A facility maintenance scheduling model incorporating opportunity and inflationary costs

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Abstract: This paper deals with facility maintenance scheduling model which incorporates opportunity and inflationary costs. A case study pertaining to a shipping firm has been defined as transportation models of minimising Maintenance Cost (MC), Maintenance-Inflation Cost (MIC), Maintenance-Opportunity Cost (MOC) and combined Maintenance-Opportunity-Inflation Cost (MOIC). The optimal schedules indicating the ship maintenance, idle and operation periods were deduced for each approach. For all the samples, the costs of the first model were significantly ($p \leq 0.05$) different from that of the other three models. To reduce cost and delays, decisions for scheduling maintenance of a fleet of ships would be better informed if based on maintenance and opportunity cost indices in both inflationary and non-inflationary conditions.

Keywords: maintenance; scheduling; Maintenance Cost; MC; opportunity cost; inflation cost; costs; transportation model; fleet of ships; preventive maintenance scheduling.

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1 Introduction

In recent years, concerns about controlling manufacturing system cost (Ji et al., 2007; Qi, 2007), quality (Mohanta et al., 2006, 2007), cycle time, profitability (Guo et al., 2007), reliability and the need to become world-class companies are major worldwide issues among manufacturing executives (Leou, 2006; Mohanta et al., 2004). These issues are crucial in the enhancement of organisation's competitiveness, survival and growth, and are provoking interests of scientists and researchers in maintenance and operations. In order to achieve business excellence, organisations are adopting various improvement methodologies such as cost reduction (Nakamura and Zhang, 2005; Quan et al., 2007), business process reengineering, total quality management, etc., which have forced many business organisations to look within on how to improve business efficiency and effectiveness (Dahal and Chakpitak, 2007; Kim et al., 2005; Zhou et al., 2007).

For large organisations, the focus is usually on improving maintenance activities such that minimum amounts of funds are expended. Since high costs are usually incurred on breakdown maintenance, an economic approach widely utilised is the implementation of preventive maintenance option (Cheung et al., 2004). Efforts are directed towards implementing an effective maintenance schedule such that the overall cost of maintenance is minimised. Unfortunately, the traditional approach in deriving maintenance schedules for a fleet of facilities to minimise maintenance alone may not address the problems of operation revenue losses and inflation cost associated with delays. Monitoring maintenance-related costs of delays and inflation are essential in order to ensure an adequate running of the organisational activities with the aim of obtaining optimum results. Thus, this work is aimed at developing a preventive maintenance schedule for a fleet of faculties to simultaneously minimise preventive maintenance, opportunity and inflation costs.

The focus of the work is to develop and apply an inflation-based framework for the maintenance scheduling model that could be applied to facilities. To accomplish this goal, the current work formulates the cost function of the maintenance scheduling model and superimposes the inflation and opportunity frameworks on it in order to capture the changes in the value of money that cannot be captured by Maintenance Cost (MC) parameters alone. Specifically, the primary objectives pursued in this work are segmented into two parts:

1 to develop and proffer solution to the inflation-based maintenance scheduling model for facilities to minimise combined-maintenance, opportunity and inflation cost

2 to compare the existing model and the inflation-based maintenance scheduling solution.

2 Theoretical framework

2.1 *Introduction*

This section presents the theoretical formulation for the various functions developed in this work for solving the preventive maintenance problem. Firstly, a schematic diagram showing a flow of steps carried out in achieving the stated objectives is shown in Figure 1. Thus, Figure 1 begins with the concurrent formulation of the models 1–4. After each of the problems has been formulated, computations of results are then made.

