Development of a simulation model for spare parts provisioning for Diesel Electric Locomotive of Bangladesh Railway

A Project Thesis
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Certificate of Project Work

This is to certify that the present work presented in this thesis is the outcome of the work carried out by the candidate under the supervision of Dr. A.F.M. Anwarul Haque, Professor, Department of Industrial & Production Engineering of Bangladesh University of Engineering & Technology.

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DECLARATION

I do hereby declare that this work has been done by me and neither this thesis nor any part of this has been submitted elsewhere for the award of any degree or diploma.

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CONTENTS

Page

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ABSTRACT

In all service organizations, both preventive and breakdown maintenance are carried out to keep the system in operating condition and to reduce the downtime as minimum as possible. The frequent complain of maintenance organization is spare parts shortage. So there is a tendency to stock spares in excess amount. But this intern incurs substantial capital cost. The excess inventory also increases the inventory carrying cost. On the other hand shortage of spare parts causes production delay in manufacturing organizations and less availability of the essential equipment in service organization resulting in loss of profit and reputation.

Diesel Electric Locomotives are used in Bangladesh Railway as motive power in Train operation. These Locomotives are to be properly maintained to attain highest level of reliability in train operation. The system of maintenance of Railway Locomotives has been developed from years of experience. Present system determines the quantity of different components to be stocked on the basis of average annual consumption of spares for schedule and breakdown maintenance. The method currently being used to determine the quantity seems to be unscientific as it does not take into consideration the different parameters of inventory and maintenance. Existing method ignores the important trade-off that exists between inventory and maintenance.

In this project work, an ordering policy (S, s) is developed by considering both inventory and maintenance related costs together where S is the maximum inventory level and s is the re-order level. A simulation model has been developed to determine (S, s) for the proposed system. Various combinations of S & s can be determined from the model. The combination of variables for which the expected total cost per unit time is minimum for a given set of parameters is the optimum.

Cost inputs of the model are different costs of Inventory & Maintenance such as unit cost of the component, order cost, holding cost, shortage cost and replacement cost etc. for a particular component. The model can be used in carrying out sensitivity analysis of different parameters.

CHAPTER ONE

- **Introduction**
- **Scope of the Present work**
- **Objective of the Present work**

1.1 Introduction

Major portion of expenditure in an Industry is generally on the men, materials and maintenance. Machine or equipment must be properly maintained for its maximum availability. Maintenance dept. is responsible for the smooth and efficient working of different machine and equipment. It helps in keeping machine & equipment in a state of maximum efficiency with economy.

Breakdown and preventive maintenance are carried out in manufacturing and service organizations. The main objectives of maintenance are to

a) ensure maximum availability of the plant and equipment by reducing failure to minimum.

b) ensure operational readiness of all equipment and thus assure the optimum availability of installed equipment for production or service and obtain the maximum possible return on investment.

c) increase the useful life of assets.

d) ensure the safety of the personnel.

e) reduce the expenditure on maintenance material and labor.

Today maintenance organization stresses on the cost and service optimality and the integration of maintenance activities with other major department activities. Inventory & maintenance management are two important terms in industrial jargon, each complementing the other and both serving towards achieving a cost and service optimal industrial environment. The present work is intended to investigate the influence of different parameters on total cost of both maintenance and inventory.

1.2 Scope of the present work

Operating items can be replaced either individually or in a group. Block replacement is a preventive maintenance scheme where a group of identical items is replaced after certain interval of time. This policy is widely acclaimed to be most cost and service effective policy for large number of low/medium cost items or where system downtime is very critical.

In this research work, a study has been carried out on the inventory and maintenance policy of Diesel Electric Locomotives used in Bangladesh Railway. Diesel Electric Locomotives are used as motive power in train operation. These Locomotives are to be maintained properly to ensure maximum reliability of the system. The system of maintenance of Railway Locomotives has been built up from years of experience. For Diesel Electric Locomotives, different types of Inspections along with the standard time for their completion have been shown below:-

Type of Inspection	Interval	Standard comp.time
C	Every 30 days	6 hr./.75 days
D	Every 90 days	8 hr./1 day
E	Every 180 days	16 hr./2 days
F	Every 365 days	80 hr./10 days
G	Every 1095 days	168 hr./21 days
GOH	Every 2190 days	360 hr./45 days

All these schedules are progressive schedules. It means that during the time of 'E' type inspection, 'C' and 'D' types are also carried out. For each inspection, there is a standard schedule of works to be done. These schedules have been prepared taking into consideration the manufacturer's recommendation and are subject to revision from time to time on the basis of experience gained.

Stores Department in Bangladesh Railway is responsible for the Inventory control. This department determines

- the re-order level of individual item,
- number of orders to be placed per year,
- cost for the total inventory.

This Department is also responsible for timely supply of maintenance materials for both preventive and breakdown maintenance and for keeping all records related to Inventory. Figure 1.2 shows procurement process of Diesel spares required for the maintenance of Diesel Electric Locomotives.

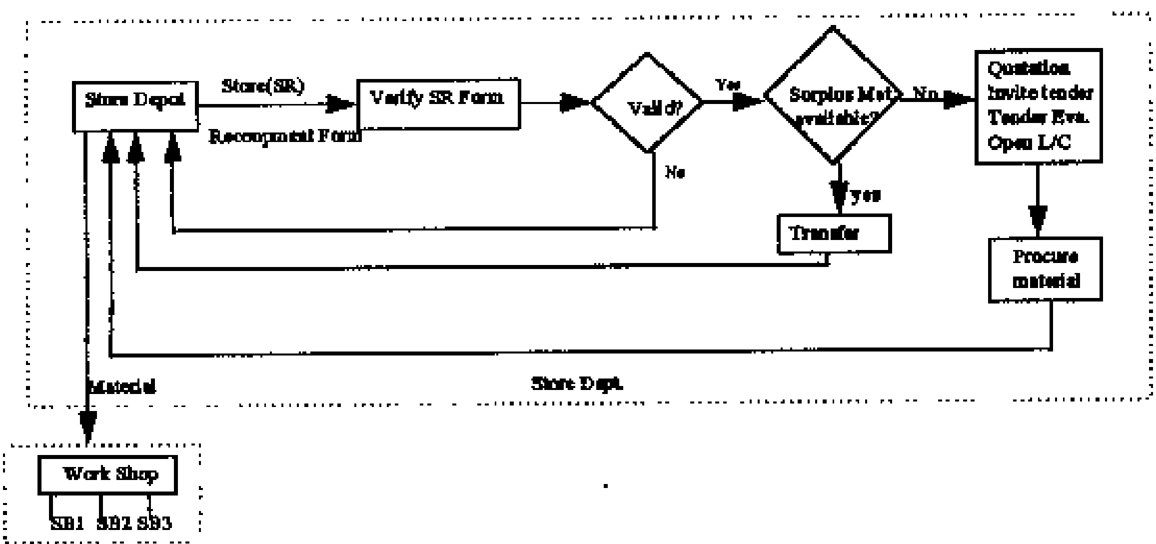


Figure 1.2.Procurement Process

Mechanical department is responsible for repair, maintenance and operation of Diesel Electric Locomotives. There are different sections for performing specific maintenance tasks. Each section performs jobs in co-ordination with other sections for timely completion of maintenance work. Necessary spares are drawn by the respective sections from the stores department by submitting requisition against specific maintenance work. Individual section reports to the work manager of the respective workshop on materials used, cost of materials, labor and the time taken to complete a type of Inspection.

Presently inventory and maintenance problems are considered almost independently. This study aims at addressing both the above problems simultaneously and developing a comprehensive model which will optimize the entire system. By optimization of Inventory & Maintenance policy, total maintenance cost can be considerably reduced, yet maintaining the same product quality.

1.3 Objective of the present work

The objectives of the present work under the context of what has been discussed above are defined as follows:-

1. To study the current Inventory and Maintenance Policy of Bangladesh Railway Locomotive .
2. To develop an (S,s) simulation model to calculate the maximum inventory level(S) and the reorder level(s) so that total cost of inventory and maintenance becomes minimum.
3. To carry out the sensitivity analysis on various cost components related to inventory and maintenance such as ordering cost, holding cost, shortage cost, failure replacement cost and preventive replacement cost.

CHAPTER TWO

Literature and Background Study

- **Introduction**
- **Different Maintenance System**
- **Maintenance Management**
- **Inventory for Maintenance**

Joint Inventory and Maintenance Policy

2.1 Introduction

Intense competition together with a rapidly advancing technology has brought about many changes in the pattern and outlook of companies' policies. Modern plant and equipment are very expensive demanding high quality of maintenance. So it is essential for the companies to keep the machine downtime as low as possible. This recognized the importance of maintenance & inventory function. This chapter presents a brief discussion on maintenance, inventory, maintenance management, inventory for maintenance and joint inventory & maintenance policy.

2.2 Different Maintenance Systems

Maintenance is developed in relation to the management functions such as finance, labour management, development, procurement and sales in order to secure good performance of elements comprising the system.

2.2.1 Total Productive Maintenance (TPM)

Total Productive Maintenance (TPM) was developed in Japan. This system was announced by the automobile parts manufacturer Nippon Denso in 1971 as an equipment maintenance method in which everyone participates in voluntary maintenance. In this way the expression "Total" in TPM perhaps meant the full participation of the expanding maintenance organization. Contrary to the specialist maintenance, it is a form in which the operators of the operation department participate. However, with the motto, "Protect your own equipment by your own hands," a revolutionary change was made so that the operating department would conduct as much maintenance work as possible as symbolized by the expressions, " you are the people who repair the equipment, we are the people who operate the equipment".

2.2.2 Types of Maintenance

The maintenance policies can be classified into following three categories:-

a) *Breakdown Maintenance (BDM) Policy :*

Machine and equipment can be operated until they fail and then repaired. This obviously crude method of maintenance is very expensive in terms of lost production and machinery destruction. BDM is the best maintenance policy only when machinery is inexpensive and spare machinery can take over resulting in no loss of production.

b) *Time Based Preventive Maintenance(TBM) :*

In TBM (Conventional Preventive Maintenance) Policy, a plant or machinery is withdrawn from service at constant intervals for repair. These intervals are usually determined statistically.

c) Condition Based Maintenance(CBM) policy :

In "CBM" policy maintenance is carried out in response to a deterioration in a machine or equipment as indicated by a change of the monitored parameter of the machine or equipment conditions.

The most essential requirement is machine condition diagnosis technology to measure and analyze the parameters such as vibration or sound that reflect the machine condition, so that detectable changes in the parameter can give sufficient advance warning for appropriate maintenance action to be taken. In the CBM policy each machine is considered individually by making fixed interval condition checks to obtain a quantitative value of the "health" of the machine. So in CBM policy, maintenance service is only allowed when measured parameters show it to be necessary. Condition checks involves taking routine measurements and comparing them with maximum acceptable levels. Roughly speaking, by adopting the CBM policy, statistical elements in failure prediction can be eliminated and the life of the machine can be extended. The machine condition should be measured at fixed intervals, and maintenance service should be executed only in case of abnormalities found in measured values. In case the measured values show no abnormalities, no maintenance service should be executed. The basic policy of CBM is to leave the smoothly running machine untouched.

2.2.3 Breakdown

According to Japan Industrial standards a failure or breakdown is the loss of specified function in a certain object (e.g. System, machine Parts). Breakdown is divided in the two categories: *function loss breakdowns & function Loss reduction breakdowns.*

Function loss Breakdown:

For most people the term breakdown means a sudden dramatic failure in which the equipment stops completely. Such unexpected breakdowns are clearly losses because production is stopped. This is called a function loss breakdown or a breakdown in which all functioning equipment stop.

Function Reduction Breakdown:

Deterioration (not failure) of equipment causes other losses even when the equipment can still operate . Long setup , adjustment times, frequent idling and minor stoppage, reduced manufacturing speed and cycle times & increased defects in process and during start-up are all possible losses of this type. Problems related to deterioration are considered function reduction breakdowns or breakdowns resulting in various losses (defects, minor losses stoppages etc.). They are caused by deterioration in specific parts of the equipment and are considered less serious than function loss breakdowns. Generally, People tend to ignore function reduction breakdowns, though in many cases, function reduction breakdowns account for the largest proportion of overall equipment losses.

2.3 Maintenance Management

Modern plant and equipment require heavy capital expenditure, making downtime extremely costly. To ensure maximum plant availability and reliability, maintenance management and control system must be developed accordingly. Maintenance is expected to be carefully planned in conjunction with production requirements and schedules so that it causes the minimum disturbances and loss of production. New products are being developed continuously and techniques, processes, systems and methods are being updated time to time. Therefore, the maintenance management science has been continuously updated to keep pace with advancement of production technology.

2.3.1 Maintenance Organization and Control

Maintenance organization may be centralized or dispersed, vertical division or horizontal division, with detail description of relation among departments, allotment of personnel, machinery measurement etc. For proper management and control following points are be considered.

Performance Analysis:

Grasping of current performance, clarification of present and future performance requirements, performance standards.

Trouble Analysis:

Analysis of the causes of troubles ,(data's and actual) statistical analysis of trouble, mean time between failure (MTBF), temporary counter measures and basic countermeasures.

