement policy has been developed. The eqn. (4.15) composed of three elements such as N, f and (P_o, P_1, P_2, ..., P_n). This equation when rearranged gives,

$$\frac{f}{N} = \frac{1}{(P_o+2P_1+3P_2+ \; . \; . \; . \; . \;)} \tag{4.16}$$

The ratio f/N at any specified period, t_n, gives an indication of some degree of 'measure of performance' of the system and it seems quite logical to assume. Thus in the present work, the level of performance is measured by using the following equation:

$$P_R = 1 - [\frac{f}{N}]_{t_n} \tag{4.17}$$

The numerical values of the term (P_o, P_1, P_2, ..., P_n) could be calculated from the cumulative Weibull distribution function, F(t) given by equation (4.2). Since the performance level depends on the values of (P_o, P_1, P_2, ..., P_n) a simulation procedure was adopted using the Weibull function. The time period, t, could be simulated by varying the number of service trips of replacement per week N_{t_p} . The original Weibull function was developed for normal replacement policy of 7 trips per week (i.e. one trip per day).

Thus the time period, t, is assumed to be of week. This time period, t, could be varied by varying N_{t_p} by using the following expression,

$$t = 7/N_{t_p} \qquad (4.18)$$

Thus for the existing policy, for $N_{t_p} = 7$, t becomes 1 week. In the present study N_{t_p} has been varied from 2 to 20.

Cost of Replacement for Various Performance Level

The average cost per period t, for individual replacement could be known from the following expression,

$$C(t) = \frac{NC_1}{\text{Average Life}} \qquad (4.19)$$

where, $C(t)$ = Average cost/period t

t = Age at replacement

C_1 = Cost of replacing an individual item.

But much benefit can not be derived from eqn.(4.19), when the total cost of replacement per year is to be determined at any specific level of performance. Thus a cost equation is developed and presented below.

Let, N be the total number of items in the system

N_1, N_2, N_3, N_4, be the number of items in zones 1, 2, 3, and 4 respectively

C be the annual cost

FC be the fuel cost

MC be the maintenance cost

C_T be the cost per trip

$C_{T_1}, C_{T_2}, C_{T_3}, C_{T_4}$ be the trip cost for zones 1, 2, 3, and 4 respectively

D_T be the total milage covered during the year

D_0 be the total road milage for the city lighting

$$C = \sum FC/_{Yr} + \sum MC/_{Yr} \tag{4.20}$$

$$\text{Average cost per mile} = \frac{\text{Annual Cost}}{\text{Total milage covered during the year}}$$

$$= \frac{C}{D_T} \tag{4.21}$$

$$\text{Trip cost, } C_T = \frac{C}{D_T} \times D_0 \tag{4.22}$$

Thus, cost of one complete trip of the entire lighting system of the city could be estimated by using equation (4.22). The immediate problem develops when one has to estimate the trip cost for a specific zone, say zone 1 consisting of N_1 light-bulbs. This is practically very difficult to ascertain the line-length in miles of the zone. Thus to resolve this problem, and in order to estimate the cost of one trip of the zone a fair-basis of apportionment has been used as follows:

For N number of light bulbs in the system,

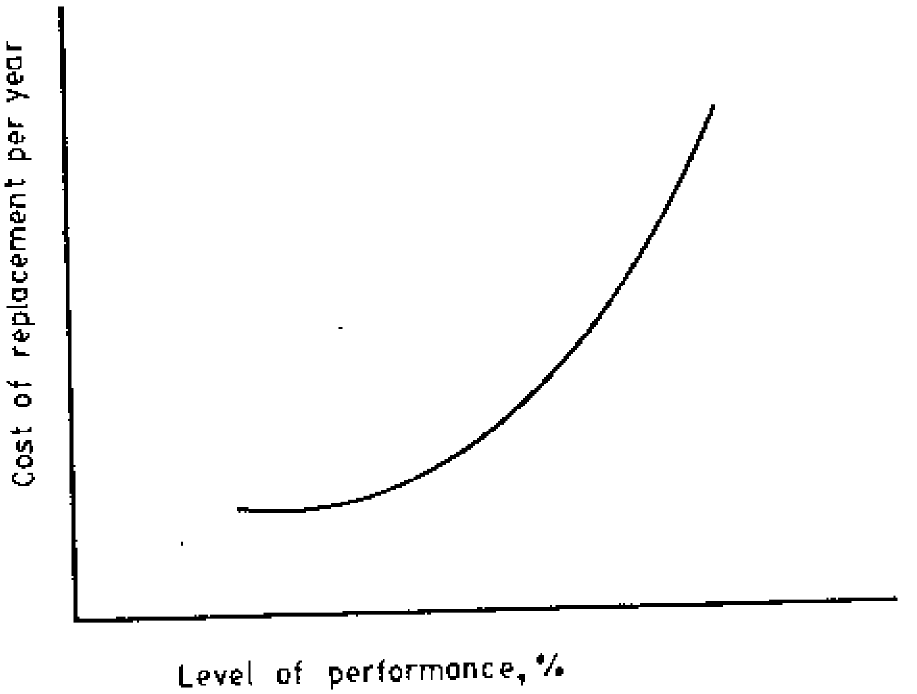
$$C_T = \frac{C}{D_T} \times D_O \quad \text{as given by eqn.(4.21)}$$

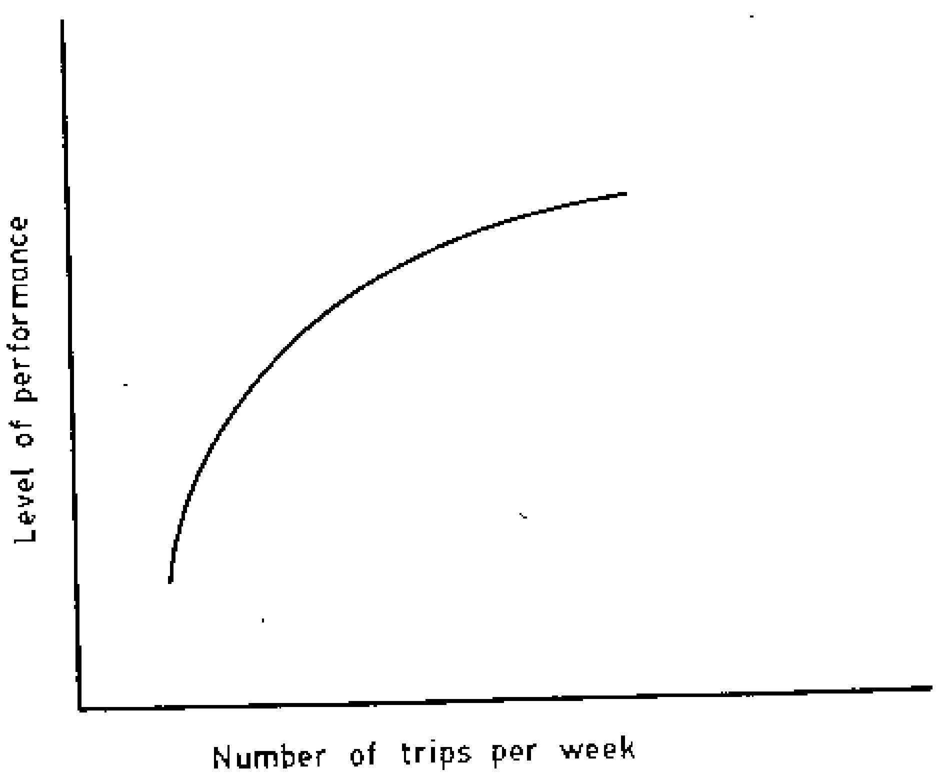
For N_1 number of light bulbs in zone 1, trip cost would be proportional such as,

$$C_{T_1} = \frac{C_T}{N} \times N_1$$

Similarly costs of single trips for other zones could be estimated.

The replacement policy of the light bulbs has definite influence on the performance level as defined in equation (4.17) and also on the cost of replacement. The performance eqn.(4.17) indicates that when f is decreased that is number of failures is decresed P_R would increase. This would be achieved by making more replacements in a period. Thus number of trips per week would require to be increased. This would increase cost of replacement. These hypotheses are depicted diagrammitically below.


Cost of replacement per year
Level of performance, %


Level of performance
Number of trips per week

CHAPTER 5

DATA COLLECTION AND ANALYSIS

In the preceeding chapter statistical models and procedures have been developed for the replacement of street light bulbs. These models are now developed using actual data obtained from the Corporation. In the present chapter, the inherent problems of data collection have been identified. The models were established by developing computer programmes in FORTRAN-IV language in an IBM 370/115 computer.

5.1 DATA COLLECTION AND ASSOCIATED PROBLEMS

Procedure for data collection should be such that the desired accuracy could be derived with loss of information kept at the lowest. At the same time there must be a clear understanding of the objectives and the requirements.

The raw data comes primarily from the following sources:

(i) Copies of standard operational maintenance or supply forms as used by the system operatives

(ii) Special data forms originated by the study group for a specific requirement for a specific period

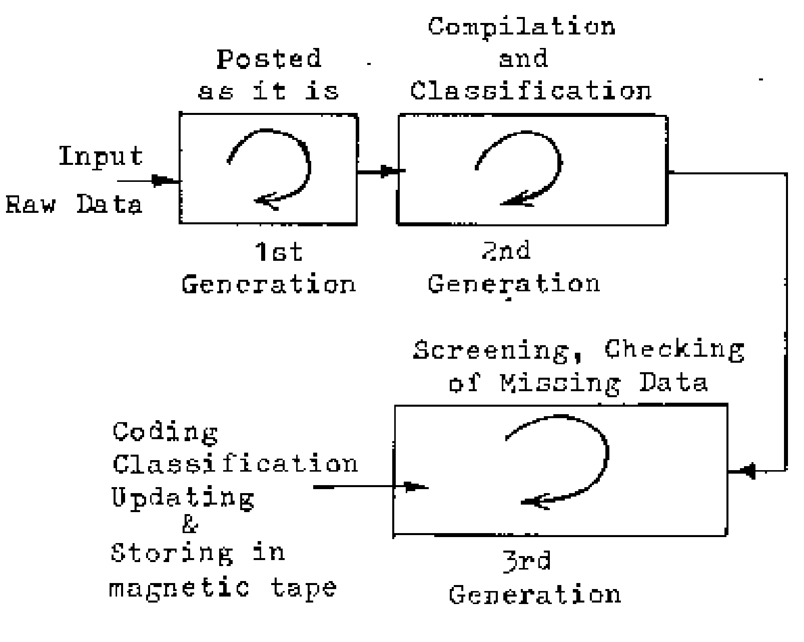
(iii) Direct data generation by instrumentation measurement, experimentation etc..

The basic means of collecting data are the study of procedures, manual evaluation of forms and interviewing of departmental representatives. The departmental employees can provide useful information in most cases. These objectives and requirements of each system are clearly and concisely stated in a procedures manual.

The data sources as mentioned above could now be catagorised into two broad classifications namely, generation of primary data and collection of data in secondary form.

In the present study data have been collected from the field records as maintained by the supervisors. These files maintain records of failure statistics of street light bulbs. The data recorded by him is of the first generation type where only the first hand records are put in the 'log book'.

The process of data collection could be depicted in a figure below:



Thus it could be observed that data could be available in any of these gereration levels as mentioned above such as (i) First generation (ii) Second generation and (iii) Third generation.

In the first generation the raw data are posted in files as obtained from the field. The file is however continuously updated. This data could be arranged sequentially, when the data are compiled according to requirement, also they are scrutinized, classified etc. to some degree and transferred to a permanent record file. These could be designated as Second generation data. Recent developments in computer technology have made possible to store massive quantity of data economically, cheaply and conveniently. In this generation the data are screened and missing data are checked. Here input data could be coded which makes it possible for easy searching and retrieval.

Problem of data collection in developing countries

The problems encountered in data collection in a developing country could be mentioned as follows:

(i) The source of data is available in its raw form, unprocessed and uncompiled. In most cases these are available in first generation form with few exceptions of second generation. Proper data storage system is absent and filing of data is processed very unwisely and unscientifically.

(ii) It is difficult to retrieve data from these records at the right time.

(iii) The records are kept unscientifically and not properly maintained. Thus missing data is not uncommon.

(iv) Relevant data could not be available at right time and needs to be extracted from a large volume of disorganised documents, log book and ledgers, etc.

(v) Documentation Centre and Data Processing Centre are seldomly found. Data Organisation and Data Management are the two vitally important activities in data handling. In most cases these are absent. Thus collection of data become extremely difficult.

The fact occasionally confronted by researcher is that the desired data are not available and that reliable data cannot be obtained because relevant records have not been kept.

5.1.1 DATA COLLECTION FOR THE PRESENT STUDY

The failure history has been collected daywise for a full year and then tabulated weekwise. Blank forms were designed for the present work. Sample of one particular month's data for a particular ward is given below (table 5a).

Table 5a   Sample data for a ward.