Many of the notations utilised in this work are adapted from Charles-Owaba (2002), with some additional notations that incorporate the frameworks of opportunity and inflation costs. These notations are:

i: indicates machine identity

j: indicates period

r: indicates number of times a machine visits for preventive maintenance

M: total number of machines in maintenance system

T: total number of periods in planning horizon

O_i: number of planned periods for machine i to operate soon after maintenance at the rth visit

Q_i: actual number of periods machine i operated soon after maintenance at the rth visit

B_i: the number of periods machine i stays in the system for maintenance during the rth visit

t_i: the number of periods machine i stays in the system for maintenance during the rth visit

k_i: the period machine i arrives for maintenance at the rth visit

j_i: the period the maintenance of machine i was completed

l_i: the number of periods machine i waited before being maintained

y_{ij}: a binary Gantt charting variable defined as 1 if machine i was actually maintained in period j, and 0, otherwise

c_{ij}: the unit cost of maintaining machine i at period j (includes non-productive penalty cost)

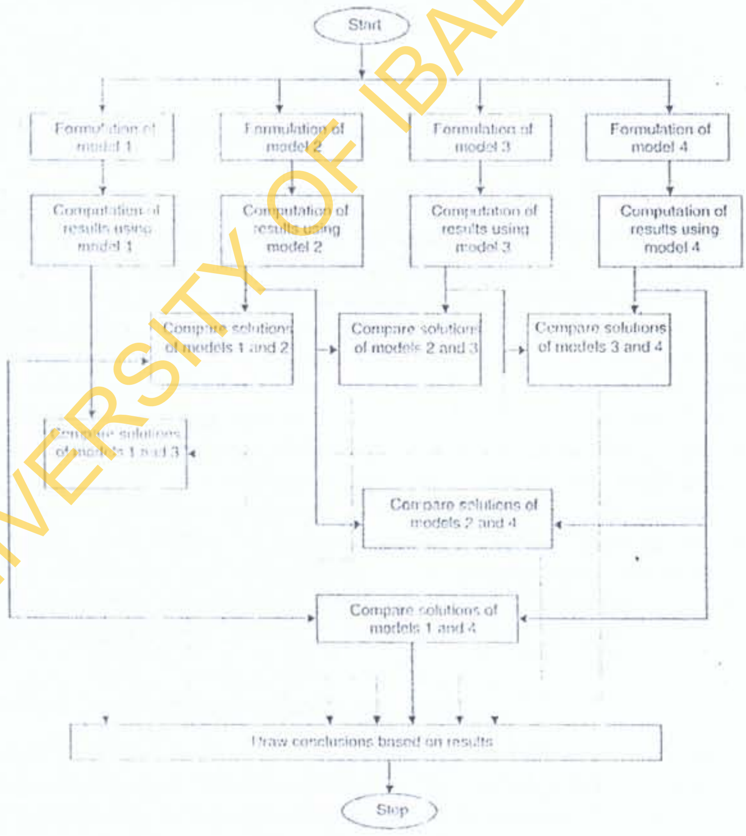
C: total cost of maintenance for the M machines within T periods

A_j: maintenance capacity at period j (number of machines that can be maintained in period)

N_i: total number of visits machine i can make for maintenance within the time horizon T

Z: total cost of maintenance.

Figure 1 The schematic diagram for the application of opportunity and inflation cost frameworks to maintenance and operation scheduling



The application of the transportation algorithm methodology involves translating the objective function of minimising the product of the index that shows the state of a facility and the algebraic sum of the period in which it is considered and the arrival time of the various facilities.

2.2 *Function formulation*

2.2.1 *Model 1: the MC function*

Since the maintenance system has many inputs, an approach towards solving the maintenance scheduling cost problem is to formulate a function that minimises the maintenance scheduling cost subject to a number of constraints. Thus, mathematically, the objective function is:

Minimise

$$Z = \sum_{i=1}^{M}\sum_{j=1}^{N}\left[\frac{c_{ij}}{(T-k_i)}\, y_{ij}\,(j-k_i+1)\right] \tag{1}$$

s.t.

$$\sum_{i=1}^{M} y_{ij} \le A_j \text{ (capacity constraint)} \tag{2}$$

and

$$\sum_{j=1}^{T} y_{ij} = \sum_{r=1}^{N} B_i^r \text{ (maintenance constraint)} \tag{3}$$