Study of Improvement:

Production improvement ,maintenance improvements ,budget, reliability, maintenance ease, automation of maintenance Work.

Standard:

Preparation and maintenance of standards and guideline sheets, maintenance standards, inspection standards ,service standards repairing cycle, checklist, parts standards.

Advancement of standardization:

Standardization of parts, materials, works, jigs, tools, procedures and terms.

Work Plan:

Long term and short term preparation plan ,inspection ,adjustment servicing, lubrication, repairing ,replacement, improvement plan ,person hour plan, material preparation, adjustment of shutdown period.

Work Instructions:

Allocation of work both internally and externally, progress control, grasping of results.

Work Control:

Utilization rate of works, reduction of waiting time, person-hour control, tool control, standard time control, worker training, education ,safety control, environmental control.

Material control:

selection of control system, purchase plan, order control, acceptance, storage, shipment, inventory, inventory control, standardization and specifications

2.4 Inventory Maintenance

An inventory problem exists when it is necessary to stock physical goods or commodities for the purpose of satisfying demand over a specified time horizon. Almost every business must stock goods to ensure smooth and efficient running of its operation. Decisions regarding how much and when to order are typical of every inventory problem. The required demand may be satisfied by stocking once for the entire time horizon or by stocking separately for every time of the horizon. The two cases correspond to overstocking and under stocking.

An overstock requires higher investment capital per unit time but less frequent occurrences of shortages and placement of orders. An under stocked, on the other hand, decreases the investment capital per unit time but increases the frequency of ordering as well as the risk of running out of stock. The two extreme situations are costly. Decisions regarding the quantity ordered and the time at which it is ordered may be based on the minimization of an appropriate cost function that balances the total costs resulting from overstocking and under stocking.

Spare parts stocking and control are necessary to fulfill following three objectives:

1. To promote increased equipment reliability and extend equipment life times through purchase , fabrication and storage of spare parts.
2. To ensure that necessary spare parts available whenever needed and thus minimized planned maintenance down time and production stoppage due to breakdowns.
3. To reduce inventories ordering and acceptance costs and storage cost.

2.4.1 A Generalized Inventory Model

The order quantity and reorder point are normally determined by minimizing the total inventory cost that can be expressed as a function of these two variables. We can summarize the total cost of a general inventory model as a function of its principal components in the following manner:

Total
(inventory cost)= (Materials Cost) + (ordering cost)+ (holding cost)+(shortage cost)

The material cost becomes an important factor when the commodity unit price becomes dependent on the size of the order. This situation is normally expressed in terms of a quantity discount or a price break, where the unit price of the item decreases with the increase of ordered quantity. The ordering cost represents the fixed charge incurred when an order is placed. Thus, to satisfy the demand for a given time period, the (more frequent) ordering of smaller quantities will result in a higher setup cost during the period than if the demand is satisfied by placing larger (and hence less frequent) orders. The holding cost, which represents the costs of carrying inventory in stock e.g., interest on invested capital, storage, handling, depreciation, and maintenance, normally increases with the level of inventory. Finally, the shortage cost is a penalty incurred when we run out of stock of a needed commodity. It generally includes costs due to loss of customer's goodwill as well as potential loss in income.

2.5 Ordering Method

Method of ordering spare parts can be broadly classified into individual orders and permanent stock method. Individual orders are for parts that ordered only as they are needed. Permanent stock is material kept on hand continuously and permanent stock methods restocks automatically whenever designated quantities for such parts drop below certain inventory level. Permanent stock methods are either based on a fixed quantity or a fixed period, depending on the method of stocking. Other new methods of replenishing permanent stock include the partial delivery and deposit system, which are arranged through special contracts with suppliers. These new system simplify ordering, delivery, storage and administrative procedures. Figure 2.6 shows various ordering methods.

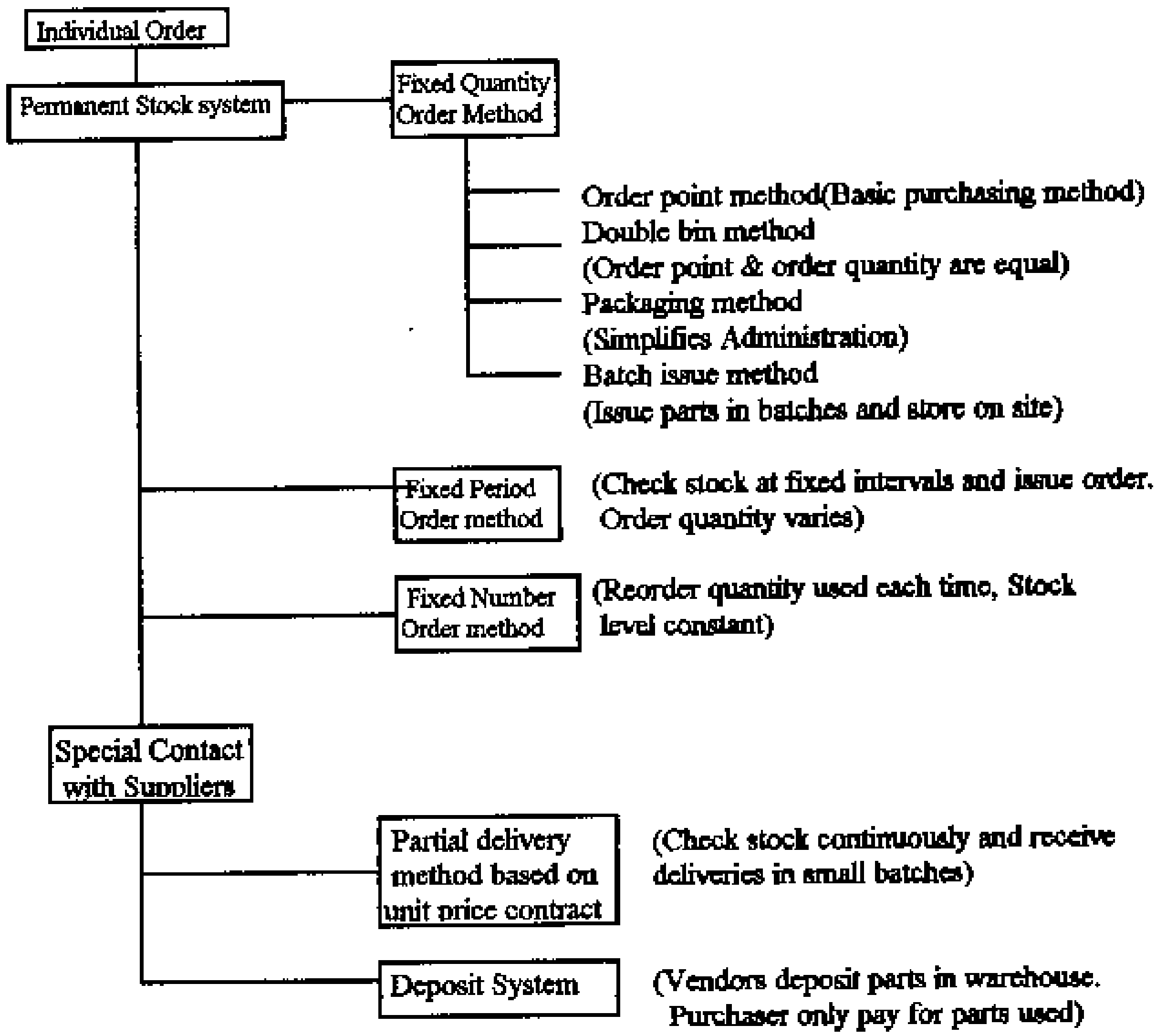


Fig. 2.5 Ordering methods

2.6 Joint Maintenance and Inventory policy

The first age based replacement policy was mathematically formulated by Barlow and Proschan [1] assuming that an unlimited number of spares units are immediately available when replacement is needed. For real time situation this is not a judicious assumption. Lead time, replacement time along with ordering policy have to be incorporated in the original model. Thomas & Osaki [2] developed an ordering policy for a single operating item considering constant lead time for spare delivery which can be summarized as follows:

Let an item start working at time zero. If that item does not fail upto a pre-specified ordering time t_0 ,an order for replacement is made at t_0 and the delivered spare is replaced immediately when it arrives, irrespective of the condition of the original item. On the other hand if the item fails before the ordering time t_0, an immediate order is placed and the delivered spare is replaced immediately when it arrives .Once spare is replaced, the cycle is repeated for an infinite time span. The cycle can be defined from the time that a delivered spare starts working to the time at which the next delivered spare starts working. Optimum ordering policy was determined by minimizing the cost function for each cycle.

Osakiet al. developed a generalized form of the model considering no repair or minimal repair of the operating item. His policy may be stated as:

an order for a spare unit is placed at a specified time t_0, and on delivery after a constant lead time L, the spare is kept in stock upto another specified time t_1 ($>$,t_0+ L). When the operating unit fails before t_o, a spare unit is ordered immediately. When the operating unit fails between $t_o + L$ and t_1, it is replaced by the spare unit in stock. The jointly optimal ordering time t^*_o ($O < t^*_o < \alpha$) and replacement time t_1 ($t_o + L$) are determined by minimizing the expected total inventory costs per unit time. This model was developed assuming constant lead time. Park and Park[3] developed a model with variable lead time.

All the above models aimed at the determination of an optimal ordering policy considering inventory function only. They take failure pattern of the operating item into account only to determine the order placement period and no consideration was given to the cost of the item related to maintenance.

The maintenance related cost of the item is reasonably high and thus can not be ignored in real time situations. Kabir and Olayan [4] indicated the complexity in developing a mathematical model that incorporates the maintenance related costs .They developed an (S. s. T) simulation model, where S is the maximum inventory level, s is the re-order level and T is the preventive replacement period. This model considered continuous review inventory policy with individual preventive maintenance of the operating item. This policy can be described as: an order of (S-s) spare units will be placed whenever the inventory level falls to s. The operating unit will be preventively replaced after interval T provided a spare is available. If the operating unit fails before T, it will be replaced as soon as the spare is available. The order lead time is considered to be randomly distributed. Optimal values of the decision variable (S, s, T) are determined by minimizing the expected total cost per unit time, where cost components include both maintenance and inventory related costs. The cost formulation of the model is as follows:

i) Ordering cost occurs at a unit replacement if the inventory level is equal to or below the reorder level.

ii) Shortage cost for a unit is incurred over the length of time for which a failure replacement is delayed due to unavailability or late arrival of stocks.

iii) Holding cost is computed for each spare unit individually and over the time it is held.

iv) Replacement cost for unit is according to the type of replacement.

The result obtained by Kabir & Olayan are very much impressive in terms of cost effectiveness, when compared to Barlow and Proschan age replacement policy supported by optimal (S, s) policy. However, the model did not consider replacement time and also the total system consisted of single or few items. But in real time situations, many items are to be replaced, so block replacement policy must prove more cost effective.

Acharyael [5] developed a mathematical model that considered block replacement of operating items for the first time with periodic review of spares inventory. They assumed that the ordering for replenishment of replacement spare is done at preventive replacement instants only.

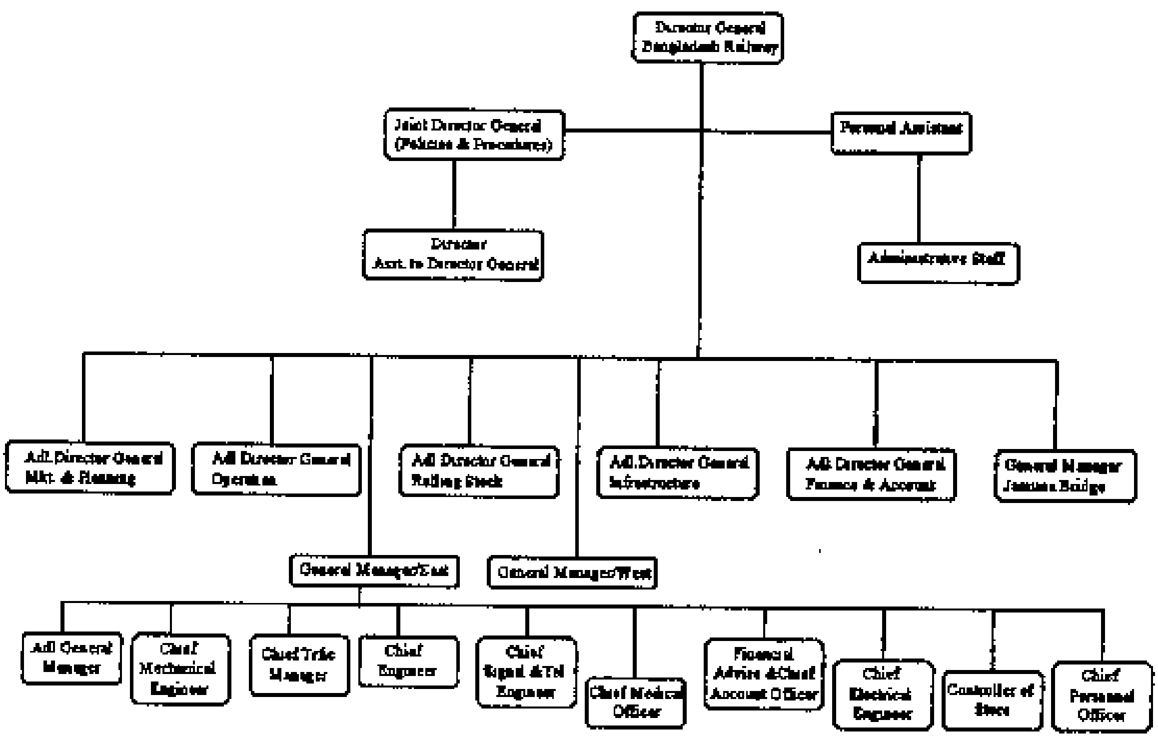
CHAPTER THREE

Inventory and Maintenance Policy of Railway

- **Introduction**
- **Inventory Policy of Bangladesh Railway**
- **Maintenance System of Diesel Electric Locomotive**

3.1 Introduction

This chapter deals with the present maintenance and inventory system of Bangladesh Railway. This is mainly confined to maintenance and inventory of Diesel Electric Locomotives. Store Department is mainly responsible for supplying materials to various Department of Bangladesh Railway and Mechanical Department is responsible for the maintenance of Locomotives, Rolling Stocks , Machines and equipment etc.The first part of this chapter deals with the inventory system and the second part with the maintenance system of Diesel Electric Locomotive. The Organogram of Director General of Bangladesh Railway is shown below upto two stages.