For the month of January 1982

Ward No.	Total No. of bulbs	Total No. of Bulbs replaced	No. of bulbs replaced			
			1st week	2nd week	3rd week	4th week
2	489	93	30	22	26	15

The entire data collection process could be devided into three parts. The first part which is already accomplished above. In the second part of the data collection, the cost figures were obtained from various sources of the Municipal Corporation namely, Electrical Division, Maintenance Division, Transport Sections etc. The cost of light bulbs, maintenance and repair costs of vehicles used for the elements. The fixed costs and storing cost of the materials were not considered. The item cost is estimated to be Taka 72.00 at 1982 price.

The maintenance and repair costs of vehicles were collected from the mechanical workshop, situated at Aga Sadek Road, Dhaka. Fuel and Lubricating costs are supplied by the transport section of the same authority. All the costs are found out vehicle- wise for the whole year; these are shown in table 5b.

Table 5b Fuel and Maintenance costs of vehicles

For the year 1982 (January-December)

Description of Vehicles	Fuel Consumption (Gallons)	Fuel Cost (Taka)	Maint. & Repair Cost in Taka	Total Millage covered
Hydraulic Ladder 4688	1448	41,583.40	34,830.00	28375
" 4689	1395	40,145.48	8,150.00	19324
" 4690	1693	49,375.87	1,290.00	25023
" 4691	1561	45,346.35	-	22644
" 4692	1015	31,062.15	1,290.00	15150
" 1208	249	7,880.44	80,414.00	2988
" 313	221	6,966.73	100,466.00	2523
Truck 4000	982	31,507.13	370.00	16573
" 2374	350	8,512.00	2,991.00	5697
Jeep 2753	735	20,621.65	16,802.00	13520
" 5850	874	25,100.71	-	17415
Total=	10523	3,08,101.91	246,615.00	169232

In the third part actual failure characteristics of light bulbs were investigated. For this purpose a test-line was selected. This test-line was located close to the University campus (near Bakshi Bazar Area). There were ten light points on the line. The line was under continuous monitor so that any replacement of a light bulb was recorded. In addition both the dates of installation of a light bulb and its date of replacement were recorded, so that actual life of the light bulb could be ascertained. The monitoring and data collection on the test-line were done for a period of 6 (six) months. The field data of the test-line is given below:

Table 5.1 Field data for ten tube lights in a test line

Bulb Point	Date of Installation	Date of 1st replacement	Calculated life, days	Date of 2nd replacement	Calculated life, days
1	09.03.83	27.03.83	18	12.09.83	168
2	09.03.83	11.06.83	94	Contd.	-
3	09.03.83	05.05.83	58	10.09.83	127
4	09.03.83	30.03.83	21	01.08.83	123
5	09.03.83	02.07.83	115	Contd.	-
6	09.03.83	24.07.83	137	Contd.	-
7	09.03.83	02.08.83	146	Contd.	-
8	09.03.83	28.05.83	70	06.08.83	69
9	09.03.83	11.04.83	32	10.09.83	150
10	09.03.83	27.04.83	48	12.07.83	76

From the above data it is observed that the actual life of a bulb is widely varied. The bulb at point No. 1 was alive for 18 days only which was fallen in the stormy and inclement weather period of the year. In the same point the second replacement took 168 days. The average life of the bulbs in the test-line was 91 days which is significantly higher than that found for the total system. From the findings of the above test line it may be concluded that unplanned and mismanaged replacement process is prevailing.

The fluctuations of the lives of the bulbs are shown in figure below:

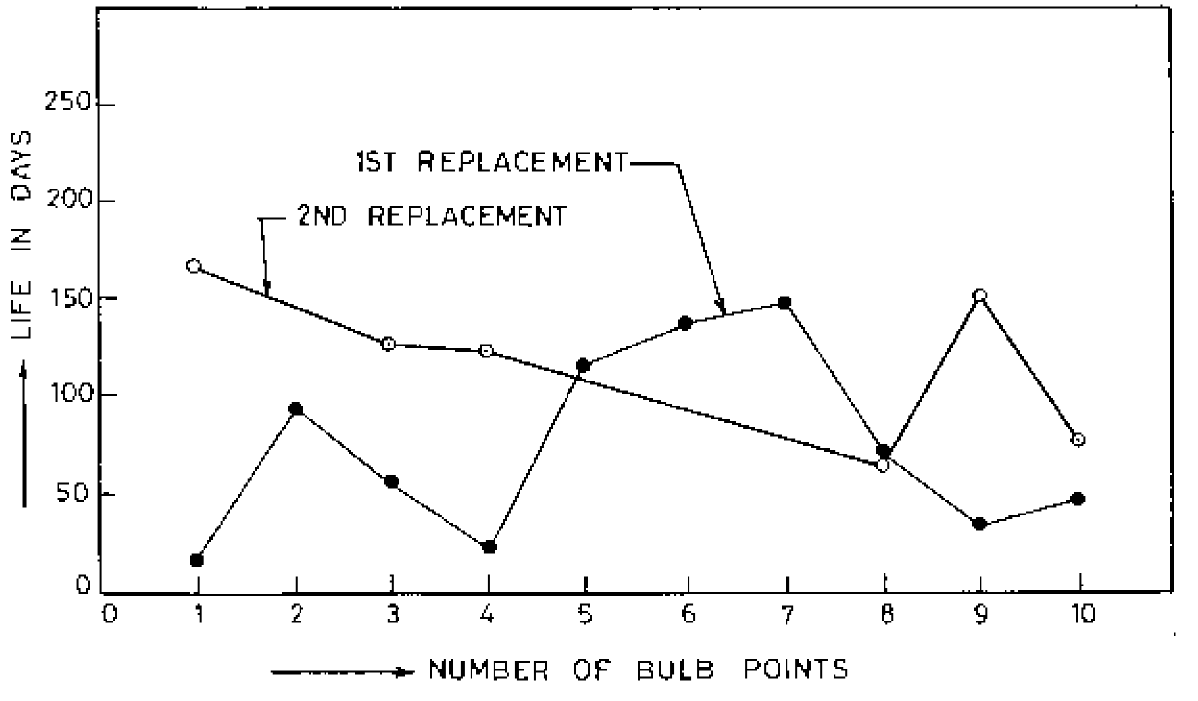


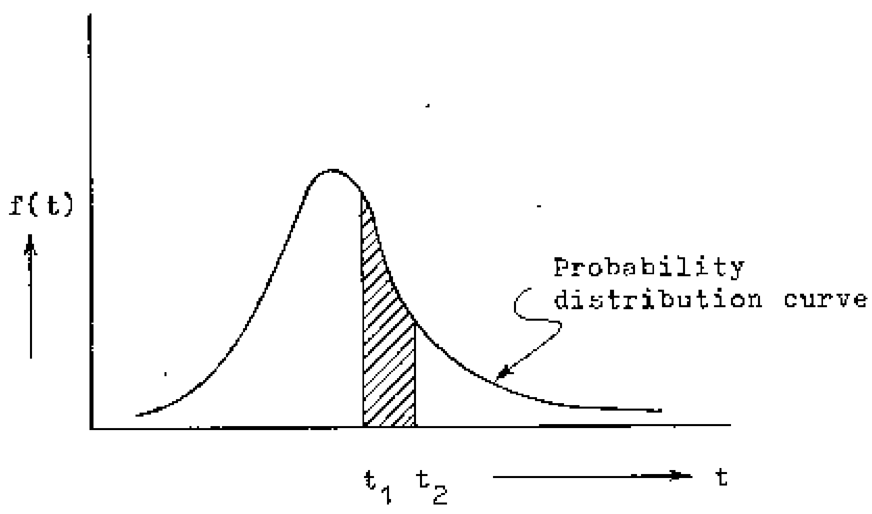
FIG. 5a FLUCTUATIONS OF LIVES OF THE BULBS IN TEST LINE

5.2 ANALYSIS OF DATA

The data were compiled and organized and transferred in computer coding sheets. These were organised wardwise for each week. The use of these data for the various models discussed in the preceeding chapter are now presented.

Failure characteristics of light bulbs

The ward-wise failure characteristics of light bulbs have been determined. This is accomplished by using data of the 'failures' and the 'suspensions' of light bulbs for each ward. The failure characteristics could now be determined as follows . From the figure given below the probability of failure of a light bulb in a specific period, t, could be explained.



The probability of failure of a light bulb between time t_1 and t_2 could be ascertained from this figure. This is given by the shaded area under the curve which is defined by a function, f(t), called the probability density function. Cumulative probability, F(t) , where $F(t_2 - t_1 = t)$ is obtained by usual integration of p.d.f. , f(t), within limits t_1 and t_2. This is equivalent to the shaded area under the curve. The p.d.f. was assumed to be a Weibull function. The scheme of transforming the failure data to Weibull probabilities is given by

$$\text{Probability of failure,} \quad FR = \frac{FO}{FO + SO}$$

Where,

FO = No. of bulbs failed in a specific week

SO = No. of bulbs in suspension (active)

Computer solution of determining the Weibull probability function is now presented.

5.2.1 DATA SPECIFICATIONS, COMPUTER PROGRAM

The input data for finding the expected number of failures are as follows:

(i) Number of class intervals for which raw data are taken

(ii) Number of wards

(iii) Number of failures in each class

(iv) Number of suspensions in each class

The input form for this case is shown in table 5.2.

Table 5.2 INPUT FORMS FOR WEIBULL ANALYSIS

Problem Name :

Class Interval :

Number of Class :

Failure and Suspension Frequencies :

Class	Failures	Suspensions
1	xxx	xxx
2	xxx	xxx
3	xxx	xxx
4	xxx	xxx
.	...	...
.	...	...
.	...	...

Mention has been made that a least square method has been used to establish the Weibull parameters. Thus a computer program, specifications of which are given below, has been developed in FORTRAN IV language.

Programme Parameter Specifications

SUBROUTINE ZK_3	a subprogramme for Weibull analysis and prints shape, scale and location parameters, failure probabilities, cumulative distribution functions, failure characteristics, and also calculates hazard rates, reliability probabilities, and the truncated mean life for each class interval.
SUBROUTINE ZK_4	a subprogramme which analyses raw data to give a cumulative density function (c.d.f.)
FUNCTION YY	a function subprogramme which evaluates the gamma function.
AI	represents the numerical number of the individual ward.
B	represents the shape parameter of the fitted Weibull distribution.
B_1	an array containing the suspension and failure items of zones.
BF	an array representing the Weibull c.d.f.
C	a constant term of the least squares equation used for the estimation of Weibull parameters.

CFR	a cumulative hazard rate calculated from the basis of raw data.
CR	represents a correlation coefficient when fitting a least squares equation for finding the Weibull parameters.
CRL	an array storing truncated mean lives for various class intervals.
CUPER	an array storing c.d.f's calculated on the basis of raw data.
EX	an array containing the values of the arguments of the exponential function in the calculation of BF.
ETA	represents the scale parameter of the fitted Weibull distribution.
F	an array containing the p.d.f's of the fitted Weibull distribution.
FM	an array giving the average of the survivals at the begining and the survivals at the end of each class interval.
FMT	the mean of the failure time distrinution (Weibull)
FO	an array containing failure frequencies for each class interval.

FR	an array representing instantenous hazard rates calculated on the basis of raw data.
G	a variable which enables summation in finding the expected number of failures within a given period and gives a renewal analysis results based on the fitted Weibull distribution in tabular form.
GAMA	a location parameter to the Weibull distribution.
H	an array storing the expected number of failures for given periods.
IGAMA	an integer variable calculated from its GAMA value to set the minimum value of a loop index variable as appropriate.
N	Number of class intervals for which raw data are taken.
NGAM	an integer depending on the value of IGAMA.
NPP	represents N + 3
NWARD	represents the number of wards from which raw data are taken.

NZ	represents the number of zones.
SB, SE	represent the number of survival at the begining and the end of each class interval, respectively.
SD	denotes the standard deviation of the fitted Weibull distribution.
SH	represents the derivative of H.
SO	an array containing the suspension frequencies for each class of interval.
T	a dummy variable used in the function subprogramme YY.
TEMP	a dummy variable used in the subroutine ZK_4.
WFR	an array storing the values of the Weibull failure rates for each class interval.
X, Y	represent the transformed data in the least squares analysis.
SX, SXSQ, SXY SY, SYSQ	variables which enable the summation of X & Y in the least squares analysis.
I, II, IJ, IN, J, JI, JJ, K, KI, KJ, KK, KM, L, LI, LJ, LL, M	loop index variables.

Output Specifications

The output from the PROGRAM contains:

(i) A print out of the input data as a check including a tabulated summary.

(ii) A hazard analysis in tabular form based on raw data.

(iii) The Weibull distribution parameters.

(iv) Cumulative failure density function.

(v) Probability density function for failure times.

(vi) The renewal analysis based on the fitted Weibull distribution which contains survival probability, truncated mean life and cumulative renewals for each class intervals.

The listing of the program is given in Appendix I.

5.2.2 OUTPUT AND RESULTS

The computer output for a particular ward has been shown in page No. 102, 103 & 104 and consolidated results of all the wards are also given (Table 5.3).

The Weibull parameters namely shape, scale and location, mean life and standard deviation have been calculated ward-wise. The formulae used for mean life and standard deviation are

$$\text{Mean, } \mu = \gamma + \eta \cdot \Gamma(1 + \frac{1}{\beta})$$

$$\text{Standard Deviation, } \sigma = \sqrt{\eta^2 \left[\Gamma(1 + \frac{2}{\beta}) - \left\{ \Gamma(1 + \frac{1}{\beta}) \right\}^2 \right]}$$

for the probability analysis based on raw data.