Note that a_i which represents the MC is expressed in terms of y_{ij}, k_i and j which are the state of the facility, the arrival time of the facility for maintenance at the dockyard, garage or when the equipment is brought to the workshop (i.e. k_i), as well as j, which represents the period that the analysis is carried out in. The objective function of model 1 is formulated in such a way that it has a component of y_{ij}, which is present in each of the constraint equations. Looking at the structure of this model, it resembles a transportation problem which could be solved through modification of the original transportation algorithm to incorporate the variations in the problem. The expression above indicates that the preventive maintenance scheduling problem of the facility is to minimise the MC for all facilities. It is understood that MC changes over time. Obviously, the more number of facilities maintained, the higher the MC. The capacity constraint states the limit of the number of facilities that the garage, dockyard or workshop could contain in the period of measurement. The maintenance constraint states the period available for maintenance. Here, the required personnel to carry out the maintenance are available.

2.2.2 *Model 2: the MC and inflation function*

As stated earlier, the cost of maintenance at different periods would be different since the cost of inputs varies with time due to inflation. This inflation factor is now incorporated in this formulation as an improvement over model formulation. The new formulation is the true cost which a maintenance planner could use in computing maintenance scheduling cost since inflation is already taken care of. This model is formulated as follows:

Objective function: minimise

$$Z = \sum_{i=1}^{M} \sum_{j=1}^{N} \left[\frac{c_{ij}}{(T - k_i)} y_{ij} \left(j - k_i + 1 \right)(1 + \alpha) \right] \tag{4}$$

s.t.

$$\sum_{i=1}^{M} y_{ij} \leq A_j \text{ (capacity constraint)} \qquad \text{(recall (2))}$$

and

$$\sum_{j=1}^{T} y_{ij} = \sum_{t=1}^{N} B_i^t \text{ (maintenance constraint)} \qquad \text{(recall (3))}$$

From the objective function, two components readily emerge: MC and inflation factor. The interpretation of the cost formulation in the objective function is that maintenance activities are carried out with inflation effect. Thus, the value obtained from this computation may be different from what is obtained in model 1. From this objective function, the component that reflects MC is

$$\sum_{i=1}^{M} \sum_{j=1}^{N} \left[\frac{c_{ij}}{(T - k_i)} y_{ij} \left(j - k_i + 1 \right) \right]$$

while the inflation effect component of the expression is $(1 + \alpha)$. This objective function is formulated in such a way that it incorporates the component of maintenance and capacity constraints from the recalled Equations (2) and (3). This structure fits the transportation algorithm in the traditional operations research literature and hence would be used to solve the problem. However, in adapting the transportation algorithm, some modifications are made to it such that a new rule relevant to the requirements of the maintenance scheduling framework presented here is made. For example, in the traditional transportation model, allocations of maximum possible units are made to cells having minimum cost values for the period-dependent MC function. A relaxation of this principle is made by allocating only one unit or none to cells having minimum MC values. This 0 or 1 value assigned here indicates the status of the facility of either being maintained or otherwise.

Basically, the transportation algorithm utilised accepts data in a matrix form. The data consists of period allocation along the horizontal axis while the various facilities are labelled along the vertical axis. The values obtained from this objective function now serves in place of the unit transportation cost of the traditional algorithm. These are the values indicated in the northeast corner of the transportation *tableau*. It is based on the comparison of these cost values that decisions on where to allocate facility for maintenance and operation are carried out. Usually, the minimum values along the horizontal or vertical columns are compared with the maximum.

The differences in these values are then used for allocating maintenance or operations activities. This forms the first iteration. The second iteration is carried out while the columns or the rows that are fully assigned are to be omitted in the next allocation.

The stage is to compute the overall idleness of the system and then the MC. Model 3 that is described below slightly differs from model 2 discussed in that it incorporates idle time (i.e. opportunity cost) and MC into the model with the exception of inflation cost.