Director General of Bangladesh Railway's Organogram

3.2.1 Procurement of Store Materials:

Store department procures materials required for various departments of Bangladesh Railway. The main objectives are to ensure

- quality of the material,
- optimum quantity to be procured,
- timely delivery of materials to the work centers,
- timely procurement of materials and
- the most economic price is negotiated.

3.2.2. Storing and Stock Control:

The first part is concerned with supervision, identification and storing of material in a safe and good condition. It protects against pilferage, damage and obsolescence. The second part is concerned with movement of goods into and out of stores and the levels of stocks at all times.

3.3 Maintenance System of Diesel Electric (DE) Locomotive:

Diesel Electric Locomotives are used in Bangladesh Railway as motive force in Train operation. A Diesel Electric Locomotive consists of one or more Diesel Engines operated from single control. Engine drives a main Generator and supplies electric current to traction motors geared to the axles. Different Electrical equipment and control devices are used to transmit the power developed by the diesel engine to the Locomotive driving wheel.

The main components of D. E. Locomotive are :

- Diesel Engine
- Air compressor
- Vacuum Exhaustor
- Main Generator
- Traction Motors
- Driver's Control Station
- Electrical Cabinet
- Auxiliary Generator
- Storage Batteries
- Trucks

Besides, Locomotives have many safety devices installed to protect the engine, electrical equipment and brake equipment. These safety devices protect the equipment from damage by automatic shutdown or give indication of the faulty operation.

The complete and systematic inspection of Diesel Electric Locomotive is of paramount importance for ensuring proper performance. The periodic inspection schedules have been set up, adherence to which will result in standardization of maintenance, and provide the necessary information for correct repair and the efficient operation of each unit.

Adjustments are not necessarily required at each inspection, but as examination is not a long procedure, the important components must be inspected regularly. Any peculiarity in sound or appearance of any moving parts must be carefully investigated and any abnormal condition to be corrected without delay. The faulty operation of any part may affect others and will eventually cause failure and possible serious damage.

Instruction Books, Maintenance and Instruction Manuals, Service Manual, owners manuals and other manufacturers service and maintenance publications are used as guide line for maintenance. However , changes or revisions to these books or manual may be issued from time to time.

3.3.1 Planning and Scheduling of Diesel Electric Locomotive:

The intervals after which a Diesel Electric Locomotive will be Overhauled is based on the periods established for scheduled maintenance inspections as follows:

Diesel Electric Locomotives are normally scheduled for performance of a maintenance event every 30 days and will undergo a General overhaul (GOH) every 6 (six) years on completion of the preventive maintenance inspection cycle illustrated in tables I and II

Table I - Diesel Electric Scheduled Inspection Interval

Inspection Type	Interval Standard	Time
C	Every 30 Days	6 Hrs. / .75 Day
D	Every 90 Days	8 Hrs. / 1 Day
E	Every 180 Days	16 Hrs. / 2 Days
F	Every 365 Days	80 Hrs. / 10 Days
G	Every 1095 Days	168 Hrs. / 21 Days
GOH	Every 2190 Days	360 Hrs / 45 Days

Table II- Diesel Electric Scheduled Inspection cycle

Months #	1	2	3	4	5	6	7	8	9	10	11	12
Insp. Type	C	C	D	C	C	E	C	C	D	C	C	F
Month #	13	14	15	16	17	18	19	20	21	22	23	24
Insp. Type	C	C	D	C	C	E	C	C	D	C	C	F
Month #	25	26	27	28	29	30	31	32	33	34	35	36
Insp. Type	C	C	D	C	C	E	C	C	D	C	C	G
Month #	37	38	39	40	41	42	43	44	45	46	47	48
Insp. Type	C	C	D	C	C	E	C	C	D	C	C	F
Month #	49	50	51	52	53	54	55	56	57	58	59	60
Insp. Type	C	C	D	C	C	E	C	C	D	C	C	F
Month #	61	62	63	64	65	66	67	68	69	70	71	72
Insp. Type	C	C	D	C	C	E	C	C	D	C	C	GOH

In table I, the different schedules, the time interval for different schedules and the time require to complete a particular shedule have been shown. For example "C" schedule should be done in every month and the time for completion of this schedule is 6 hrs. Similarly "D" schedule should be done in every three months and its completion time is shown in the table. The Schedules are Progressive schedules i.e. at the time of 'E' Schedule, 'C' & 'D' Schedules are also done.

In Table II the different schedules to be carried out for a Locomotive in her six yearly cycle is shown. In the 1st month "C" schedule is to be done for a Locomotive and in 72nd month "G" schedule is to be done. C,D & E are called light schedule and F,G & GOH are called heavy schedule. As the schedules are progressive, at the time of GOH all the schedule are done i.e. all the tasks of different schedule are performed. Table shows the different schedules to be done in different month. For all the schedules, there are prescribe forms for the tasks to be performed.

Parts Record :

It is maintained for each assembly and other components which are individually numbered. This gives a ready answer to any query regarding the location of any component at any time. It is also helpful in ascertaining a particular component failed repeatedly.

Locomotive History File :

For each Diesel Electric Locomotive, history file is maintained which contains following information:

(a) Part nos. of components, Manufacturers clearances.

(b) Details of all schedule maintenance done

(c) Details of lub. oil changes & readings

(d) Details of Component changed.

(e) Details of all accidents, failures and troubles

(f) Details of all modifications, trial conducted on the Locomotive.

3.3.2 Revisions to Scheduled Inspection Interval:

Diesel Locomotive cyclical inspection schedules, procedural guidelines and controls are developed to provide inspection, repair, management and control information necessary for the economical efficient operation and maintenance of each locomotive and maintenance facility. This optimizes fleet availability and reliability.

Scheduled inspection intervals can be affected by technological change and operational experience. It is the responsibility of technical service and Quality Assurance personnel to determine and recommend any revision to the inspection intervals that can benefit maintenance operations while sustaining locomotive fleet and facilities objectives. Any recommendation for revision to the inspection intervals must have the technical approval of the Chief Mechanical Engineer before submission for final approval. Recommendations are to be submitted to the Chief Executive, Central Locomotive Workshop/Parbatipur for production impact assessment by the Production Planning and Control Committee. Based upon their findings, the Chief Executive, Central Locomotive Workshop/Parbatipur may submit the recommended change to the Joint Director/Mechanical for issuance of a directive and revision of this manual.

Scheduled Inspection and Overhaul

The Master Locomotive Maintenance Schedule (MLMS) and the Detailed Annual Maintenance Schedule (DALMS) are prepared to plan, balance and control the flow and workload of locomotive preventive maintenance scheduled inspections, General Overhauls and unscheduled special repairs into maintenance facilities These also enable the facility management authorities to know the volume and nature of the maintenance workload and consequently forecast and prepare the physical, human and financial resources accordingly. Once the MLMS and DALMS schedules have been prepared, they should not normally be altered except under special circumstances and for which permission should be obtained from the CMS's office. This will include situations when essential materials are not available to meet the schedule, or when premature locomotive failures alter the workload, or indicate that maintenance intervals (overhauls) should be decreased to eliminate the failures. Individual facilities and operating Districts/Divisions are required to adhere rigidly to the dates laid down in the detailed annual Locomotive Maintenance Schedule so that the locomotive and component inspection, repair and production schedules in associated shops are not affected.

Special Repairs

Special Repairs may be incorporated into production plans:

- at times of locomotives failure ;
- when locomotives are damaged as a result of derailment or collision;
- when programmed modifications to locomotives are to be made.

Prior to release to service from a maintenance facility locomotives subject to special repairs must receive a schedule 'B' Trip Inspection.

The following works are carried out on locomotives in the major Running Sheds and Facilities at Pahartali, Chittagong Port Yard, Dhaka, Ishurdi and Parbatipur :

- 'A' Trip Servicing ;
- Light Running Repairs ;
- Scheduled : C (30 day); D (90 day); E (180 day) inspections ;
- Minor Special Repairs, Component changeouts and Trouble Shooting;
- Lubricant and Fuel Oil Analysis (CGPY excepted) ;
- Preparation of locomotives for shipment to workshop or CLW facilities for heavy repair and GOH.

The following works are carried out on locomotives in workshops at Pahartali, Dhaka and Parbatipur :

- Intermediate Scheduled F (360 day) and G (1080 day) Inspections ;
- Intermediate Special Repairs and Component change-outs too heavy to be undertaken in Sheds;
- Load Box Testing of Diesel Electric Locomotives ;
- Overflow of General Overhauls from the CLW on the advice of the CWX/CLW and approval of the Chief Mechanical Engineer;
- Overflow of Component Rebuilds from the CLW on the advice of the CEX/CLW and approval of the Chief Mechanical Engineer;
- Minor equipment modifications.

The following works are to be carried out at the Central Locomotive Workshop :

- All Locomotive General Overhauls;
- All Locomotive Component Rebuilds;
- Special Repairs too heavy to be undertaken at the Workshops;
- Heavy Wreck Repairs (Special);
- Programmed Locomotive Electrical Modifications, Rehabilitation's and Rewiring;
- Lubricant and fuel oil detailed analysis.
- Minor Locomotives Spares Manufacture.

3.3.3 Accuracy of Reports and Forecasts

The success of the preventive maintenance shopping program is dependent upon the accuracy and timely submission of the Management Information System(MIS) and Production Planning & Control (PP&C) reports from each facility. Works Managers must ensure both accuracy and timely submission of reports from their facility to enable the PP&C Committee's review and updating of the forecasted shopping program each month.

Time Standards for Completion of Scheduled Works

The time standards for Scheduled Inspections work in Running Sheds, Workshops and the Central Locomotive workshop are as follows :

Type of Inspection	Time Standard
A	2 Hours
B	4 Hours
C	6 Hours
D	8 Hours
E	2 days
F	10 days
G	21 Days
GOH	45 Days

The breakdown of tasks and the time required to perform them may be shown on detailed inspection sheets to control the timely outrun of locomotives.

The time limits for Scheduled inspections, and for specific work tasks, are subject to change. Any change will be based upon analyses and evaluations conducted and recommended by personnel authorized by the Chief Executive, Central Locomotive Workshop, to perform such studies.

3.3.4 Work Performed Behind Schedule

When C or D inspection are not accomplished within 15 days of its programmed 30 or 90 days cycle, it is to be superseded by the next scheduled inspection at the earliest convenience by advancement of the next higher order inspection, i.e., 'C' inspection tasks are included in a 'D' inspection.

If not accomplished at the next scheduled date, 'E', 'F', and 'G' inspections, or General Overhauls, must be re-planned for the following inspection date and cannot be superseded by the next inspection in succession. Upon completion and release of a locomotive from GOH, the unit will be placed on the six years progressive cycle of preventive maintenance inspections.

CHAPTER FOUR

Simulation Model Development

- **Introduction**
- **Steps in Simulation Modeling**
- **The Conceptual Model**
- **Cost Formulation**
- **Simulation Software and Coding**
- **Simulation Procedure**

4.1 Introduction

This chapter is devoted to the concept of simulation and the development of simulation models, especially in the context of the present research problem. At first the nature of simulation is discussed along with the steps to be followed to develop a valid and credible simulation model. The next section describes the general problem stated in chapter one in the context of a specific maintenance organization system. This system and the components within it are mathematically and logically related to develop a simulation model. The final section of this chapter introduces the computer program and the SIMSCRIPT II.5 simulation language used to code the program.

4.2 Steps in Simulation Modeling

Most real-world systems are too complex to allow realistic models to be evaluated numerically, and these models can be developed by Simulation. In simulation computer is used to evaluate a model numerically over a time period of interest , and data are gathered to estimate the desired true characteristics of the model. The different types of simulation are used in analyzing real world problems .

It is the nature of the system elements that defines the type of the models, which may be of the following three dimensions;

a. static or dynamic,

b. deterministic or stochastic

c. continuous or discrete event.