The gamma function is evaluated from the following formula

$$\Gamma(n) = n^n e^{-n} \sqrt{\left\{ \frac{2\pi}{n} (1 + \frac{1}{12n} + \frac{1}{288n^2}) \right\}}$$

for large values of n. For values of n greater than 1, it gives accurate result of gamma function.

The failure characteristics and statistics of the different wards were determined by INPUTing 40 sets of data. For comparison purpose of the failure patterns, the parameters are summarised in table 5.3. It is found that the shape parameters of ward No. 6, 13, 20 & 25 are very small thus the distribution could be explained as hyper exponential in nature measuring that no efficient replacement method is in operation. Some of the wards, such as ward No. 4, 5, 8, 9, 10, 11, 14,18,22,24,26,28,29,30,31,32,33,34,37,39 with the values of the shape parameter close to unity, the distribution patterns could be explained as exponential. But ward No. 23,27,35 and 38 have their β -values more than unity.

The free failure time (γ) is zero, thus the two-parameter Weibull distribution used. The mean life varies from 12.02 to 88.77 and standard deviation ranges from 15.38 to 69.88 with the exception of two exceptional wards with very low β -values. Most of the β - values are found approximately close to 1 indicating exponential distribution.

From the above discussion, it has become clearer that the two concepts of replacement such as (i) Replacement policy for each division and (ii) Replacement policy for each ward could not be of any use to the management. Firstly, for division-wise replacement various wards are grouped with dissimilar failure patterns, thus a single replacement policy would not be effective. Secondly, for ward-wise replacement, forty various replacement policies could require to be adopted. This is not a practical proposition. Thus the existing 'division' and 'ward' concepts of replacement are not acceptable. Accordingly a new 'zone' concept as introduced in chapter 4 is now developed in the following article.

Table 5.3

Characteristics and statistics of wards

Ward No.	FO	N	β	η	μ	σ
1	344	116	0.57	7.47	12.02	22.48
2	871	489	0.89	26.44	28.08	31.75
3	792	795	0.88	50.08	53.34	60.66
4	634	441	1.02	31.27	31.02	30.41
5	790	470	1.02	27.87	27.60	26.93
6	806	270	0.20	10.82	1375.95	22282.98
7	955	824	0.91	40.86	42.68	46.82
8	711	596	1.00	38.44	38.46	38.45
9	465	263	1.02	25.56	25.31	24.68
10	2362	4200	0.95	86.74	88.77	93.96
11	245	116	0.95	20.46	20.90	21.91
12	697	360	1.06	24.23	23.65	22.21
13	170	53	0.41	7.20	22.66	68.85
14	488	328	0.95	31.54	32.23	33.79
15	550	396	0.91	34.53	36.16	39.82
16	972	690	1.05	32.44	31.81	30.24
17	394	282	0.88	33.02	35.23	40.19
18	608	493	0.94	37.13	38.25	40.79
19	613	399	1.05	28.83	28.24	26.78
20	490	130	0.30	4.15	40.11	221.26

Table 5.3 (continued)

Ward No.	FO	N	β	η	μ	σ
21	681	265	1.05	16.49	16.17	15.38
22	716	405	0.86	26.06	28.18	32.91
23	1000	610	1.19	26.73	25.19	21.17
24	538	383	0.94	33.20	34.13	36.26
25	1244	385	0.22	7.89	462.39	5546.93
26	2774	3505	0.93	63.21	65.25	96.88
27	3007	3848	1.12	57.59	55.32	48.58
28	913	997	1.00	53.01	53.14	53.37
29	1216	913	1.02	36.38	36.06	35.26
30	1178	997	0.93	42.18	43.72	47.21
31	1132	1298	0.94	59.44	61.22	65.27
32	1151	696	0.97	29.35	29.78	30.77
33	986	590	0.94	28.11	28.97	30.91
34	1314	795	0.84	26.29	28.76	34.26
35	1184	1282	1.13	49.43	47.25	41.70
36	1414	1126	0.73	36.91	45.09	63.05
37	1262	782	0.84	29.19	32.09	38.56
38	1096	1044	1.20	41.73	39.25	32.77
39	1504	763	0.92	22.94	23.86	25.44
40	685	539	1.03	40.18	39.77	38.73

5.3 ESTABLISHMENT OF ZONES FOR THE LIGHTING SYSTEM OF THE CITY

Mention has been made that the whole lighting system of the Dhaka city is under the jurisdiction of two electrical divisions under the Corporation. These two divisions were created on the basis of administrative point of view. The logical approach should be to divide the division on the basis of similarity of failure patterns rather than administrative case. Thus some basis and criteria were sought for the proposed new division(s). There are statistical methods such as Discriminant Analysis Method and Cluster Analysis Method for the purpose and these methods would perhaps be appropriate in the current application. Unfortunately, no computer library package were available to the author from any source, thereby the author has to resort to the following heuristic approach. The Weibull parameters such as shape and scale were considered to be the important and influential parameters which control the pattern and shape of the Weibull curve. Thus, the zoning process was accomplished based on these parameters.

Confidence intervals of shape parameter

Confidence intervals on the shape parameter, β must be evaluated since decisions may be based upon this value. Figure 5b gives factors F_β against same size n for different S - confidence levels (99%, 95%, 90%) on β.

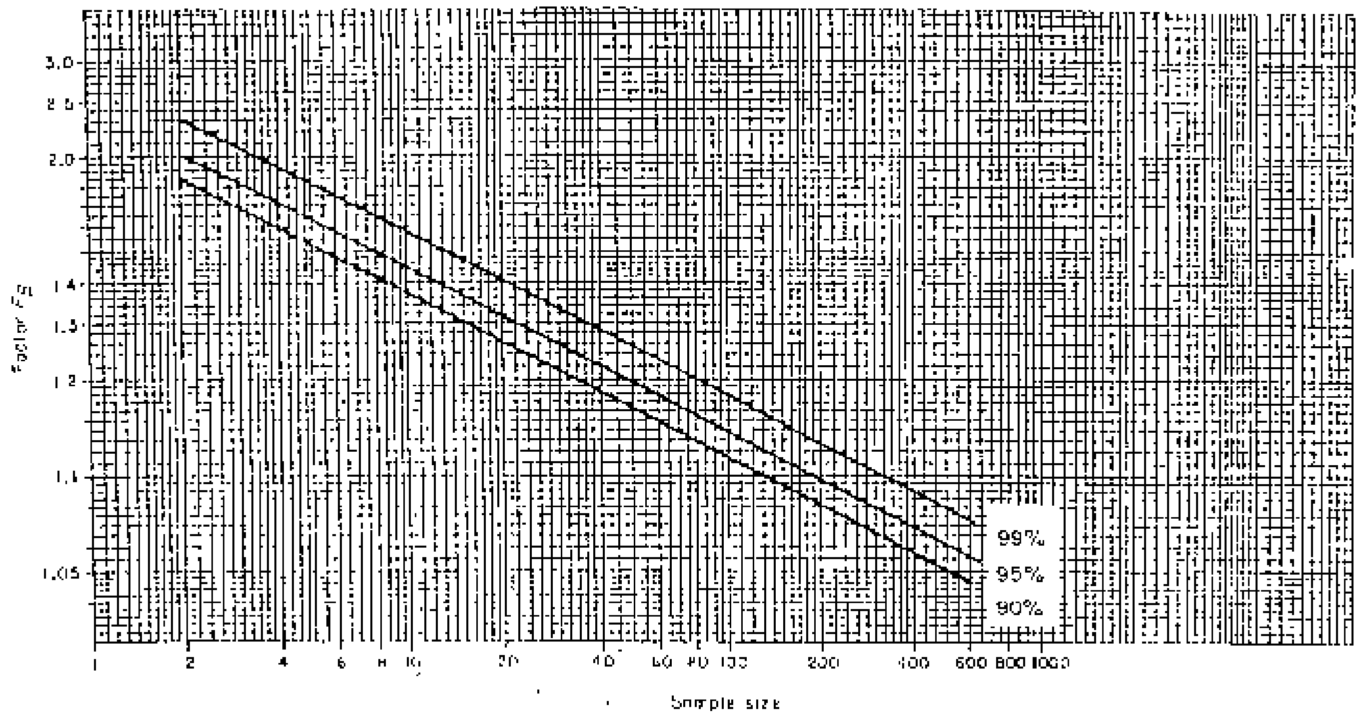


Figure 5b. Confidence limits for shape parameter β for different confidence values

The upper and lower S - confidence limits are then

$$\beta_u = \hat{\beta} F_\beta \quad \text{and} \quad \beta_1 = \hat{\beta} \frac{1}{F_\beta}$$

which is rearranged in the form

$$\frac{\beta}{F_\beta} \leq \hat{\beta} \leq \beta F_\beta \quad .$$

It has been observed that the β has an expected value of 1.0 considering the forty wards together, explaining that failure probability distribution is negative exponential. The factor F_β for (n=40 and PR = 90%) was found from fig. 5a to be 1.18; thus the confidence intervals are

$$0.84 \leq \beta \leq 1.18 \quad .$$

From the above interval limits, the wards could be classified into three main groups as follows:

i) Wards with β -values are less than 0.84

ii) Wards with β -values between 0.84 and 1.18

iii) Wards with β -values higher than 1.18

But group (ii) is further broken into following two groups as bulk of wards fall under this group.

a) Wards with β -values between 0.84 and 1.0

and b) Wards with β -values between 1.0 and 1.18

Thus the four groups emerged are given below:

5.3.1 COMPUTER OUTPUT AND RESULTS FOR THE ZONES

The original data bank for FO, SO for the wards were used for the program as developed in art. 5.2.1. But the program has slightly been modified tailored to the requirement of the zones. This modification was necessary so that it could generate a set of new arrays FO, and SO for the individual zones as follows:

i) The program will search for the relevant wards of the zone in the master file.

ii) The FO and SO arrays for the wards found in (i) above were cumulated and new arrays of FO and SO were generated for the zones.

The output from the computer for one such zone, for example, is given in pages 79,80,81 and consolidated output are shown in table 5.5.

Table 5.5 Derived Weibull parameters for failure distribution zonewise

Zone	β	η	μ	σ
I	0.88	20.80	22.13	25.12
II	0.91	44.89	46.97	51.68
III	1.04	41.53	40.84	39.14
IV	1.18	35.15	33.21	28.18

Group I	$\beta \leq 0.84$
Group II	$0.8 < \beta \leq 1.0$
Group III	$1.0 < \beta \leq 1.18$
Group IV	$\beta > 1.18$

The ward-wise distribution of the above groups termed as zone I, zone II, zone III and zone IV are shown in table 5.4.

Table 5.4 VARIOUS WARDS FALLING UNDER THE ZONES

Zone	β - value	Wards
I	Less than 0.84	1, 6, 13, 20, 25, 36
II	0.84 to 1.0	2, 3, 7, 10, 11, 15, 16, 17, 18, 22, 24, 26, 30, 31,32,33,34,37,39
III	1.0 to 1.18	4, 5, 8, 9, 12, 14, 19, 21, 27, 28, 29, 35, 40
IV	Greater than 1.18	23, 38

The other factor namely scale parameter, η was not considered since suitable method was not available to find the confidence limits for this parameter.

ZONE NUMBER# 4

TABULATED DATA SUMMARY

CLASS	FAILURES	SUSPENSIONS
1	30	1624
2	37	1617
3	31	1623
4	42	1612
5	27	1627
6	31	1623
7	29	1625
8	27	1627
9	34	1620
10	37	1617
11	39	1615
12	43	1611
13	38	1616
14	49	1605
15	43	1611
16	44	1610
17	42	1612
18	43	1611
19	34	1620
20	45	1609
21	45	1609
22	42	1612
23	49	1605
24	48	1606
25	48	1606
26	38	1616
27	42	1612
28	48	1606
29	62	1592
30	64	1590
31	66	1588
32	69	1585
33	61	1593
34	51	1603
35	47	1607
36	43	1611
37	58	1596
38	46	1608
39	49	1605
40	57	1597
41	40	1614
42	36	1618
43	41	1613
44	45	1605
45	29	1625
46	28	1626
47	37	1617
48	39	1615

WEIBULL DISTRIBUTION PARAMETERS

SHAPE PARAMETER= 1.18
SCALE PARAMETER= 25.15
LOCATION PARAMETER= 0.0
MEAN LIFE= 23.21
STANDARD DEVIATION= 20.18

CUMULATIVE FAILURE DENSITY FUNCTION

0.01	0.03	0.05	0.07	0.09	0.12	0.14	0.16	0.18	0.20	0.22	0.24	0.27	0.29	0.31	0.33	0.35
0.42	0.44	0.45	0.47	0.49	0.50	0.52	0.53	0.55	0.56	0.58	0.59	0.60	0.62	0.63	0.64	0.6
0.70	0.71	0.72	0.73	0.74	0.75	0.76	0.76	0.77	0.78	0.79	0.80	0.80	0.81	0.82	0.82	0.83
0.85	0.86	0.86	0.87	0.87	0.88	0.88	0.89	0.89	0.90	0.90	0.90	0.91	0.91	0.91	0.92	0.92
0.93	0.93	0.94	0.94	0.94	0.94	0.95	0.95	0.95	0.95	0.95	0.96	0.96	0.96	0.96	0.96	0.96

PROBABILITY DENSITY FUNCTION FOR FAILURE TIMES

0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

RENEWAL ANALYSIS BASED ON THE FITTED WEIBULL DISTRIBUTION

CLASS	SURVIVAL PROBABILITY	TRUNCATED MEAN LIFE	CUMULATIVE RENEWALS
1	0.985	0.993	0.015
2	0.967	1.969	0.033
3	0.947	2.925	0.054
4	0.926	3.862	0.075
5	0.905	4.776	0.098
6	0.884	5.672	0.121
7	0.862	6.545	0.145
8	0.840	7.396	0.170
9	0.819	8.226	0.195
10	0.797	9.034	0.220
11	0.776	9.821	0.245
12	0.755	10.585	0.271
13	0.734	11.331	0.298
14	0.714	12.055	0.324
15	0.694	12.759	0.351
16	0.674	13.443	0.378
17	0.655	14.108	0.405
18	0.635	14.753	0.432
19	0.617	15.379	0.460
20	0.598	15.986	0.488
21	0.580	16.576	0.516
22	0.563	17.147	0.543
23	0.546	17.702	0.571
24	0.529	18.239	0.599
25	0.512	18.759	0.628
26	0.496	19.264	0.656
27	0.481	19.753	0.684
28	0.466	20.226	0.713
29	0.451	20.684	0.741
30	0.436	21.128	0.770
31	0.422	21.557	0.799
32	0.409	21.973	0.828
33	0.395	22.374	0.856
34	0.382	22.763	0.885
35	0.370	23.139	0.914
36	0.357	23.503	0.943
37	0.346	23.854	0.972
38	0.334	24.194	1.001
39	0.323	24.523	1.030
40	0.312	24.840	1.060
41	0.301	25.147	1.089
42	0.291	25.443	1.118
43	0.281	25.729	1.147
44	0.271	26.005	1.177
45	0.262	26.272	1.206
46	0.253	26.529	1.235
47	0.244	26.776	1.264
48	0.236	27.016	1.294

PROBABILITY ANALYSIS BASED ON RAW DATA

CLASS	PROB OF FAILURE	CUM. PROB OF FAILURE
1	0.018	0.018
2	0.022	0.040
3	0.018	0.058
4	0.024	0.082
5	0.015	0.097
6	0.017	0.114
7	0.015	0.129
8	0.014	0.143
9	0.018	0.161
10	0.019	0.180
11	0.019	0.199
12	0.022	0.221
13	0.019	0.240
14	0.025	0.264
15	0.020	0.283
16	0.022	0.305
17	0.019	0.324
18	0.019	0.343
19	0.013	0.356
20	0.019	0.375
21	0.019	0.394
22	0.017	0.410
23	0.020	0.431
24	0.019	0.450
25	0.018	0.468
26	0.012	0.480
27	0.014	0.494
28	0.017	0.511
29	0.025	0.537
30	0.026	0.562
31	0.025	0.588
32	0.039	0.627
33	0.021	0.648
34	0.014	0.661
35	0.011	0.672
36	0.009	0.680
37	0.017	0.696
38	0.010	0.707
39	0.011	0.718
40	0.015	0.733
41	0.004	0.737
42	0.001	0.739
43	0.004	0.743
44	0.009	0.752
45	0.0	0.752
46	0.0	0.752
47	0.002	0.753
48	0.003	0.756

It is observed that the value of shape parameter of the Weibull function for the zones ranges from 0.88 to 1.18. The β-value for zone-1 is the minimum (β = .88) which indicates that the bulbs in this zone have failed earlier before they could attain their average lives. So this zone should be critically looked into for the possible causes of these early failures and thereby steps should be taken to alleviate this situation. In the other zones the failure distributions would approximate to negative exponential thus the failure behaviours in terms of failure times are random.

For the improvement of the situation steps may be taken to ensure that supply of quality materials required for the system in terms of starters, chokes, light bulbs etc. is to be maintained. This will also require that optimum quantity of the materials are to be available at right time and properly kept in store.

5.4 DEVELOPMENT OF CHARACTERISTIC CURVES

It was the objective of the present work to establish a relation between annual cost of replacement (variable costs) and percentage level of performance and hence frequency of service trips per period (week) was ascertained. The replacement policy would then be, determination of the number of service trips per week throughout the year for a desired level of performance. This could be achieved by generating characteristic curves such as:

i) Annual cost of replacement vs. percentage level of performance

ii) Percentage level of performance vs. frequency of service trips per week.

Referring to the model earlier discussed in order to calculate the various parameters such as average failures, total failures per year and various service periods (by simulation) are introduced in the scheme of the computer program as follows:

The probability of failure for a period, t, has been determined by using

$$P_t = -\left(\frac{t}{\mu}\right)^{\beta} \quad \text{and}$$

then cumulative probability of failure, F(t), could be calculated as

$$F(t) = -e^{P_t} + 1.0 \qquad \ldots\ldots\ldots \qquad (5.1)$$

Using equation (5.1) probability for any time period, T, could be found out as P(T)

$$P(T) = F(T) - F(T - 1)$$

Average life in weeks of the items has been calculated as,

$$SX = \sum_{T=1}^{T=n} P(T).T$$

where, n = No. of weeks of the year.

The average failures FX could be calculated from

$$FX = \frac{X}{SX}$$

where, X = Number of bulb points.

FX = Average number of failures.

The level of performance, PR, was then found out using

$$PR = \frac{FS}{X} \times 100 \qquad \ldots\ldots\ldots\ldots \qquad (5.2)$$

where, FS = X − FX

The total number of failures in a year could be estimated using eqn. 4.3 in chapter 4.

Finally the cost of replacement per year was calculated by using the following cost equation.

Cost of replacement/$_{Yr}$,

CR = Total No. of failures x item cost + No. of trips/yr x cost/trip x No. of weeks ...(5.3)

The average cost per mile, C, could be calculated by equations (4.20) and (4.21). The average trip cost for any zone i, $CT_i = C \times D_i$ ....(5.4)

where, D_i = Total road milage for zone i.

Trip costs have been calculated for each zone using the equations (4.21) and (5.4). The calculation of the trip cost for zone-I has been shown below, for example.

The basic data are obtained as

Item	Value
Total road milage, D_o	450 miles
Total number of bulb points, N	32916
Number of bulbs in zone-I, N_1	2080
Annual Fuel cost, FC	Tk. 3,16,101.90
Annual Maintenance cost, MC	Tk. 2,46,615.00
Total milage covered (Annual), D_T	169232 miles

Now, $D_1 = \frac{D_o}{N} \times N_1$

where, D_1 = estimated milage for zone-I

D_1 is estimated as follows:

$$D_1 = \frac{450}{32916} \times 2080$$

$$= 28.436 \text{ miles}$$

And $C = \frac{FC + MC}{D_T}$

$$= \frac{316101.90 + 246615.00}{169232}$$

$$= 3.325 \text{ Tk/Mile}$$

Thus, trip cost for zone-I,

$$CT_1 = C \times D_1$$

$$= 3.325 \times 28.436$$

$$= 94.5497$$

$$= 94.55 \text{ Taka.}$$

Similarly for the other zones trip costs were calculated as shown below:

Zone	Total No. of bulb points	Trip cost* (Tk.)
I	2080	94.55
II	18137	824.47
III	11045	502.04
IV	1654	75.19

* All costs are at 1982 prices.

5.4.1 DATA SPECIFICATIONS, COMPUTER PROGRAM

The input data for performance and cost analysis for each zone contains:

i) Number of zones in the system

ii) Number of wards for each zone

iii) Number of estimated trips for finding the cost of replacement per year and performance

iv) Cost of individual item

v) Trip cost for each zone

vi) The Weibull distribution parameters for each zone

vii) Number of bulbs in each zone.

Program Parameter Specifications

BETA	represents shape parameter fitted to Weibull distribution
$COST_1$	denotes cost of item bulbs
$COST_2$	indicates the cost of one trip to find the cost of replacement per year
ETA	represents scale parameter fitted to Weibull distribution
F	represents the probability of failure during period
FK	the total number of fails per year
FS	represents average survivals
FX	represents average failure
NT	denotes number of bulb points in the zone.
NW	represents number of weeks per year.
NZ	the number of zones.
PF	denotes the level of performance, %
SX	represents average life in weeks
T	represents the period or replacement
TRP	the number of trips per week
XTP	a dummy variable used for finding the cost of replacement

The mathematical hieuristic procedure developed earlier was then converted to a computer program in FORTRAN IV language. The format specifications for inputs have been given in free format.

5.4.2 OUTPUT SPECIFICATIONS

The output of this program contains:

i) A print out of the input trips and Weibull parameters along with the total number of points for each zone.

ii) Tabulated results based on the fitted Weibull distribution and input data containing period of replacement, total number of failures per year, percentage level of performance and cost of replacement per year for each given trips.

The computer program has been listed in Appendix II

The cost of replacement per year and percentage level of performance for different strategies of replacements in terms of number of replacement trips per week have been calculated using the equations (5.2) and (5.3). The results of these values for each zone are tabulated in table 5.6. Then characteristic curves of cost of such replacement vs. percentage level of performance for the zones have been plotted as shown in Figures 5.1, 5.2, 5.3 & 5.4 and percentage level of performance vs. number of trips per week have been plotted in Figs. 5.5, 5.6, 5.7 & 5.8. It is found that the cost of replacement increases very rapidly when the level of performance exceeds 98%. The level of performance increases rapidly when the number of service trips increases beyond 10 trips per week.

Table 5.6 Cost of replacement per year vs. percentage level of performance for various zones and various frequency of service replacement

Trips/ week	Type of result	Number of Zones I	II	III	IV
2.00	PR	84.90	92.57	91.55	89.77
	CR	310520.19	1400822.00	872369.00	147986.50
3.50	PR	91.06	95.68	95.09	94.02
	CR	344895.69	1553289.00	970181.94	164748.00
5.00	PR	93.65	96.95	96.53	95.77
	CR	353862.94	1611359.00	1004976.38	169976.38
6.00	PR	94.68	97.46	97.10	96.46
	CR	361832.06	1661329.00	1035949.63	174868.31
7.00	PR	95.42	97.81	97.51	96.96
	CR	368837.88	1708360.00	1064987.00	179400.31
8.00	PR	95.98	98.09	97.82	97.34
	CR	369389.00	1728870.00	1076059.00	180640.13
10.00	PR	96.77	98.47	98.25	97.86
	CR	382228.31	1820775.00	1132788.00	189440.74
12.00	PR	97.30	98.72	98.54	98.21
	CR	393825.13	1908446.00	1186695.00	197719.06
14.00	PR	97.68	98.90	98.75	98.47
	CR	404709.56	1993700.00	1238982.00	205697.69
20.00	PR	98.37	99.23	99.12	98.92
	CR	432833.75	2232209.00	1384203.00	227486.88

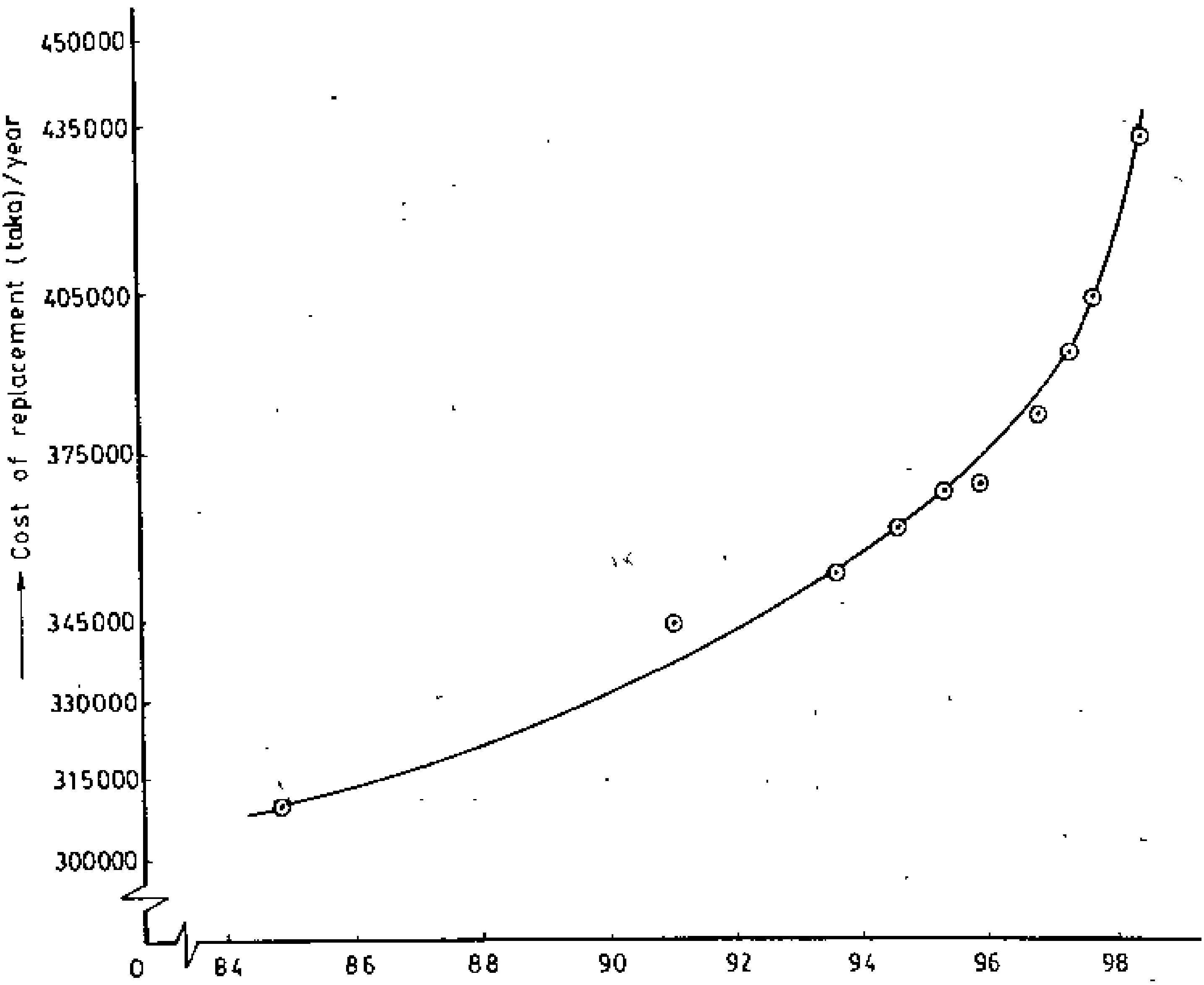


Fig.5.1. Characteristic curve of cost of replacement vs. level of performance, % for zone number-1