A model simulating maintenance and inventory functions is expected to contain discrete, probabilistic events since the system experiences stochastic changes of its states only at countable numbers of points in time. Accordingly the simulation model developed in this chapter has to be dynamic, stochastic and a discrete event in type.

Detailed simulation modeling and coding are in fact just part of an overall simulation effort to understand or design a complex system. Figure 4.2 shows the necessary steps that will compose a typical, sound simulation study, and the relationship among them.

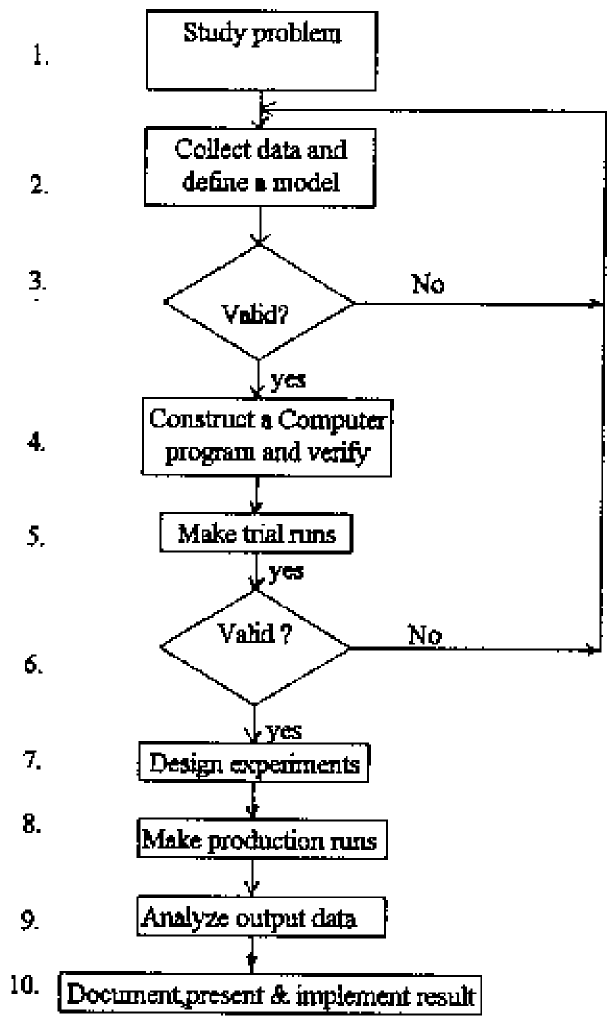


Figure 4.2. Steps in a simulation Study

Steps in simulation studies can be explained as follows:-

The problem for which simulation model is to be developed is identified and studied. Data related to the problem to be collected and a model for solving problem is to be defined. If the model is found valid, a computer program is to be developed. Otherwise model is to be redefined. Trial run of the computer program to be made. After successful trial run, steps to be followed are Design experiments, Production runs, Output data analysis, printing result, presentation and implementation of result.

Not all models are supposed to contain all these steps and be in the order stated. Some studies may contain steps that do not fit neatly into the sequence shown in figure 4.2. Moreover, simulation studies do not have a hard and fast sequential process. Therefore, it often may be a good decision to reshuffle the steps, in case new insights are obtained after any one of them. Fruitful simulation models could only be developed after the verification (checking of whether program is performing as intended) and validation (checking of whether the conceptual model is an accurate representation of the system under study). Credibility of the model is marked with successful implementation of the simulation results.

4.3 The Conceptual Model

The problem considered in this present work is to determine the Maximum Inventory and Re-order level for a particular type of component used in Diesel Electric Locomotive of Bangladesh Railway. The components are replaced after a certain interval of time T provided the spares are available. Otherwise components will be replaced as soon as the stock is replenished. If a component fails before time T , the failed component will be replaced after its failure if spare is available. The following assumptions have been made to develop the conceptual model.

1. A single type of operating component is considered only. The item is used in all Diesel Electric Locomotives. All the spares for the item, along with the operating one are identical in terms of their parameters and characteristics such as life time, design etc.
2. It is assumed that it is more cost effective to replace rather than repair any of the failed items.
3. All items are replaced after certain time intervals called the block replacement period. Any item failing between these group replacement instants are replaced instantaneously if spares are available.
4. The spares in inventory do not deteriorate with the passage of time.
5. The failure or block replacement of the component is perfect.
6. The failure rate for each item increases with time and each replacement introduces a new item with new life.
7. The unit cost of the items is a constant independent of time or order quantity.
8. The inventory policy to be investigated is continuous review (S,s) type.
9. The inventory shortage cost includes the direct loss of profit due to idling of the system and the indirect loss in terms of bad reputation of the organization.

4.4 Cost Formulations

Maintenance and inventory related costs and assumptions on their nature have been considered in this model. The maintenance costs are the individual breakdown replacement cost per unit item (C_f) and the block preventive replacement cost per unit item (C_p).

Among the inventory costs, the most important ones are the costs for carrying inventory. The cost of carrying inventory is not simply the storage cost but it includes the cost of the money tied up with the inventory and also other considerations such as cost of insurance, pilferage, deterioration, packing, obsolescence, costs of equipment and handling machine. This cost is also called inventory holding cost. Let (C_h) be the holding cost for each spare item held for each time unit. The cost of not having the required inventory or out-of-stock cost is accrued to the total cost when a spare part is not available at hand has to be backordered. This type of cost has direct effects on profit and indirect cost is bad reputation of the organization. Inventory shortage cost (C_s) is considered to be calculated for each unavailable spare item for each time unit as long as this unavailability remains. The ordering cost includes all the components encountered throughout the inventory procurement process. Let (C_o) be regular ordering cost. Maintenance costs include breakdown and block replacement costs which include cost of tools and equipment, labor and the costs of facilities such as electricity, gas, water etc.

Computation of the total cost for the system can be made in the following ways.

1. Ordering cost (C_o) is incurred after every instant the inventory level *(IL)* goes below the reorder level for the (S,s) system,and is charged instantaneously.

   $TC = TC_p + C_o$, for $s \geq IL > 0$

   where TC is the latest of most recently updated total cost and TC_p is the total cost previous to the placement of the order.

2. Inventory holding cost (C_h) is computed for the inventory level between any two events taking place in the system that generate demand for one or more spare parts. Let t be the present simulated time and t_e the time of the previous demand or inventory replenishment event. Then the holding cost is added to the total cost according to the following manner.

   $TC = TC_p + C_h\,(t - t_e)\,IL$ for $IL > 0$

3. The inventory shortage cost (C_s) is calculated for each unavailable spare part for each time unit so long this unavailability remains. When the inventory level falls below zero, no further demands could be satisfied and these are backordered, while the system remains idle until the shipment arrives and the inventory level is updated. This cost is calculated in a similar fashion as the holding cost.

   $TC = TC_p + C_s(t-t_e)IL$ for $IL < 0$

4. Block replacement cost (C_p) is included in the total cost after the fixed block replacement periods *(T)* in the following manner.

$$TC = TC_p + N_o . C_p$$

Where N_o is the total number of operating items. If the inventory level does not permit all the N_o items to be replaced in the preventive maintenance schedule, block replacement is carried out until the inventory is depleted. After that the rest $(N_o . IL)$ items are assigned a special mode which enables their replacement, when spares become available. In such case shortage cost for $(N_o . IL)$ items is incurred which is to be added to total cost and can be charged as

$$TC = TC_p + IL.C_p + (N_o - IL)\ C_s(t\text{-}t_e) \quad \text{for } N_o > IL > 0$$

5. The individual failure replacement cost (C_f) is calculated in the event of failure of N_i items provided required number of spares is available. In case of insufficient inventory, the available spares are exhausted. The rest $(N_i - IL)$ items are then back ordered and the operating unit remains idle until the inventory is replenished. These unsatisfied demands are then charged with inventory shortage cost only. Taking t as the present simulated time, t_e the time of the next event,

$TC = TCp + N_i C_f$, if all demands could be satisfied

$= T_{cp} + ILC_f + (N_i - IL).C_s(t - t_e)$, Otherwise

The total cost is zero for $t=0$ and increases with time as all these various costs are added to it. This continues until a specified simulation period T is reached. After that the total cost is divided by the simulation period to get the total cost per unit time.

4.5 Simulation Software and Coding

SIMSCRIPT II.5 is a general programming language containing the capabilities for building discrete-event, continuous, or combined simulation models. It has the programming feature of FORTRAN, ALGOL AND PI/L Law & Kelton. Furthermore its English-like and freeform syntax make SIMSCRIPT II.5 simulation programs almost self-documenting. Because of its general process approach, its sophisticated data structures, and its powerful control statements, this language is often used for large, complex simulation models.

The conceptual simulation model described in the previous sections falls into the discrete event category because it is evident that the state of the proposed system described in the previous section changes with discrete points in time. All discrete event models share a number of common components and there is a logical organization for these components that promote the coding, debugging and future changing of the computer program. The following components are expected to be found in most discrete event models.

System state:

The collection of state variables necessary to describe the system at a particular time.

Simulation clock:

A variable giving the current value of the simulated time.

Event list:

A list containing the next time when each type of event will occur.

Statistical counters:

Variable used for storing statistical information about system performance.

Initialization routine:

A subprogram to initialize the simulation model at time zero.

Timing routine:

A sub-program that determines the next event from the event list and then advances the simulation clock to the time when that event is to occur.

Event routine:

A subprogram that updates the system state when a particular type of event occurs.

Library routines:

A set of subprograms used to generate random observations from probability distributions that were determined as part of the simulation model.

Report generator:

A subprogram that computes estimates (from the statistical counters) of the desired measures of performance and produces a report when the simulation ends.

4.5.1 Organization of the Program

A computer simulation program consists of the following modules:-

Preamble:

It is the introductory module whose statements are declarative and non-executable. This module is used to define all the building blocks, the global variables, the basic time unit of time for the simulation clock, and the desired measure of system performance.

Main:

This is the module where the execution of a SIMSCRIPT program begins. In the present program this routine is used to read input cost and statistical parameters for the simulation by calling the COST and STATISTICS routines, to initialize the system by calling the INITIALIZE routine, and to place the *initial* event records in to the event list using the ACTIVATE statement. The simulation actually begins after the execution of the START SIMULATION statement, which is nothing but just a call to the in-built timing routine. The control then is transferred between the three basic events, arrival of a regular or expedited order, block preventive and breakdown replacement. These events are described in the CHECK, FAILURE and REPLACEMENT routines respectively. Whichever event takes place, the system operating cost is updated by the routine EVALUATION. Execution of the END statement in the MAIN module will occur only when the event list no longer contains any process notices. The simulation will also terminate if a STOP statement is executed in some routine.

Cost:

This routine is called from the MAIN module to read the input cost parameters. Costs include order cost, inventory holding and shortage cost and preventive replacement and breakdown replacement cost.

Statistics:

This routine called from the MAIN module to assign the values for the statistical parameters for the system. These are the statistical parameters of the component life time and order lead time distributions and the number of the presently employed random number generating stream.

Initialize:

This routine, when called from the MAIN, assigns the initial state to the system parameters. The operating components are assigned their lifetimes, the performance parameters are set to their initial value of zero. The simulation clock remains still at time equal to zero.

Replacement:

Control is transferred from the MAIN to this routine at the instants of block preventive replacement. The following actions are taken through this event routine when invoked.

1. A demand for the replacement of all the operating components is created.
2. The items that are due to fail at the present simulated time are identified and replacement is carried out as long as spares are available.
3. All other items are then replaced as long as the inventory level remains above zero.
4. If there are some items that are failed but still could not be replaced due to spare shortage are assigned to remain failed until the next time unit.
5. If there are some items that are still operating, then these are assigned a special mode which enables the program to mark them and carry out replacements whenever spares are available.
6. The block preventive replacement costs are calculated according to the cost formulations and the total cost is updated.

Failure:

This routine is also invoked from the MAIN when the present simulation time coincides with the breakdown time of one or more of the operating components. The following action are taken accordingly.

1. The total number of the components failed on this instant is determined by calling the routing IDENTIFY. The demand for spares is created for these items. Failed items are replaced with new ones if spares are available.

2. In case of spare unavailability, the operating component remains idle until the spare is available.

3. A check is carried out if there are such items to be replace as stated in the action number five in the previous routine. These items are replaced if spares are available.

Evaluation:

This routine is called from MAIN to calculate the total operating cost for the simulation period. It also checks the inventory level and prevailing order status to create a regular order.

Order:

This routine is called from EVALUATION to dispatch a regular order spare parts. An order for *(S-present inventory level)* items for the *(S,s)* system is placed if the order status is in *off* state.

Report:

This routine is activated from MAIN after the simulation is over. It prints the system and cost parameter inputs and also the output values of total cost per unit time.

4.6 Simulation Procedure

After setting data, the job left remains determination of the procedure to search for the optimum values of the decision variables. These are the parameters of continuous inventory review technique, the optimal values of maximum allowable stock level *(S)*, reorder level *(s)* and the optimal block replacement interval *(T)*.

Selection of the ranges of the values of the decision variable has been made at first. Priority has been given to the choice for suitable values for the system and at the same time avoid heavy computational time. The maximum allowable stock level S and the stock reorder level s have been varied from 200 to 600 units of spare items and O to 100 units of spare items respectively with increments of 50 and 10 units respectively. The block replacement interval T has been searched from 100 to 800 time units with increments of 100 time units. After finding approximate ranges of the decision variables, search for the optimal value *(S,s)* and block replacement time is made by varying decision variables by 10 units.