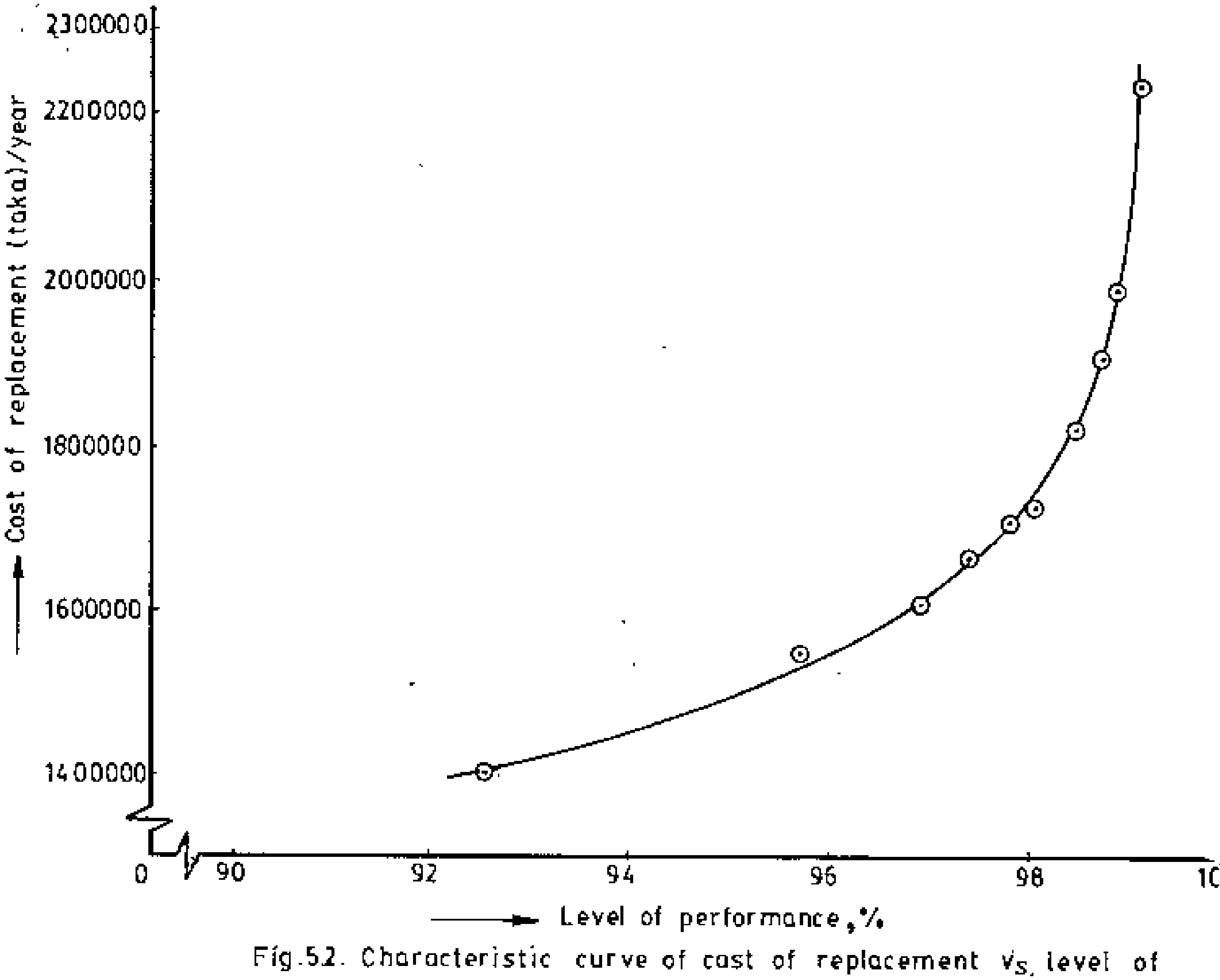


Fig.5.2. Characteristic curve of cost of replacement vs. level of performance,% for zone number-2

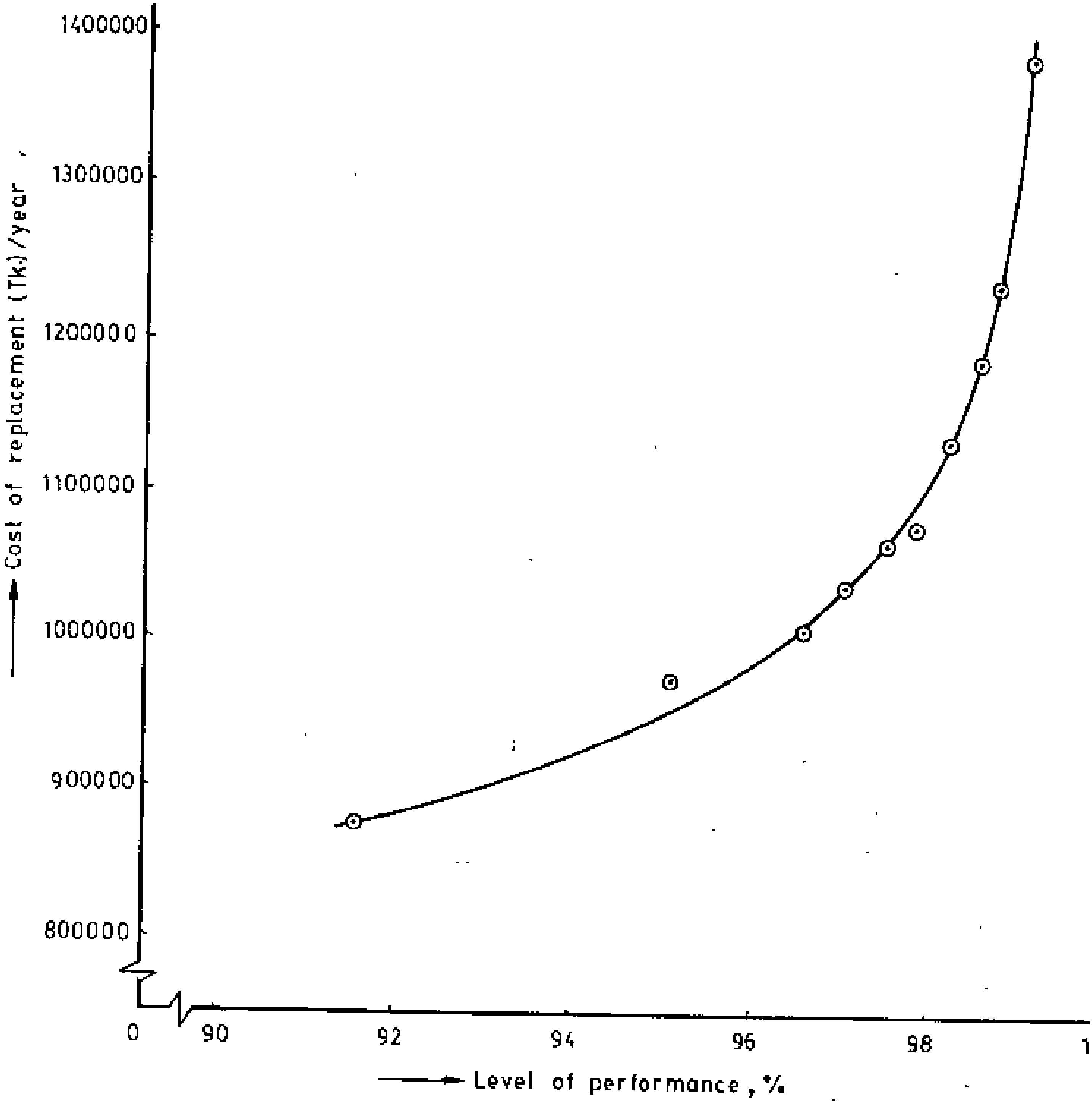


Fig.5.3. Characteristic curve of cost of replacement vs. level of performance % for zone number - 3

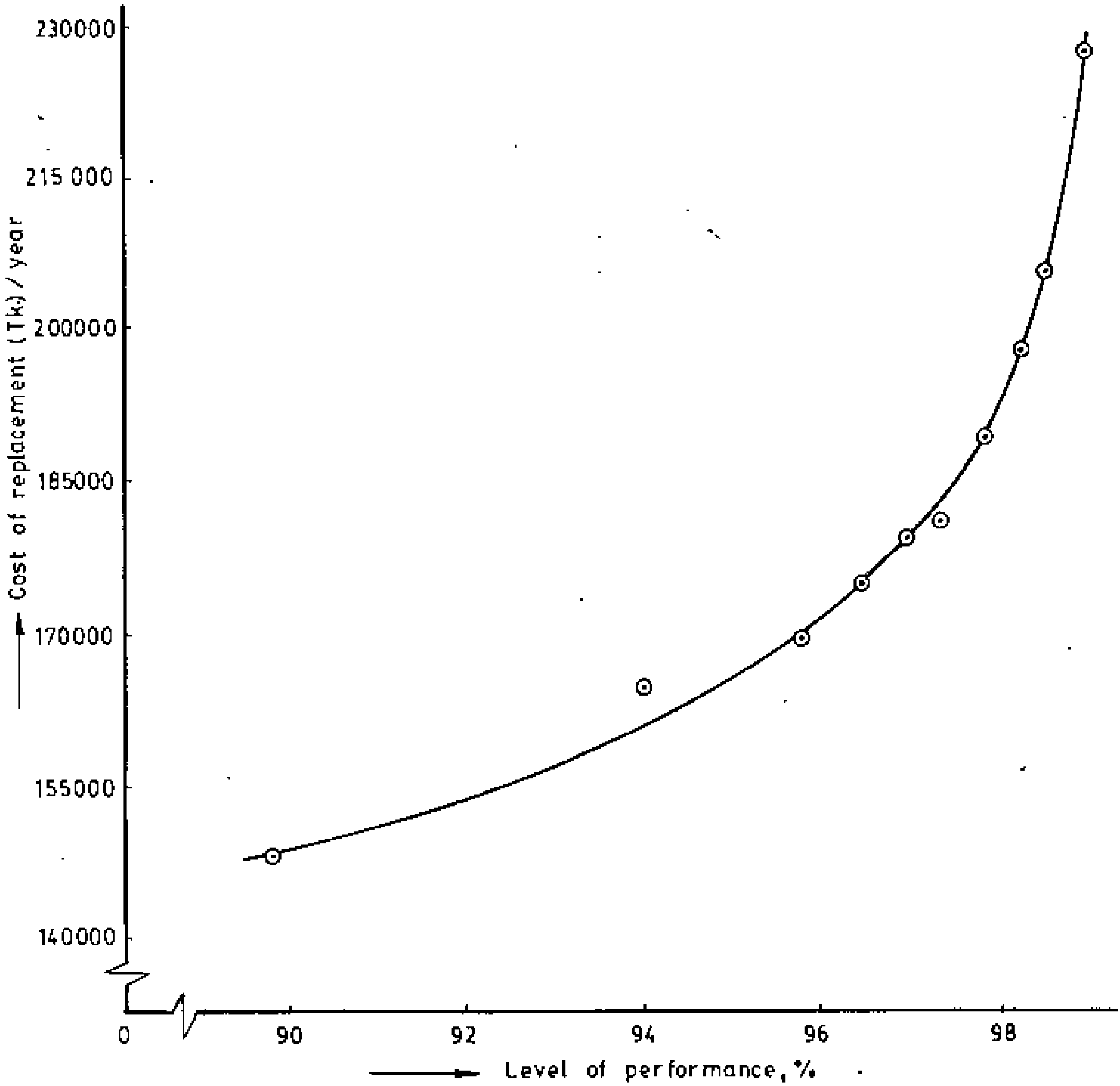


Fig.5.4 Characteristic curve of cost of replacement vs. level of performance, % for zone number-4

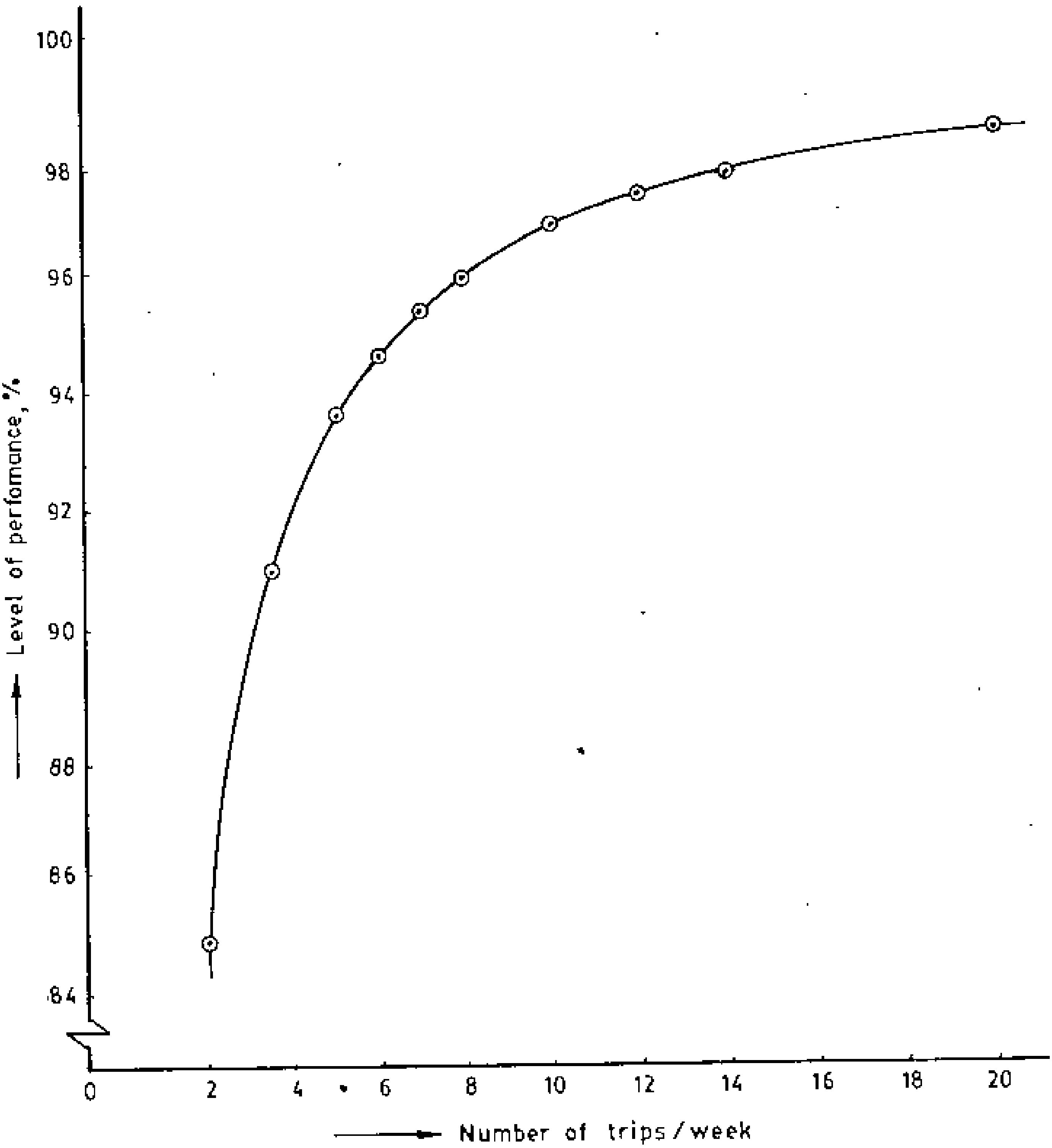


Fig. 5.5. Characteristic curve of level of performance,% Vs. number of trips per week for zone number-1

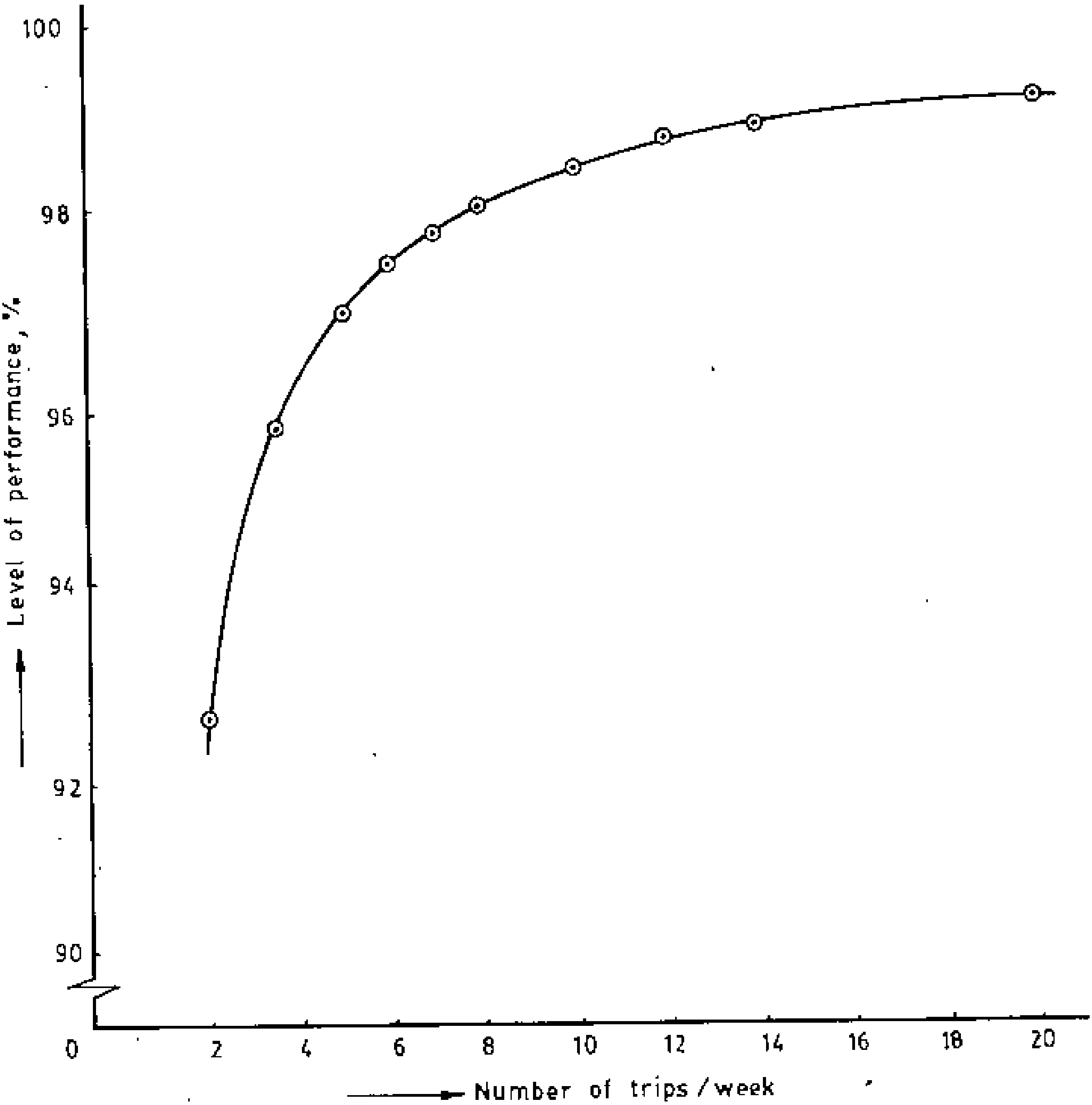


Fig. 5.6. Characteristic curve of level of performance, % Vs. number of trips per week for zone number - 2

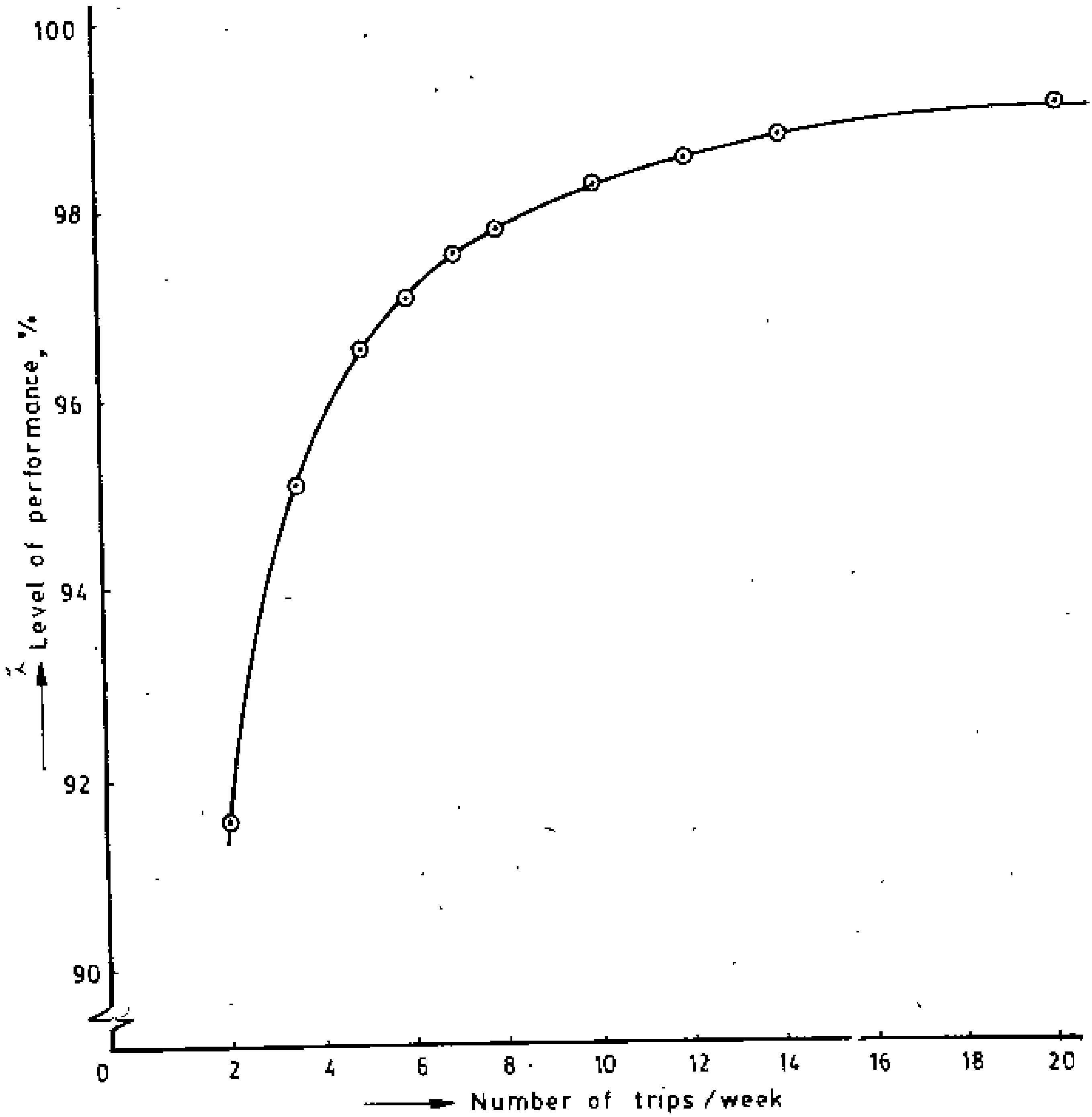


Fig. 5.7. Characteristic curve of level of performance % vs. number of trips per week for zone number-3