The simulation program has been run with the chosen values of the system parameters and decision variables for the existing system of Railway and for the combined system of Inventory and maintenance.

The total cost per unit time is determined with the presented sets of data of different parameters with Optimal value of Block Replacement Period and existing block replacement period for the component under consideration.

The optimal value of Inventory can be determined from the model by ignoring maintenance related costs. similarly optimal maintenance cost can be determined by ignoring Inventory related costs.

CHAPTER FIVE

Experimental Data

- **Introduction**
- **Input Data**
- **Experimental Data**

5.1 Introduction

This chapter contains the most important part of the project work. This chapter deals with the collection of failure particular of the component under consideration to determine its distribution, development of a valid stochastic simulation model.

After the development of a valid and credible simulation model, the next task is to run the program. This is the determination of initial conditions for the simulation runs, the length of warm-up period, the length of simulation runs and the number of independent simulation runs; Law and Kelton, [6]

5.2 Input Data

The step next to problem formulation is the collection of information and data on the system of interest. Five years failure data of Dhaka based Diesel Electric Locomotives has been collected. These failures were due to failure of different components of Locomotive. Present work is confined to failure of Locomotive due to compressor. Failure particulars of Locomotives due to compressor is given in appendix-A. The model developed is complex and real data related to inventory and Maintenance costs are difficult to obtain as the detail particulars do not maintained in the respective departments.

5.2.1 Component Life Time Distributions

The data collected for failure of Diesel Electric Locomotive due to compressor is tested to find out component life time distributions. Test result in finding the distribution is given in Appendix-B. This data fit into Weibull distribution. For order lead time, Weibull distribution is assumed.

This continuous distribution, widely known as a *family of distribution* , Kabir & Olayan, [4] is very much versatile and play a very important role in the statistical analysis. In simscript II.5, pseudo-random data, matching weibull distribution can be generated by calling the in-built routine weibull.f (α,β,n) where n is the number of random number generating stream. The statistical information on the Weibull distribution is given in Aappendix-C along with the typical shapes that can be produced by the Weibull distribution for the failure density function, cumulative failure distribution and hazard rate.

5.2.2 Selection of the Cost Values

Inventory Related Costs:

The inventory related costs are the regular ordering costs, inventory holding and shortage costs. The regular ordering cost (C_o) includes administrative cost such as Paperwork, postage, processing cost of ordering, rent of building, depreciation of m/c & equipment used in processing order, advertising cost, Bank charge etc. It has been taken Tk.3000.00. The inventory holding cost per spare per unit time (C_h) has been considered as 25% of the unit cost per year and is Tk. 1.25. Unit cost of the component under consideration is Tk. 950.00. Similarly, the inventory shortage cost has been taken Tk.50.00 per spare per unit time.

Maintenance Related Costs:

Maintenance related costs are the costs incurred due to failure replacement for individual item and preventive block replacement of items after a definite interval of time. Both failure and preventive replacement costs include cost of facilities, land & building, cost of m/c & equipment used for replacement, direct and indirect labor cost. The cost of preventive replacement per item (C_p) has been considered 12% of the cost of the component. Here (C_p) is Tk. 114.00 and (C_f) has been considered double of (C_p) and is Tk. 228.00.

5.3 Experimental Data

First, a set of data of different parameters for the system under consideration is fixed and after that only one parameter is varied keeping all other parameter unchanged to test the effect of the varied parameter on the system under consideration. From the chosen valued of the various input parameters, a number of data groups have been set to study the effect of these parameters on system response. The simulation program has been executed with these data sets with necessary replications. Following are different sets of data taken to determine (S,s) and to analyze the effect of different parameters on the system.

a. Data of different parameters:

The following set of data has been used for the system under consideration.

α_t	β_t	α_o	β_o	C_f	C_p	C_h	C_s	C_o
1.17	21.48	3.00	10	228.0	114.0	1.25	50.0	3000

Table 5.3a Data of different parameter

b. Study on Ordering Cost:

Here only the regular ordering cost is varied keeping the values of other parameters constant. The data sets taken to study the effect of regular ordering cost on total cost per unit time are,

α_t	β_t	α_o	β_o	C_f	C_p	C_h	C_s
1.17	21.48	3.00	10	228.0	114.0	1.25	50.0

Data Set	1	2	3	4	5	6	7	8
C_o	1000	2000	3000	4000	5000	6000	7000	8000

Table 5.3b. Data sets to study the effect of regular ordering cost.

c. Study on Inventory Holding Cost:

Only the Inventory holding cost is varied keeping other parameters unchanged. The following data sets have been taken to test the effect of inventory holding cost on the total cost per unit time

α_t	β_t	α_o	β_o	C_o	C_f	C_p	C_s
1.17	21.48	3.0	10	3000	228	114	50

Data Set	1	2	3	4	5	6	7	8
C_h	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0

Table 5.3c. Date sets to study the effect of inventory holding cost

d. Study on Inventory Shortage Costs:

Only the Inventory shortage cost is varied keeping other parameters unchanged. The following data sets have been taken to test the effect of inventory shortage cost on the total cost per unit time.

α_t	β_t	α_o	β_o	C_f	C_p	C_h	C_o
1.17	21.48	3.00	10	228.0	114.0	1.25	3000

Data Set	1	2	3	4	5	6	7	8
C_s	0	50	100	150	200	250	300	350

Table 5.3d. Data sets to study the effect of inventory shortage cost.

e. Study on Block Replacement Cost:

Only the Inventory block replacement cost is varied keeping other parameters unchanged. The following data sets have been taken to test the effect of block replacement cost on the total cost per unit time.

α_t	β_t	α_o	β_o	C_f	C_s	C_h	C_o
1.17	21.48	3.00	10	228.0	50.0	1.25	3000

Data Set	1	2	3	4	5	6	7	8
C_p	90	100	110	120	130	140	150	160

Table 5.3e. Data sets to study on the effect of block replacement cost.

f. Study on Failure Replacement Cost.

The failure replacement cost is varied keeping other parameters unchanged. The following data sets have been taken to test the effect of failure replacement cost on the total cost per unit time per unit time.

α_t	β_t	α_o	β_o	C_p	C_s	C_h	C_o
1.17	21.48	3.00	10	114.0	50.0	1.25	3000

Data Set	1	2	3	4	5	6	7	8
C_f	180	200	220	240	260	280	300	320

Table 5.3f. Data set to study the effect of individual item failure replacement cost.

g. Study of Block Replacement Period:

The block replacement period is varied keeping other parameters unchanged. The following data sets have been taken to test the effect of block replacement period on the total cost per unit time.

α_t	β_t	α_o	β_o	C_p	C_s	C_h	C_o
1.17	21.48	3.00	10	114.0	50.0	1.25	3000

Data Set	1	2	3	4	5	6	7	8
T	100	200	300	400	500	600	700	800

Table 5.3g. Data set to study the effect of block replacement period on total cost.

CHAPTER SIX

Results and Discussion

- **Introduction**
- **Effect of different Parameters**
- **Results on Cost Effectiveness**

6.1 Introduction

This chapter presents results obtained from the previously set data by running the simulation program. The results for all the data sets have been presented in both tabular and graphical forms. Effects of the various cost parameters on system performance is analyzed in this chapter.

6.2.1 Effect of Maximum Inventory Level.

Program has been run to test the effect of the decision variable maximum inventory level (S) on the total operating cost per unit time keeping other parameters fixed . Maximum Inventory Level has been determined with fixed block replacement period T for the component under consideration. The fixed block replacement period for the component under consideration is 365 days. The total cost per unit time with different values of S obtained with the fixed set of data of different parameters is presented in Table 6.2.1.

Sl.No.	Maximum Inventory S	Total Cost per unit Time
1	200	851
2	250	484
3	300	208
4	350	260
5	400	312
6	450	375
7	500	439
8	550	521
9	600	652
10	650	846

Table 6.2.1 Effect of Maximum Inventory Level on total cost per unit time

The graph plotted for different values of S and the total cost per unit times shown in figure 6.2.1.The cost function is found to be convex. This is because lower values of (S) implies lesser inventory on hand and need more frequent orders. It may even induce significant inventory shortage cost. On the other hand, keeping larger maximum inventory level is penalized by substantial load of inventory holding cost.

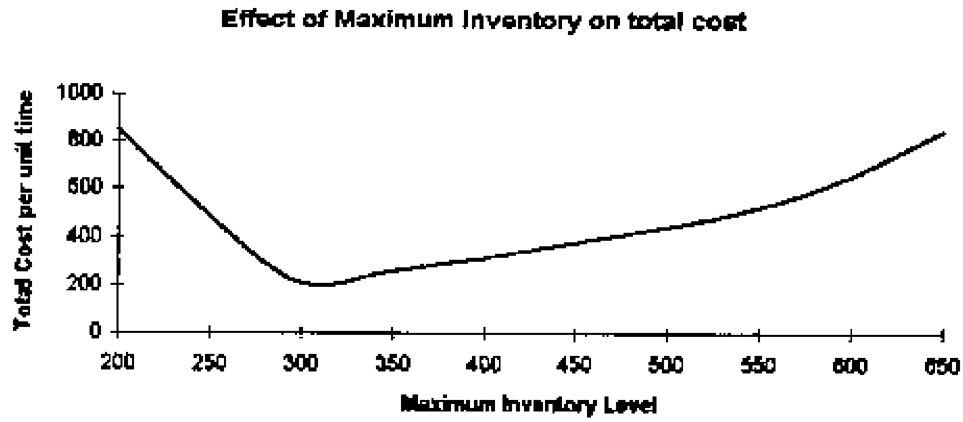


Figure 6.2.1 Effect of Maximum Inventory Level on total cost per unit time

6.2.2 Effect of Reorder Level on Total Cost

The total cost per unit time with different values of reorder level s obtained with the fixed set of data of different parameters is presented in Table 6.2.2.

Sl No.	Reorder Level s	Total Cost per unit Time
1	0	821
2	10	650
3	20	480
4	30	395
5	40	300
6	50	250
7	60	208
8	70	235
9	80	295
10	90	425
10	90	575

Table 6.2.2 Effect of Reorder Level on total cost per unit time

The graph plotted for different values of reorder level s and the total cost per unit time is shown in figure 6.2.2. The cost values have been obtained for the existing system for various values of the reorder level while keeping the other parameters constant. The cost function in this case has also been found to be convex. This can be explained due to the fact that smaller reorder levels cannot guard against sudden large demands (those in cases of block replacements) and results in high inventory shortage cost. At the same time, larger reorder level means a considerable inventory has to be carried throughout, which again, increases the total cost.

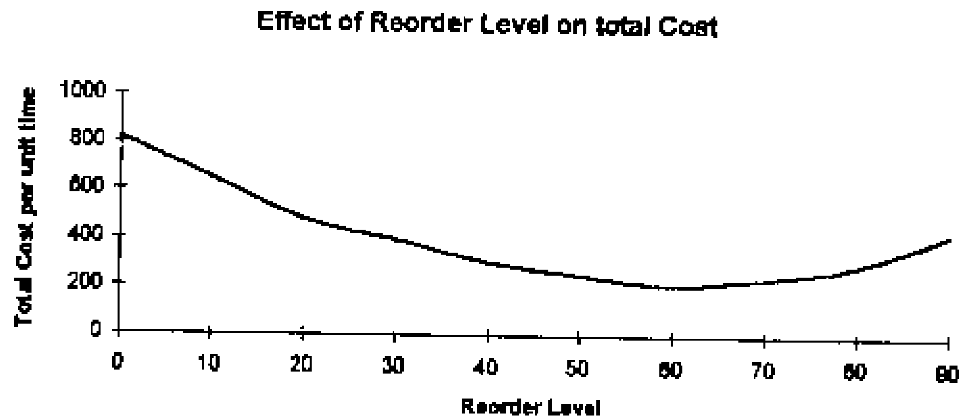


Figure 6.2.2 Effect of Reorder Level on the total operating cost per unit time

6.2.3 Effect of Block Replacement Period on Total Cost

To investigate the effect of block replacement period on total cost program was executed for a single set of (S, s) values and different values of block replacement periods while keeping the other parameters constant. The total cost per unit time with different values of block replacement period obtained with the fixed set of data of different parameters is presented in Table 6.2.3

Sl No.	Block Replacement period T	Total Cost per unit Time
1	100	8551
2	200	4183
3	300	837
4	400	222
5	500	1260
6	600	884
7	700	3304
8	800	4314

Table 6.2.3 Effect of Block Replacement Period on total cost per unit time .

The total cost per unit time for different values of block replacement period is shown in figure 6.2.3. It shows several minimum points with an overall downward trend. Riggs [8] suggests that the first minimum point of the cost function is taken to be the optimum point if this value is lesser than the cost obtained considering individual breakdown costs only.