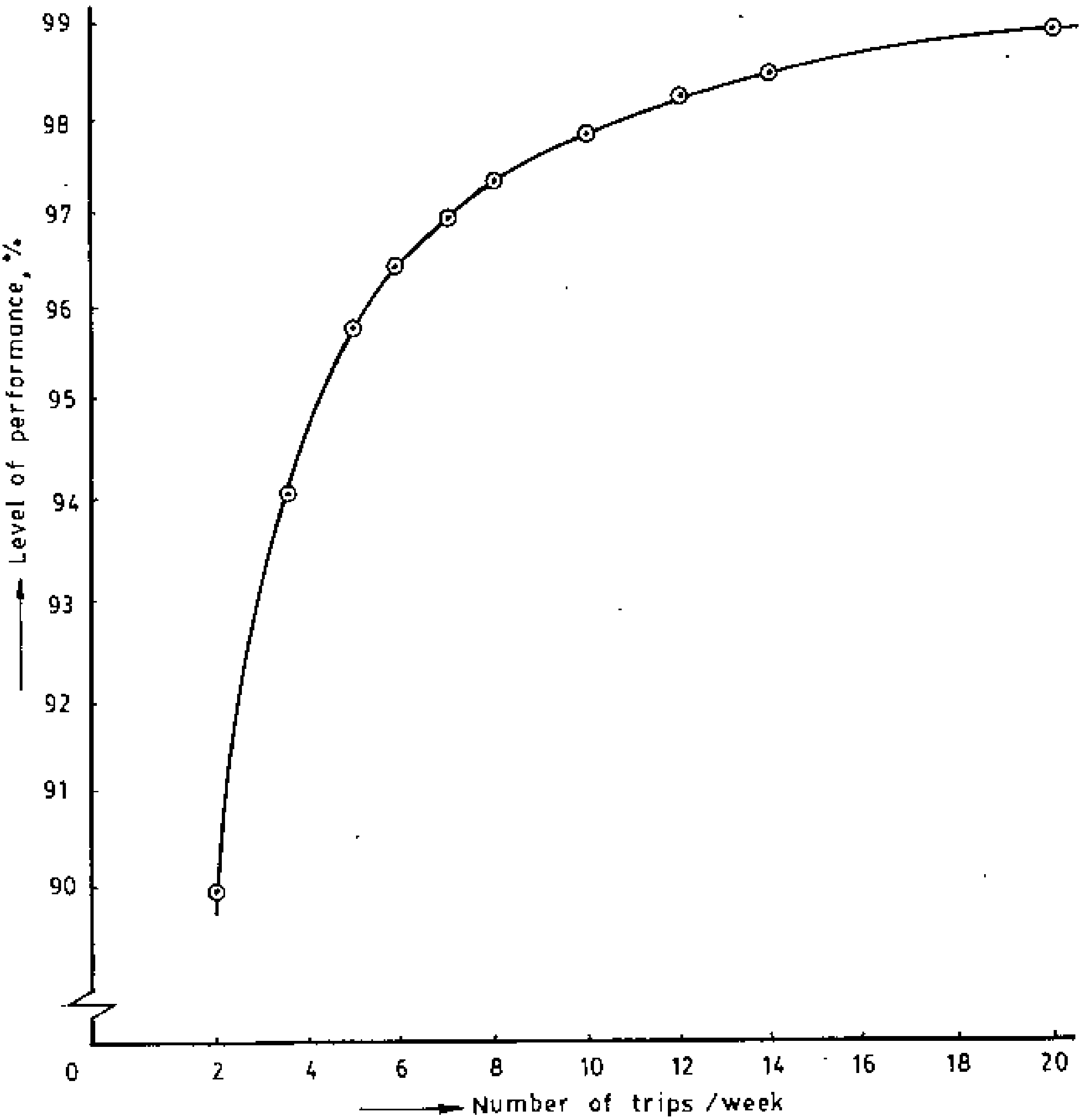


Fig.5.8. Characteristic curve of level of performance,% vs. number of trips per week for zone number-4

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS FOR FUTURE WORK

6.1 CONCLUSION

The objective of the present work was to apply the Operations Research technique in replacement of light bulbs of Dhaka city. Existing lighting system of the Corporation has been studied and the various weaknesses of the system identified. To remove the defects of the system and thus to evolve a better system the techniques of Operations Research and Statistics have been employed. With the present policy, the management has no control over maintaining a specified level of performance of the lighting system measured in terms of percentage of active light bulbs in the system at any time. Moreover, the management could not ascertain the level of cost involvement for each unit increase of the performance. Thus to overcome these inherent problems analytical methods have been used with the past one year's data for the existing lighting area comprising of forty 'wards' in two Divisions. The failure patterns of these wards were known when a theoretical failure distribution such as Weibull distribution was fitted. Analysing and comparing the Weibull parameters of these distributions - it was obserbed that some wards could be grouped together as they indicated similar failure patterns. Thus the replacement policy would be same for the wards and from management point of view it would be useful to combine these wards and create a zone. On the basis of this argument, the entire lighting system was devided into four zones.

The pure service replacement policy has been proposed for each zone. Weibull probability function has been used to find total failures for the year, and the long run average number of fails. This would be achieved by varying the service replacement policy in terms of service trips per week. Thus for any particular service replacement policy when the long run average fails per period was known, the percentage survivals were calculated. This percentage survivals was designated as performance level of the system. Thus for various policies of replacements, percentage levels of performance of the system were calculated. Relationship between this percentage levels of performance and service replacement policy has been shown in figs 5.5, 5.6, 5.7, & 5.8 in chapter 5.

The annual cost of replacement relates nonlinearly with percentage level of performance. These are shown in figs 5.1, 5.2, 5.3 & 5.4 for the four zones. From the cost equation mentioned in chapter 5, it is found that total cost has two components (i) item cost and (ii) total trip costs. The individual item cost and the trip costs components of the cost equation are linear but the number of average failure(f) per year varies non-linearly with performance. Thus the cost curves become nonlinear with performance.

The management now can use this approach as a 'tool' for decision making in terms of formulating replacement policy of the system. It can set any cut-off point in terms of the percentage level of performance; accordingly, the cost of replacement per year could be ascertained when the fixed cost is added. On the other hand the total cost of replacement per year could be known (at 1982 price level) adopting a policy for replacement of light bulbs at a predetermined performance level. Due to inflation or any other reason the cost parameters may change in which case new sets of characteristic curves could be generated by the computer package already developed.

6.2 SCOPE AND RECOMMENDATIONS FOR FUTURE WORK

The scope of future work are given as follows:-

(i) There have been advances towards computerised data processing. Thus striking results and better management decisions are possible through this computer application. In this respect data storing and record keeping should be computer based. Future work may be directed in exploring the feasibility of installing mini-computers for the corporation.

(ii) Numerical Taxonomy (Cluster analysis) is a powerful tool so also the discriminant analysis. A project should be carried out to investigate possible alternatives in redesigning the system in terms of zones using those methods. Thus for each zone appropriate replacement policies could be used.

(iii) The models developed in the present work are based on data obtained from a single source. In addition the time scale of the project has meant that these models could not be exhaustively tested. The author is very much aware that a statistical model of the type needs more data. Thus any future work should consider this aspect.

(iv) In the present work only the existing system of failures of light bulbs (as it operates) has been considered without considering the reasons behind their failures. This was rather deliberate because of the time constraint and scope of the present work. It could now be stressed upon that a separate study may be made in this context. Thus procedures should be developed to control the system and thus to improve its operation; in this regard a detailed system study may be made on all the components of the system especially the critical components such as the chokes, starters, fuses etc. and also the environmental factors and conditions which affect the system. It may be mentioned that factors such as weather conditions, seasonality effects etc. are the few important factors which fall under this category. There exists some 'invisible' factors from within the organization which also need consideration as they significantly affect the system operation. These are artificial but need deliberate control.

[illegible]

TABULATED DATA SUMMARY

CLASS	FAILURES	SUSPENSIONS
1	14	[illegible]
2	[illegible]	[illegible]
3	[illegible]	[illegible]
4	5	[illegible]
5	6	[illegible]
6	[illegible]	[illegible]
7	10	[illegible]
8	5	[illegible]
9	14	[illegible]
10	6	[illegible]
11	7	[illegible]
12	[illegible]	[illegible]
13	[illegible]	111
14	[illegible]	[illegible]
15	7	[illegible]
16	10	[illegible]
17	[illegible]	[illegible]
18	13	[illegible]
19	6	[illegible]
20	9	[illegible]
21	[illegible]	[illegible]
22	7	[illegible]
23	4	[illegible]
24	[illegible]	[illegible]
25	14	[illegible]
26	5	[illegible]
27	6	[illegible]
28	4	[illegible]
29	[illegible]	[illegible]
30	[illegible]	[illegible]
31	11	[illegible]
32	[illegible]	111
33	7	109
34	[illegible]	[illegible]
35	[illegible]	[illegible]
36	10	[illegible]
37	[illegible]	[illegible]
38	[illegible]	[illegible]
39	7	[illegible]
40	4	112
41	5	[illegible]
42	3	113
43	7	109
44	6	[illegible]
45	7	[illegible]
46	[illegible]	[illegible]
47	5	111
48	4	[illegible]

RELIABILITY ANALYSIS BASED ON RAW DATA

CLASS	PROB OF FAILURE	CUM. PROB OF FAILURE
1	0.121	0.121
2	0.023	0.145
3	[illegible]	0.210
4	0.023	[illegible]
5	0.055	[illegible]
6	0.047	[illegible]
7	[illegible]	[illegible]
8	0.012	0.419
9	0.097	[illegible]
10	0.065	[illegible]
11	[illegible]	[illegible]
12	0.0	[illegible]
13	0.014	[illegible]
14	0.032	[illegible]
15	0.022	[illegible]
16	0.044	[illegible]
17	0.069	[illegible]
18	0.063	0.730
19	0.019	0.754
20	0.027	[illegible]
21	0.0	[illegible]
22	0.013	[illegible]
23	0.0	0.794
24	0.047	0.842
25	0.052	[illegible]
26	0.0	[illegible]
27	0.004	0.904
28	0.0	[illegible]
29	0.0	[illegible]
30	0.032	[illegible]
31	0.029	0.961
32	0.0	0.961
33	0.0	0.961
34	0.0	0.961
35	0.0	0.961
36	0.028	[illegible]
37	0.0	0.984
38	0.0	[illegible]
39	0.0	[illegible]
40	0.0	[illegible]
41	0.0	[illegible]
42	0.0	[illegible]
43	0.003	0.987
44	0.013	1.001
45	0.0	1.001
46	0.0	1.001
47	0.0	1.001
48	0.0	1.001

WEIBULL DISTRIBUTION PARAMETERS

SHAPE PARAMETER= 0.57
SCALE PARAMETER= 7.47
LOCATION PARAMETER= 0.0
MEAN LIFE= 17.03
STANDARD DEVIATION= 22.45

CUMULATIVE FAILURE DENSITY FUNCTION

0.27	0.23	0.45	0.53	0.33	0.59	0.62	[illegible]	0.67	[illegible]	0.71	0.73	[illegible]	[illegible]	0.77
0.84	0.94	0.85	[illegible]	[illegible]	0.87	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.91	0.91
0.53	0.93	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.95	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	0.97	[illegible]	0.37	0.97	0.67	0.97	[illegible]	0.97	0.97	0.97	0.37	[illegible]	[illegible]
0.99	[illegible]	0.98	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.98	[illegible]	[illegible]	[illegible]

PROBABILITY DENSITY FUNCTION FOR FAILURE TIMES

0.27	0.10	0.07	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.02	0.01	[illegible]
0.01	0.01	[illegible]	[illegible]	0.01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.00	0.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.00	0.00	[illegible]
0.00	0.00	0.00	[illegible]	0.00	[illegible]	[illegible]	[illegible]	[illegible]	0.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

RENEWAL ANALYSIS BASED ON THE FITTED WEIBULL DISTRIBUTION

CLASS	SURVIVAL PROBABILITY	TRUNCATED MEAN LIFE	CUMULATIVE RENEWALS
1	0.72[illegible]	0.5[illegible]4	0.2[illegible]2
2	0.674	1.3[illegible]0	0.490
3	0.5[illegible]2	2.125	0.[illegible]
4	0.447	2.[illegible]	0.732
5	0.431	3.127	0.8[illegible]7
6	0.414	3.[illegible]	0.976
7	0.3[illegible]1	3.957	1.0[illegible]
8	0.[illegible]3	4.[illegible]23	1.195
9	0.22[illegible]	4.[illegible]	1.30[illegible]
10	0.237	4.[illegible]33	1.411
11	0.2[illegible]7	5.[illegible]	1.512
12	0.2[illegible]5	5.5[illegible]	1.615
13	0.2[illegible]	5.[illegible]20	1.71[illegible]
14	0.245	6.036	1.810
15	0.225	6.[illegible]	1.904
16	0.213	6.516	2.001
17	0.202	6.725	2.0[illegible]
18	0.191	6.[illegible]22	2.1[illegible]
19	0.182	7.10[illegible]	2.291
20	0.173	7.23[illegible]	2.372
21	0.164	7.453	2.4[illegible]4
22	0.157	7.[illegible]15	2.5[illegible]3
23	0.145	7.758	2.5[illegible]
24	0.143	7.[illegible]14	2.735
25	0.13[illegible]	8.[illegible]55	2.824
26	0.1[illegible]3	8.[illegible]1[illegible]	2.912
27	0.124	8.[illegible]14	3.[illegible]
28	0.119	8.[illegible]	3.[illegible]2
29	0.114	8.[illegible]	3.176
30	0.1[illegible]5	8.[illegible]	3.2[illegible]
31	0.10[illegible]	8.7[illegible]	3.350
32	0.101	8.[illegible]74	3.4[illegible]
33	0.097	8.972	3.52[illegible]
34	0.0[illegible]	9.067	3.[illegible]5
35	0.095	9.1[illegible]	3.[illegible]94
36	0.0[illegible]	9.2[illegible]	3.[illegible]
37	0.0[illegible]2	9.[illegible]30	3.[illegible]
38	0.079	9.[illegible]11	3.9[illegible]
39	0.076	9.[illegible]	4.0[illegible]
40	0.074	9.[illegible]	4.126
41	0.071	9.[illegible]	4.234
42	0.068	9.7[illegible]	4.2[illegible]
43	0.066	9.[illegible]	4.373
44	0.064	9.[illegible]30	4.457
45	0.061	9.900	4.541
46	0.0[illegible]5	9.[illegible]	4.62[illegible]
47	0.057	10.015	4.708
48	0.0[illegible]5	10.075	4.791