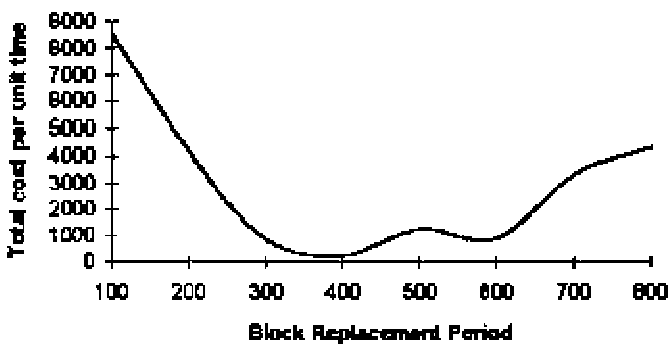


Figure 6.2.3 Effect of Block Replacement Period on Total Cost per unit time

6.2.4 Effects of Ordering Cost

Ordering cost directly influences the optimization of inventory related variables and thus have significant effect on both the combined system and the existing system of maintenance and inventory policies of Bangladesh Railway. This is reflected in the numerical results presented in table 6.2.4

Data Set	Combined system with optimal T			Existing system with fixed T		
	S	s	Total Cost	S	s	Total Cost
1	240	40	190	300	60	208
2	250	50	191	300	60	208
3	260	60	192	300	60	209
4	260	60	195	300	60	209
5	270	65	198	300	60	209
6	270	65	201	300	60	209
7	280	65	205	300	60	210
8	280	70	210	300	60	211

Table 6.2.4. Results illustrating the effects of ordering cost on total cost.

Graphs plotted with different values of ordering cost for the combined system and the system under study is shown in figure 6.2.4a and 6.2.4b. Increase in ordering cost causes the system to operate with higher inventory levels in order to preclude the events of more frequent ordering. For the existing policy, the total cost per unit time increases with the increase of ordering cost with out affecting the decision variables. So optimization of maintenance or inventory policy only can not give global optimal solution.

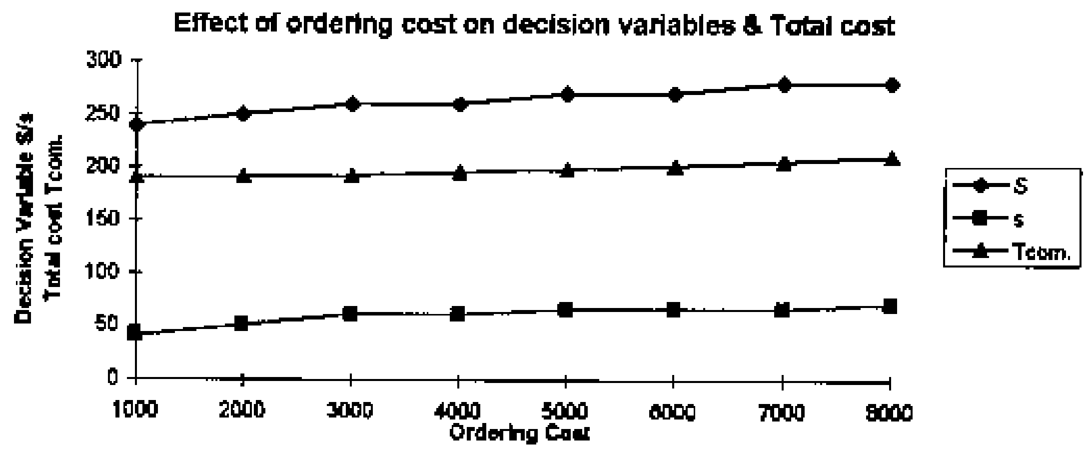


Figure 6.2.4a. Effect of ordering cost on decision variables & total cost.

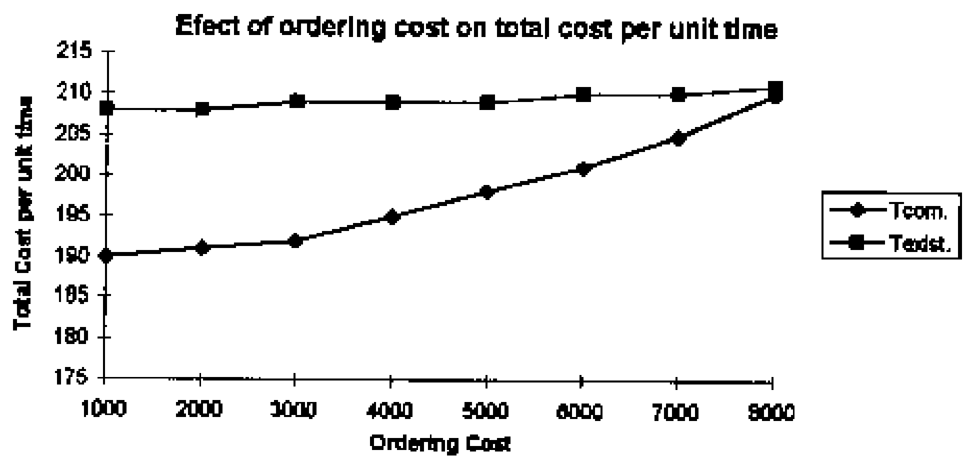


Figure 6.2.4b. Effect of ordering cost on total cost per unit time for the existing and combined system.

6.2.5 Effects of Inventory Holding Cost

The results obtained with different data set of Inventory holding costs are presented in table 6.2.5 for the combined system and the existing system.

Data Set	Combined system with optimal T			Existing system with fixed T		
	S	s	Total Cost	S	s	Total Cost
1	330	70	170	300	60	171
2	320	60	195	300	60	300
3	310	60	199	300	60	471
4	300	50	201	300	60	621
5	290	50	211	300	60	721
6	280	50	219	300	60	921
7	280	40	228	300	60	1100
8	270	40	246	300	60	1271

Table 6.2.5 Results illustrating the effects of inventory holding cost on system behavior.

Graphs plotted with these results are shown in figure 6.2.5a and in figure 6.2.5b. It is found that the maximum inventory level and the reorder level decrease with the increase of Inventory Holding Cost. The impact of Inventory Holding Cost on the system is very significant. The total cost per unit time becomes very less when the Inventory holding cost is very low. It reduces shortage cost, frequent ordering cost by maintaining higher Inventory and Reorder levels.

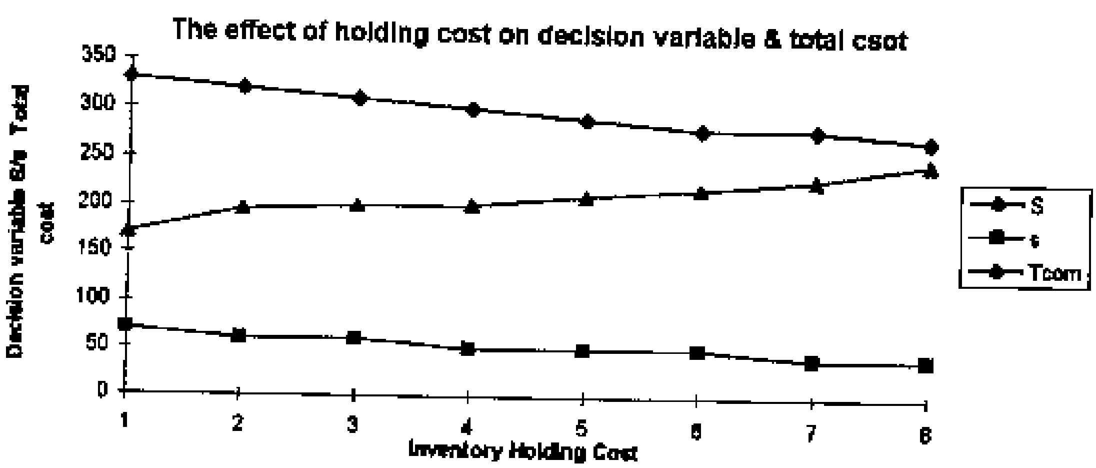


Figure 6.2.5a. Effect of holding cost on decision variables and total cost.

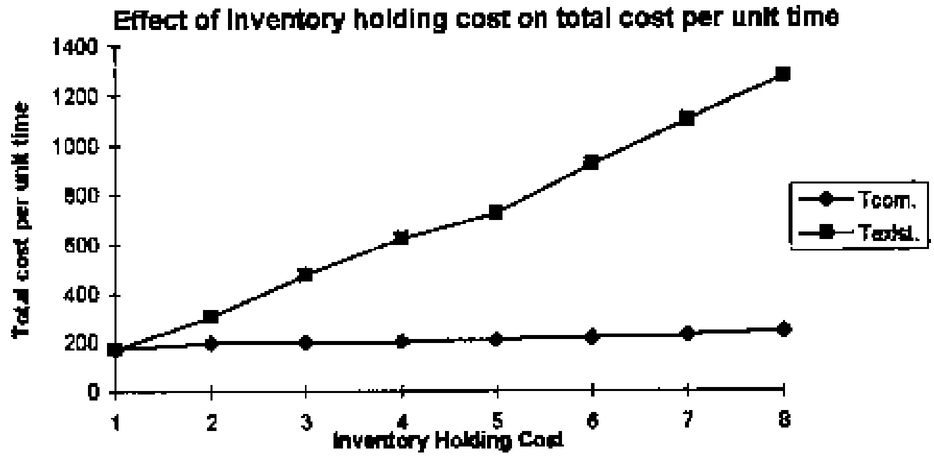


Figure 6.2.5b. Effect of holding cost on total cost per unit time for the existing and combined system.

6.2.6 Effect of Inventory Shortage Cost

Results for the investigation on the effects of inventory shortage cost on system behavior is given in table 6.2.6.

Data Set	Combined system with optimal T			Existing system with fixed T		
	S	s	Total Cost	S	s	Total Cost
1	250	25	170	300	60	207
2	260	60	192	300	60	208
3	265	60	194	300	60	210
4	270	70	197	300	60	211
5	280	75	199	300	60	213
6	290	75	202	300	60	214
7	300	80	204	300	60	215
8	300	80	211	300	60	217

Table 6.2.6 Results illustrating the effects of inventory shortage cost on system behavior.

Inventory shortage cost routes out the possibility for under stocking them with adjustment to a maintenance policy. Therefore the effect of inventory shortage cost is expected to increase the reorder level and consequently the inventory holding cost. Graphs are plotted showing the values of decision variables for the combined system and the total cost per unit time for combined & existing system. Both S & s is higher for higher value of shortage cost. The higher value of s,guards against shortage of spares and protect the system from incurring higher shortage cost. S & s is less for lower shortage cost resulting less total cost per unit time.

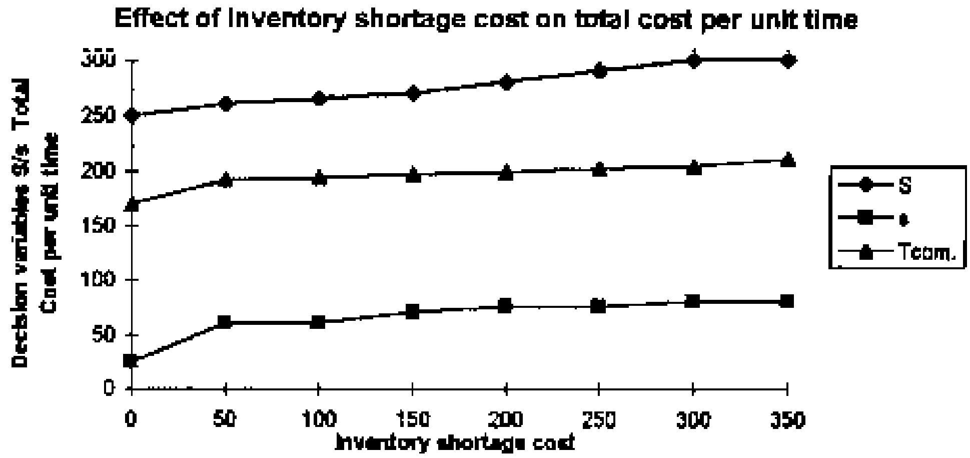


Figure 6.2.6a. Effect of shortage cost on decision variables and total cost.

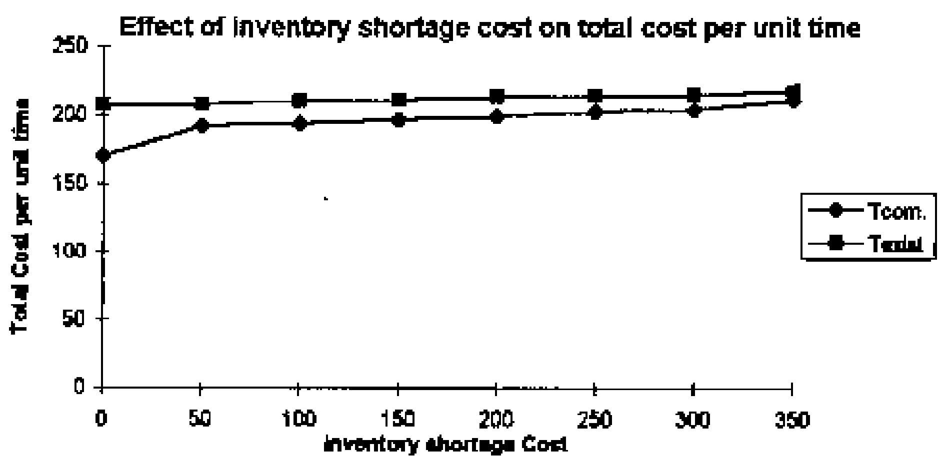


Figure 6.2.6b. Effect of shortage cost on total cost per unit time for the existing and combined system.

6.2.7 Effect of Block Preventive Replacement Cost

Table 6.2.7 shows the results of the investigation on the effect of the block replacement cost on the system behavior. Block replacement cost directly affects the combined maintenance and inventory policies. Increase in the block replacement cost results in increase of the block replacement period to reduce huge preventive maintenance cost and the tendency is towards adopting a breakdown maintenance strategy. The inventory level in such cases need not be too high since there are no sudden large demands. Graphs plotted with different values of Block Replacement cost for the combined system and the system under study are shown in figure 6.2.7a and 6.2.7b.

Data Set	Combined system with optimal T			Existing system with fixed T		
	S	s	Total Cost	S	s	Total Cost
1	250	50	185	300	60	205
2	260	60	192	300	60	206
3	260	60	193	300	60	208
4	270	60	198	300	60	209
5	280	65	200	300	60	211
6	280	65	202	300	60	212
7	285	65	204	300	60	214
8	290	65	211	300	60	216

Table 6.2.6 Results illustrating the effects of block replacement cost on system behavior.

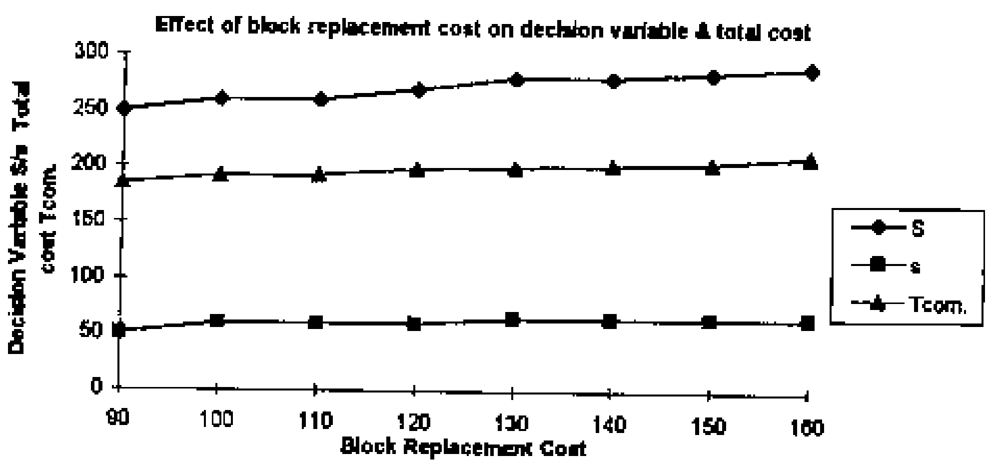


Figure 6.2.7a. Effect of block replacement cost on decision variables and total cost.

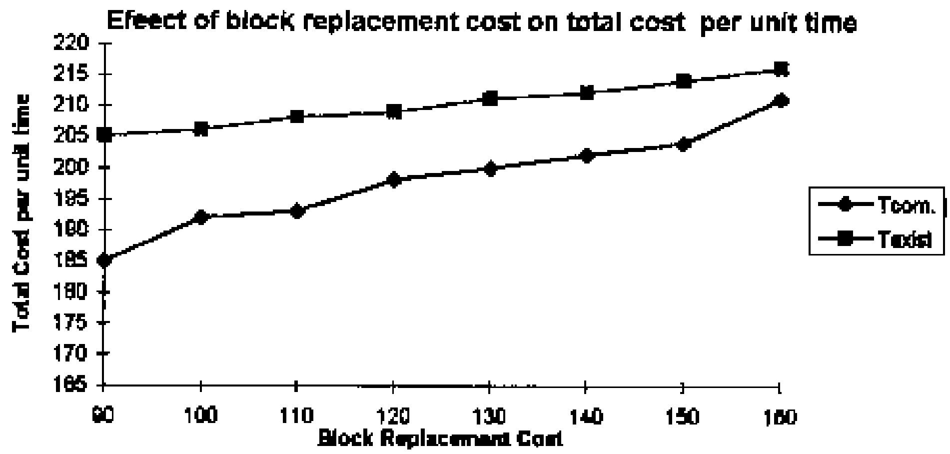


Figure 6.2.7b. Effect of block replacement cost on total cost per unit time for the existing and combined system.

6.2.8 Effect of Failure Replacement Cost

Table 6.2.8 presents the numerical values obtained after running the program with the given set of data.

Data Set	Combined system with optimal T			Existing system with fixed T		
	S	s	Total Cost	S	s	Total Cost
1	250	50	190	300	60	208
2	260	50	192	300	60	208
3	260	60	193	300	60	208
4	270	60	194	300	60	208
5	280	60	295	300	60	208
6	280	65	297	300	60	208
7	285	65	204	300	60	208
8	290	65	209	300	60	208

Table 6.2.8 Results illustrating the effects of failure replacement cost on system behavior.

The effects of individual failure or breakdown cost on the decision variables on the system is exactly opposite to those of the block replacement cost. This is quite anticipated because smaller values of breakdown cost will encourage failure, rather than preventive maintenance. Therefore the increase of this cost will induce a switch over from failure to preventive maintenance. Graphs plotted with different values of failure costs are shown in figure 6.2.8a and 6.2.8b

For higher breakdown cost values, the inventory levels also become high. This can be explained due to the fact that adoption of a preventive maintenance policy requires sufficient inventory to meet the large demands at the block replacement instants and to prevent the inventory shortage cost that may arises during block replacement of components.

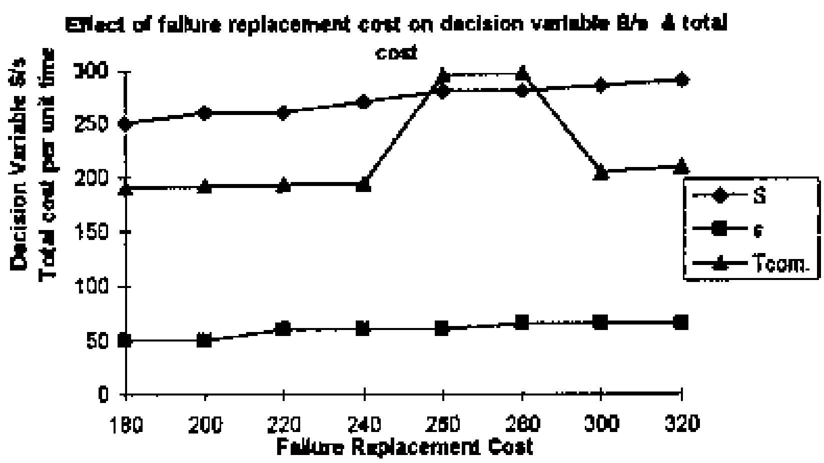


Figure 6.2.8a. Effect of failure replacement cost on decision variables and total cost.

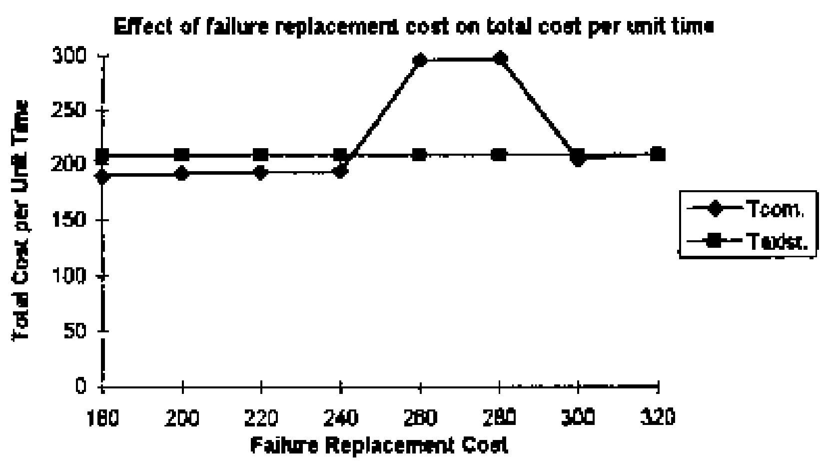


Figure 6.2.8b. Effect of failure replacement cost on total cost per unit time for the existing and combined system .

6.3 Cost Effectiveness of the Model

Program has been run to test the effect of the decision variables, maximum inventory level (S) and reorder level (s), on the total operating cost per unit time keeping other parameters fixed .Total cost per unit time has been determined with fixed block replacement period T for the component under consideration and with that of optimal T .The fixed block replacement period for the component under consideration is 365 days.The optimal value of T is determined with a set of value of (S,s) putting inventory related cost equal to zero.The total cost per unit time with fixed value of T of the existing system and that of the combined system with optimal value of T with various S is presented in table 6.3 .

Sl No.	Combined system with opt.T		Existing system with fixed T	
	S	Total Cost	S	Total cost
1	230	350	230	501
2	240	265	240	452
3	250	220	250	411
4	260	192	260	370
5	270	195	270	301
6	280	205	280	248
7	290	230	290	226
8	300	250	300	208
9	310	265	310	221
10	320	302	320	283
11	330	368	330	351

Table 6.3 Effect on total cost per unit time for the combined and the existing system

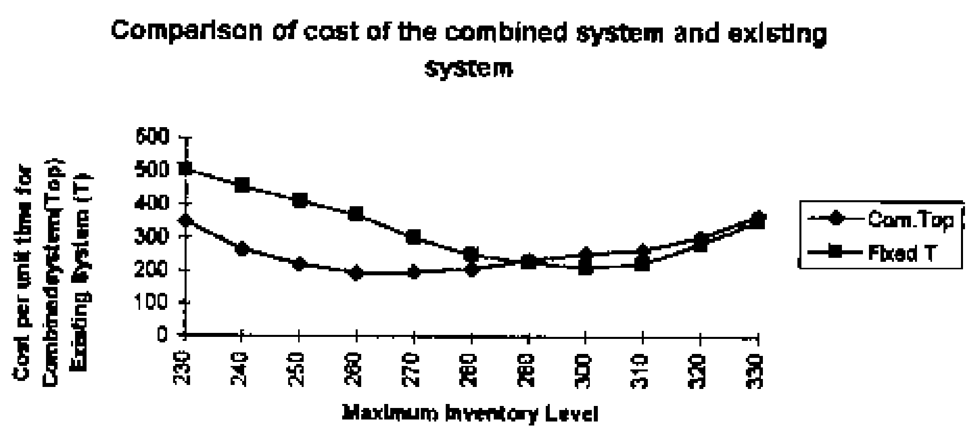


Figure 6.3 Total cost per unit time for the combined system and the existing system.

Graph plotted with the results shown in figure 6.3. From the figure it is found that both the curve are similar to EOQ curve. But it is seen from the curves that the total cost per unit time for the combined system is less than that of existing system of Bangladesh Railway. This is due to the fact that the combined system optimized both inventory and maintenance related costs. On the otherhand, the system under consideration of Bangladesh Railway optimized inventory related costs only. It ignores the trade off between Inventory and maintenance. Again the optimal T obtained from the model is 450 days which is >T for the existing system. It means that block replacement of the component is made much earlier and as a result total cost per unit time becomes higher as the component is replaced earlier than its expected life.

CHAPTER SEVEN

Conclusions and Recommendations

- **Introduction**
- **Conclusions**
- **Recommendations for Future Work**

6.1 Introduction

This chapter is intended to draw conclusions on the present research and to put forth some recommended actions that are supposed to complement and consolidate the study. Conclusions are drawn on the basis of the findings of the study in view of the scope and objectives of the present work. The next section contains the concluding remarks on the performance and significance of the proposed jointly optimized block replacement maintenance and continuous review inventory control (S, s, T) policy. The last section is devoted to furnish some recommendations for future work.

6.2 Conclusions

The general problem considered in this present work is to develop a combined maintenance and inventory policies for a service organization where there is no accumulation of in process inventory. The existing system of spares provisioning of Bangladesh Railway does not consider maintenance related costs and parameters in optimizing Inventory.Hence the existing system of Bangladesh Railway can not give optimal soluation. Here a model has been developed for spares provisioning by considering both inventory and maintenance related costs and parameters.Program has been run varying different operating parameters. The results of both the systems are compared and it is found that the model developed is more effective than the system presently used in Bangladesh Railway. So it can be concluded that a policy which consider either Inventory or maintenance policy alone, can not ensure global optimality.

The following conclusion may be drawn:

1. A combined policy which considers both Inventory and maintenance together gives better result than when they are considered separately. The optimum replacement interval for the combined system developed is different from that of maintenance policy only.

2. The component life time shape parameter determined from the data taken from Bangladesh Railway is quite low. It means lower hazard rate and does not show

aging of the component. It is found that the existing T is much less than that of optimal T obtained for the combined system for a fixed set of data.So the total cost per unit time for the combined system is found much less than that obtained for fixed interval T of the existing system.

3. For very close value of the Block replacement and the Failure replacement cost, the model suggests failure replacement policy when considered in terms of cost only.

4. Block replacement period changes decisions variables(S,s).High value of block replacement period results in frequent failure of operating component increasing total cost per unit time.