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APPENDICES

APPENDIX - I

Computer Programme to determine the Weibull parameters

```
DOS FORTRAN IV 360N-FO-479 3-8          MAINPGM          DATE   26/09/83       TIME   09.48.12

      C     PROGRAMME FOR FINDING EXPECTED NUMBER OF FAILURES
            DIMENSION FO(55),SD(55),H(55),W(99),CRL(75),F(99),SH(55),WHR(99),
           1COPER(53),EX(99),SU(50),UE(25),P(15),FR(35),CFR(50),RL(75)
            COMMON FO,SD,H,SH,CRL,F,SP,WHR,RL,C,PIN,CX,SB,SU,N,FR,CFR,NOK,NK
            INTEGER FL,SO
            ICOUNT = 0
            READ(1,5)N, NWARD
          5 FORMAT(2I4)
        599 ICOUNT=ICOUNT+1
            IF(ICOUNT.GT.NWARD)STOP
            WRITE(3,10)ICOUNT
         10 FORMAT(1H1/////,15X,'WARD NUMBER=',I3,/,15X,12('-'))
            READ(1,15)(FO(I),SD(I),I=1,N)
         15 FORMAT(20I4)
            CALL ZKS
            H(1)=F(1)
            DO 50 I=2,N
            M=I-1
            G=0.
            DO 51 J=1,M
            KJ=I-J
         51 G=(1.-H(KJ))*F(J)+G
         50 H(I)=G+F(I)
            SH(1)=H(1)
            DO 52 KM=2,N
         52 SH(KM)=H(KM)-H(KM-1)
            WRITE(3,920)
        920 FORMAT(1X,////,5X,'RENEWAL ANALYSIS BASED ON THE FITTED WEIBULL DI
           1STRIBUTION',/,3(4X,63('-')),//,5X,'CLASS',5X,'SURVIVAL',5X,'HAZARD
           2TO',5X,'CUMULATIVE',/,15X,'PROBABILITY',5X,'MEAN LIFE',5X,'RENEWAL
           3S',/)
            DO 53 IN=1,N
            WRITE(3,921) IN,RL(IN),CRL(IN),H(IN)
        921 FORMAT(7X,I2,9X,F5.2,9X,F6.3,9X,F6.3)
         53 CONTINUE
            GO TO 599
            END
```

```
DOS FORTRAN IV 360N-FO-479 3-8          ZKS          DATE   26/09/83       TIME   09.48.24

        204 FORMAT(3X,/,5X,'PROBABILITY DENSITY FUNCTION FOR FAILURE TIMES',/,
           1 5X,45('-'))
            WRITE(3,205)(F(JJ),JJ=1,NKP)
      C     FINDING HAZARD RATE FROM WEIBULL DISTRIBUTION
            DO 81 LL=1,N
         81 WHR(LL)=F(LL)/(1.0-CF(LL))
            DO 82 LI=1,N
         82 RL(LI)=1.0-CF(LI)
            CRL(1)=(1.0+RL(1))/2.0
            DO 83 LJ=2,N
         83 CRL(LJ)=CRL(LJ-1)+(RL(LJ-1)+RL(LJ))/2.0)
            RETURN
            END
```

```
DOS FORTRAN IV 360N-FO-479 3-8          MAINPGM          DATE   26/05/83     TIME    06.49.05

      C       FUNCTION SUBPROGRAM
      C
              FUNCTION YY(F)
              YY=[illegible]
             1/((360.0*(F**2))))
              RETURN
              END
```

```
DOS FORTRAN IV 360N-FO-479 3-8          MAINPGM          DATE   26/05/83     TIME    06.49.18

      C       SUBROUTINE SUBPROGRAM FOR FINDING CUMULATIVE DENSITY FUNCTION
      C       FROM RAW DATA
              SUBROUTINE ZKA
              DIMENSION F(50),SL(50),H(50),D(50),CRL(50),[illegible],SH(50),[illegible],
             1AL(50),CUPER(50),[illegible],FR(50),[illegible]
              COMMON [illegible]
              INTEGER F1,SJ
              TEMP=F(1)*SD(1)
              SU(1)=F(1)
              FR(1)=SU(1)/TEMP
              DO 850 I=2,N
              XTP=0.0
              II=I-1
              SU(I)=F(I)
              DO 860 J=1,II
              I2=I-J
        860   XTP=XTP+F(J)*SU(I2)
              FR(I)=(SU(I)-XTP)/TEMP
              IF(FR(I) .LT. 0.0)FR(I)=0.0
        850   CONTINUE
              WRITE(3,302)
        302   FORMAT(1X,/////,10X,'GROUPED DATA SUMMARY',/,10X,22('-'),/,10X,
             1'CLASS',5X,'FAILURES',5X,'OBSERVATIONS',/)
              DO 99 J=1,N
              WRITE(3,303)J,F(J),[illegible](J)
        303   FORMAT(13X,I2,5X,I3,11X,I4)
         99   CONTINUE
              WRITE(3,300)
        300   FORMAT(2X,///,10X,'RELIABILITY ANALYSIS BASED ON RAW DATA',//,10X,
             *20('-')/,3X,'CLASS',5X,'PROB OF FAILURE',3X,
             *'CUM. PROB OF FAILURE',//)
              CUPER(1)=FR(1)
              DO 95 I=2,N
              CUPER(I)=CUPER(I-1)+FR(I)
         95   CONTINUE
              WRITE(3,301)(I,FR(I),CUPER(I),I=1,N)
        301   FORMAT(7X,I2,11X,F8.5,11X,F8.5)
              RETURN
              END
```

```
C        SUBROUTINE FOR WEIBULL ANALYSIS
         SUBROUTINE ZKJ
         DIMENSION FJ(55),SU(55),H(55),H(55),CF(55),
        1 F(99),SH(55),WK(55),FL(55),CUPER(55),CX(55),S(55),E(55),FM(55)
        2,FR(55),CFM(55)
         COMMON FL, SU, TG, DF,CAL,T,SH,WFR,UU,CUPER,EX,SH,SE,TR,FZ,WEIR,N,
        1NT
         INTEGER FU, SU
         CALL ZK
         WRITE(3,200)
   200   FORMAT(1X,////,10X,'WEIBULL DISTRIBUTION PARAMETERS',/,10X,32('*'
        1),/)
         IF(CUPER(1))62,61,62
    62   GAMA=0.0
         GO TO 63
    61   IF (CUPER(2))65,64,65
    65   GAMA=1.0
         GO TO 63
    64   IF(CUPER(3))66,66,67
    67   GAMA=2.0
         GO TO 63
    66   GAMA=3.0
    63   IGAMA=IFIX(GAMA)+1
         NGAMN=N-IGAMA+1
         SY=0.0
         SYSQ=0.0
         SX=0.0
         SXY=0.0
         SXSQ=0.0
         DO 58 K=IGAMA,N
         IF(CUPER(K).GE.1.0010) GO TO 290
         Y=ALOG(ALOG(100.0/(100.0-CUPER(K)*100.0))))
         SY=Y+SY
         SYSQ=Y**2+SYSQ
         X=ALOG(FLOAT(K)-GAMA)
         SX=X+SX
         SXY=X*Y+SXY
         SXSQ=X**2+SXSQ
    58   CONTINUE
   290   CR=(SXY-(SX*SY)/NGAM)/ABS(SQRT((SXSQ-(SX*SX)/NGAM)*(SYSQ-(SY*SY)/
        1NGAM)))
         B=((SXY*NGAM)-(SX*SY))/((SXSQ*NGAM)-(SX*SX))
         C=(SY-(B*SX))/NGAM
         ETA=EXP(((ALOG(ALOG(100./(100.0-63.2))))-C)/B)
         EXT=GAMA+(YY(1.0+(1.0/B))*ETA)
         SD=SQRT((ETA**2)*(YY(1.0+(2.0/B))-(YY(1.0+(1.0/B)))**2)))
         WRITE(3,201) B
   201   FORMAT(10X,'SHAPE PARAMETER=',F5.2)
         WRITE(3,205) ETA
   205   FORMAT(10X,'SCALE PARAMETER=',F5.2)
         WRITE(3,206) GAMA
   206   FORMAT(10X,'LOCATION PARAMETER=',F8.2)
         WRITE(3,207) EXT
   207   FORMAT(10X,'MEAN LIFE=',F8.2)
         WRITE(3,208) SD
   208   FORMAT(10X,'STANDARD DEVIATION=',F8.2)
C        FINDING WEIBULL PROBABILITIES
         NPP=N+3
         ISP=1
   802   DO 69 KK=ISP,NPP
         IF( FLOAT(KK)-GAMA)71,72,72
    72   EX(KK)=((FLOAT(KK)-GAMA)/ETA)**B
         GO TO 73
    71   EX(KK)=0.0
    73   PF(KK)=1.0-EXP(-EX(KK))
    69   CONTINUE
         IF(PF(NPP).GT.0.950.OR.NPP.GT.59)GO TO 801
   805   ISP=NPP+1
         NPP=ISP
         GO TO 802
   801   WRITE(3,202)
   202   FORMAT(1X,'CUMULATIVE FAILURE DENSITY FUNCTION',/,5X,35('*'))
         WRITE(3,203)(PF(JJ),JJ=1,NPP)
   203   FORMAT(1H ,5X,20F6.2)
         F(1)=PF(1)
         DO 70 KJ=2,NPP
    70   F(KJ)=PF(KJ)-PF(KJ-1)
         WRITE(3,204)
```

APPENDIX - II

Computer Programme to determine the relationship between annual cost of replacement and level of performance

```
DOS FORTRAN IV 360N-FO-479 3-8          MAINPGM          DATE   28/11/83      TIME      1

              DIMENSION T(10),INP(10),F(999),PF(10),   CS(10),  FK(10),XN(999)
        C     NZ=NUMBER OF ZONES
        C     NW=NUMBER OF WEEKS/YEAR
              READ(1,1)NZ,NW
            1 FORMAT(2I4)
              READ(1,5)(INP(I),I=1,10),COST1
        C     INP(I)=NO.OF TRIPS PER WEEK OF I TYPES
            5 FORMAT(11F5.0)
        C     COST1=COST OF ITEM EACH.   COST2=COST OF ONE TRIP
              DO 2 I=1,10
            2 T(I)=7.0/INP(I)
              IC=1
           55 CONTINUE
              WRITE(3,10)IC
           10 FORMAT(1H1////,10X,'ZONE NUMBER=',I4,/,10X,13('-'))
              READ(1,15)BETA,ETA,COST2,NT
           15 FORMAT(3F10.3,I5)
        C     NT=NO.OF FOLD POINTS IN THE ZONE
              WRITE(3,20)BETA,ETA,NT
           20 FORMAT(///,10X,'SHAPE PARAMETER=',F6.3/10X,'SCALE PARAMETER=',F8.2
             1/10X,'TOTAL NO. OF POINTS=',I4/5X,100('-')///)
              WRITE(3,45)
              DO 25 J=1,10
              XT=0.0
              S=0.0
              I=1
           30 XT=XT+T(J)
              B=-(XT/ETA)**BETA
        C     F(I)=PROBABILITY OF FAILURE DURING PERIOD I
              F(I)=-EXP(B)+1.0-S
              S=S+F(I)
              IF(S.GE.0.9990)GO TO 35
              I=I+1
              GO TO 30
           35 SX=0.0
        C     SX=AVERAGE LIFE,WEEKS
              DO 40 K=1,I
              SX=SX+F(K)*K
           40 CONTINUE
              X=FLOAT(NT)
        C     FX=AVERAGE FAILURES
              FX=X/SX
              FS=X-FX
        C     FS=AVERAGE SURVIVALS
              PF(J)=FS/X*100.0
        C
        C
        C
        C
        C
              XT=T(J)
              XN(1)=F(1)*X
        C     FK(J)=TOTAL FAILS PER YEAR
              FK(J)=XN(1)
              DO 65 IX=2,I
              XT=XT+T(J)
              IF(XT.GT.NW)GO TO 75
              XTP=0.0
              II=IX-1
              DO 70 IA=1,II
              XTP=XTP+F(IA)*XN(IX-IA)
           70 CONTINUE
              XN(IX)=XN(1IX)+XTP
              FK(J)=FK(J)+XN(IX)
           65 CONTINUE
           75 CS(J) = FK(J)*COST1+INP(J)*COST2*NW
        C
           25 CONTINUE
              WRITE(3,50)(INP(J),T(J),FK(J),PF(J),CS(J),J=1,10)
        C
           45 FORMAT(1H ,10X,'TRIPS/WEEK',3X,'PERIOD REPLACEMENT',3X,'TOTAL FAIL
             1S PER YR.',3X,'PERFORMANCE   ',3X,'COST OF REPL./YR.'//)
        C
           50 FORMAT(1H ,13X,F6.2,10X,F10.3,11X,F10.1, 1X,F10.2,10X,F10.2)
              IC=IC+1
              IF(IC.GT.NZ)STOP
              GO TO 55
              END
```

APPENDIX-III

Flow Chart of the Computer Programme given in Appendix-II.