5. The extent of influence of one cost parameter on decision variables(S,s) depends on the value of other parameters.

6. It is observed that the holding and the ordering cost have more influence on the optimal value of S.

7. For a very low value of shortage cost, the total cost per unit time becomes very low indicating that the failure of the component does affect the system and low value of s can meet the requirement of the system.

8. Obtaining analytical results for the system considered could be extremely difficult. This is because the total cost estimation for the combined maintenance and inventory cycle in terms of either inventory level or time units seems to be an insurmountable problem. The stochasticity in component failures and order delivery adds further complexity and thus simulation comes to play the role of savior. However, simulation itself is statistical sampling only and therefore the results can be accepted only after rigorous statistical analysis technique. The process is very much time consuming and selection of the searching values of the decision variable affects the findings significantly. But simulation has proved

to be a powerful tool in analyzing the behavior of complex systems as reflected from the study.

9. The (S,s) policy presented here can be applied in service organization and can be used as analytical tool to test the impact of different parameters. The model developed is applicable for a system which is totally independent.

6.3 Recommendations for Future Work

In perspective of the problems and findings, the following recommendations can be put forth:

1. The work can be extended to make investigation on the component repair policy rather than replacing them or on both repair and replacement of failed components.

2. Further work can be conducted in order to optimize the system having system downtime, work-in-process-inventory and also for the systems which are inter-dependent.

5. Experiments can be carried for a number of operating components in the system

6. Further researches can be carried out considering non-identical components that may or may not have the same failure patterns and different cost parameters.

References and Appendices

- **References**
- **Appendix - A**
- **Appendix - B**
- **Appendix - C**
- **Appendix - D**

REFERENCES

1. Barlaw, and Prochan, L.A, "Joint Optimization of Age Based Replacement Policy", Journal of the American Production and Inventory Control Society, vol.25, 1978

2. Osaki, S., N. Kaio and Thomas, "*A Summary of Optimal Ordering Policies*", IEEE Transactions on Reliability, Vol. 30, 1981, pp. 272-277.

3. Park, Y.T. and K.S. Park, "*Generalized Spare Ordering Policies with Random Lead Time*", European Journal of Operations Research, Vol. 23, 1978, pp. 320-330.

4. Kabir, A.B.M.Z. and Ahmed S.A., "*Joint Optimization of Age Replacement and Continuous Review Spare Provisioning Policy*", International Journal of Operations and Production Management. (Accepted to be published, 1995a.)

5. Acharya, D., G. Nagbhushanam and S.S.Alam, " Jointly Optimal Block-Replacement and Spare Provisioning Policy ", IEEE Transactions on Reliability, Vol. R-35, No. 4, October 1995, pp. 447-451.

6. Law, A.M. and W.D. Kelton, "*Simulation Modeling and Analysis*", Second Edition, McGraw Hill International Edition, 1991.

7. Cochran, W.G. and G.M. Cox, *"Experimental Designs"*, Second Edition John Wiley & Sons, 1957.

8. Riggs, J.L., *"Production Systems: Planning, Analysis and Control", Third* Edition, John Wiley & Sons, 1981.

9. Sarker, R.A., Personal Communication, 1995.

10. Morrow., Maintenance Engg. Handbook.

11. Higgins, L.R., and L.C. Morrow, *"Maintenance Engineering Handbook"*, First Edition, McGraw-Hill Publishing Company, 1977.

12. Law, A.M., and C.S. Larmey, *"An Introduction to Simulation Using SIMSCRIPT II.5"*, CACI Products Company, 1994.

13. Russell, E.C., *"Building Simulation Models with SIMSCRIPT II.5"*, First Edition, CACI Products Company, 1989.

14. Tocher K.D. *"The Art of Simulation"*, Second Edition, The English Universities Press Ltd., 1963.

15. Starr, M.K., and D.W. Miller, *"Inventory control: Theory and Practice"*, First Edition, Prentice-Hall Inc., 1962.

APPENDIX-A

Failure & repair statistics of locomotive due to a particular component

Sl No.	Locomotive No.	Time between Failure	Repair time of Locomotive
1	2109	-	7
2	2310	23	2
3	2515	20	5
4	2314	23	7
5	2505	1	2
6	2314	26	2
7	2502	44	4
8	2322	27	5
9	2507	13	7
10	2412	1	2
11	2508	18	2
12	2507	1	2
13	2522	56	4
14	2503	6	2
15	2508	20	3
16	2322	3	1
17	2503	30	6
18	2319	10	1
19	2407	2	2
20	2511	43	4
21	2305	1	2
22	2511	6	2
23	2317	16	2
24	2513	25	4
25	2507	14	1
26	2507	27	1
27	2516	9	1
28	2318	6	2
29	2504	2	1
30	2515	28	4
31	2313	40	2
32	2504	50	1
33	2515	2	1
34	2404	40	1
35	2508	5	2
36	2310	15	1
37	2410	41	6
38	2509	19	2
39	2508	16	1
40	2403	31	2
41	2403	35	2
42	2307	23	1
43	2517	1	1
44	2319	36	1
45	2411	17	2
46	2516	29	1
47	2324	39	2

APPENDIX-B

X	*LN (x)*	*ALPH*	*ALPH*	*X^AL*	*X^AL*LN*	*Defference*
23	3.135494	1.18	1.18	40.44258	126.8074737	0.000376
20	2.995732		1.18	34.29378	102.7349924	For Beta=21.4861
23	3.135494		1.18	40.44258	126.8074737	
1	0		1.18	1	0	
26	3.258097		1.18	46.73763	152.2763642	
44	3.78419		1.18	86.95092	329.0387525	
27	3.295837		1.18	48.86628	161.0552732	
13	2.564949		1.18	20.62781	52.90929205	
1	0		1.18	1	0	
18	2.890372		1.18	30.28458	87.53369493	
1	0		1.18	1	0	
56	4.025352		1.18	115.5745	465.2278468	
6	1.791759		1.18	8.283588	14.84219673	
20	2.995732		1.18	34.29378	102.7349924	
3	1.098612		1.18	3.655974	4.016497797	
30	3.401197		1.18	55.3354	188.2066293	
10	2.302585		1.18	15.13561	34.85103568	
2	0.693147		1.18	2.265768	1.570510542	
43	3.7612		1.18	84.32385	318.2872327	
1	0		1.18	1	0	
6	1.791759		1.18	8.283588	14.84219673	
16	2.992589		1.18	26.35491	73.07133332	
25	3.218876		1.18	44.62407	143.6393507	
14	2.639057		1.18	22.51288	59.41278448	
27	3.295837		1.18	48.86628	161.0552732	
9	2.197225		1.18	1.336614	29.36842182	
6	1.791759		1.18	8.283588	14.84219673	
2	0.693147		1.18	22.65768	1.570510542	
28	3.332205		1.18	51.00896	169.9722897	
40	3.688879		1.18	77.70175	286.6323823	
50	3.912023		1.18	101.1078	395.535989	
2	0.693147		1.18	2.265768	1.570510542	
40	3.668879		1.18	77.70175	286.6323823	
5	1.609438		1.18	6.680125	10.75124683	
15	2.70805		1.18	24.42236	66.13698559	
41	3.713572		1.18	79.99907	297.0823204	
19	2.944439		1.18	32.27968	95.04555424	
16	2.772589		1.18	26.35491	73.07133332	
31	3.433987		1.18	57.5184	197.5174505	
35	3.555348		1.18	66.37435	235.9839227	
23	1.335494		1.18	40.44258	126.8074737	
1	0		1.18	1	0	
36	3.583519		1.18	68.61783	245.8932771	
17	2.833213		1.18	28.30934	80.20639668	
29	3.367296		1.18	53.16547	179.0238572	
39	3.663562		1.18	75.41474	276.2865479	
940	116.1656			1716.737	5790.852246	
20.43478						
14.87872						
221.3762						

APPENDIX-C

Weibull	Weibull (α,β)	
Density	$f(x) = \alpha\beta^{\alpha}x^{\alpha-1} e^{-(x/\beta)^{\alpha}}$	if $x > 0$
	$= 0$	otherwise
Distribution	$F(x) = 1 - e^{-(x/\beta)^{\alpha}}$	if $x > 0$
		otherwise
Parameters	Shape parameter $\alpha > 0$, Scale parameter $\beta > 0$	
Range	$[0 - \infty]$	
Mean	$[\beta/\alpha]\ \Gamma(1/\beta)$	
Variance	$[\beta^2/\alpha]-\{2\Gamma(2/\alpha) - 1/\alpha[\Gamma(1/\alpha)^2\}$	
Comments	The exponential (α) and Weibull $(1,\beta)$ are the same	
	$\beta < 1$ represents a decreasing hazard rate or the debugging period. $\beta = 1$ represents a constant hazard rate or the normal life period. $\beta > 1$ represents an increasing hazard rate or the wearout period. Possible applications: Time to complete some task, time to failure of a piece of equipment etc.	

Information regarding the Weibull distribution

```
preamble

        define costs, stat, init, replace, fail, evaluation, order, and check as routines

        define ord.cost, unit.cost, nor.hcost, abn.hcost, fail.cost, rep.cost, acost, nor.cost  and
        cost as real variables

        define x, y, z, mu, alpha, xx, yy, ord.state, replaced, time, run, rev.period,  rep.period,
        inv.level, nos.failed, small.s, big.s,i, next.fail, level, demand,ord.arrive,ord.qty,rep.time,
        rev.time, yyy and order.lead as integer variables

        define fail.time and mode as 1-dimensional arrays

end

main
        ' ' open unit 10 for output, name=``result.dat `` ' '
        ' ' use unit 10 for output ' '
        reserve fail.time as 60
        reserve mode as 60
        call costs
        call stat

        for big.s = 260 to 340 by 10 do
        let rep.period = 365
        let rev.period = 60

        call init

        for  i = 1 to 60 do
             let next.fail=weibull.f (x,y,z)
             let fail.time (i) = time + next.fail
             let mode (i) = 1
        loop

        for time = 0 to 2190 do
                if time = ord.arrive call check always
                if time = rev.time call order always
                if time = rep.time
                        call replace
                else
                        call fail

                endif
```

Cont'd P/2

```
                    let inv.level = inv.level-demand
                    call evaluation
          loop
          print 1 line with cost thus
          cost = ********.****
          let acost=cost / 2190.0
          print 1 line with acost thus
          acost = ********.****
loop
end

routine stat

          let  x =1 . 17
          let  y = 21 . 48
          let  z = 6

          let  xx =3
          let  yy =10
end

routine costs

          let ord. cost =3000.0
          let nor.hcost =1.25
          let abn.hcost =-50.0
          let fail.cost = 228.0
          let rep.cost =114.0
          let unit.cost = 950.0

end

routine  init

          let cost = 0.0
          let ord.stat = 0
          let replaced = 0
          let time = 0
          let rep.time = rep.period
          let rev.time = rev.period
          let inv.level= big.s
          let nos.failed = 0
```

Cont'd P/3

```
end

routine fail

        for i =1  to  60  do
                if time = fail. time (i)
                if mode (i) = 1  nos.failed=nos.failed always
                let level = inv.level
                if leve l> 0
                        let next.fail = weibull.f (x,y,z)
                        let fail.time(i) = time+ next.fail
                        let mode (i) =1
                        let level = level-1
                else
                        let fail.time (i) = time+1
                        let mode (i) = 0
                endif
                always
        loop
        for i =1  to 60  do
                if mode (i) = 5
                        if inv.leve l> 0
                        let next.fail = weibull.f (x,y,z)
                        let fail.time (i) = time+next.fail
                        let mode (i) =1
                always
        always

        loop
        let demand = nos.failed
        let cost = cost+fail.cost*demand
        let nos.failed = 0
end

routine replace

        let demand=60
        let level=inv.level
        let rep.time=rep.time + rep.period

        for i =1  to 60  do
                if time = fail.time (i) mode (i) = 0 always
        loop
```

Cont'd P/4

```
        for i =1  to 60  do
                if level 1>0 and mode (I)=0
                let next.fail=weibull.f (x,y,z)
                let fail.time (i)=time+next.fail
                let level=level-1
            always
        loop

        for i =1  to  60  do
                if level > 0 and mode (i)=1
                let next.fail=weibull.f(x,y,z)
                let fail.time (i)=time+next.fail
                let mode (i)=1
                let level=level-1
            always
        loop
        for i=1 to 60 do
                if level <=0 and mode (i)=0
                        let fail.time (i) =fail.time (i)+1
                always
        loop

        for i  = 1 to 60 do
                if level <=0 and mode (i)=1  mode (i)=5 always
        loop
        let cost = cost+demand*rep.cost
end

routine evaluation
        if inv. level <=0
                let cost=cost+abn.hcost*inv.level
        else
                let cost=cost+nor.hcost*inv.level
        endif
end

routine order

        let ord.stat = 1
        let order.lead = weibull.f(xx,yy,z)
        let ord.qty = big.s - inv.level
        let cost = cost + ord.cost + ord.qty*unit.cost
```

Cont'd P/5

```
        let ord.arrive = time + order.lead
        if order.lead=0
                inv.level = inv.level + ord.qty
                ord.stat = 0
        always
end
```