2.2.3 *Model 3: the maintenance and opportunity cost*

Opportunity cost, which relates to operation revenue losses of facilities due to idleness is a vital cost that should also be incorporated into the maintenance scheduling cost computation. If taken care of, the maintenance crew tries to release facilities that may incur high opportunity cost.

The model is minimise

$$Z=\sum_{i=1}^{M}\sum_{j=1}^{N}\left\{\frac{c_{ij}}{(T-k_i)}\left[y_{ij}(j-k_i+1)-\left(T-(Q_i+t_i)\right)\right]\right\} \qquad (5)$$

s.t.

$$\sum_{i=1}^{M} y_{ij} \le A_j \text{ (capacity constraint)} \qquad \text{(recall (2))}$$

and

$$\sum_{j=1}^{T} y_{ij} = \sum_{r=1}^{N} B_i^r \text{ (maintenance constraint)} \qquad \text{(recall (3))}$$

The objective function here has components of the state of the facility (i.e. y_{ij}), which may be in operation or otherwise, and a component of the idle time of the facility. This idle time is measured as the difference between the total planned period for the organisation (i.e. T), and the sum of actual number of periods that facility i operated soon after maintenance (i.e. Q_i), and the number of periods the facility stays in the system for maintenance. Also, this objective function is formulated by taking into consideration the capacity and maintenance constraints of recalled Equations (2) and (3).

2.2.4 *Model 4: the maintenance, opportunity cost and inflation function*

The problem is to
Minimise

$$Z=\sum_{i=1}^{M}\sum_{j=1}^{N}\left\{\frac{c_{ij}}{(T-k_i)}\left[y_{ij}(j-k_i+1)-\left(T-(Q_i+t_i)\right)\right](1+\alpha)\right\} \qquad (6)$$

s.t.

$$\sum_{i=1}^{M} y_{ij} \le A_j \text{ (capacity constraint)} \qquad \text{(recall (2))}$$

and

$$\sum_{j=1}^{T} y_{ij} = \sum_{r=1}^{N} B_i^r \text{ (maintenance constraint)} \qquad \text{(recall (3))}$$

Note that $c_{ij}/(T-k_i)$ is preferred to c_{ij}/k_i since Z is all about MC and maintenance of facilities starts after the arrival period and not before the arrival time k. Hence, MC should be distributed in the period in which the facility is available for maintenance, that is, $(T-k_i)$ where $T = 24$.

2.2.5 *Step-by-step solution approach for models 1–4*

Having stated the models 1–4, the approach in solving them is similar, and is as detailed below:

Step 1 Obtain the entry parameters through the knowledge of operation periods, maintenance periods, arrival periods, maintenance capacity, number of machines to be maintained and the total periods of maintenance. These are designated as: θ_i^r; B_i^r; K_i^r; A_j; C_{ij}; M; T; N, respectively.

Step 2 Develop the transportation *tableau* by

1 Indicating the values of the objective function cost and positions where Y_{ij} are 1. The function costs are indicated in the boxes while the values of Y_{ij} are stated below the boxes.

2 Based on the values of B_i and A_j (which are stated along the vertical and horizontal columns, respectively), allocations of Y_{ij}s are made.

3 The subcost for ship is then computed by multiplying the values in the boxes by the Y_{ij} values (i.e. 1).

4 sum up all these costs to make up the total cost.

Step 3 Set up the table that indicates the ship maintenance, operations and idle periods (months)

1 Idleness is calculated from the transportation *tableau* by observing when the ship starts maintenance and its discontinuities. These discontinuities of periods of maintenance are added up as the idle time for the ship.

2 The maintenance period is read as the B_i.

3 The operation period is then obtained from the subtraction of the idle and maintenance periods from the total available periods.

4 The sum, mean and standard deviations of the idle and operation periods are then obtained.

Step 4 Set up the cost of the schedule either in the inflationary or non-inflationary period.

1 Cost from the *tableau* is obtained as the subtotal of costs indicated in step 2(c).

2 Cost of idleness is then calculated based on the knowledge of the revenue losses of ships per unit period of analysis.

3 Cost of schedule is obtained as the sum of cost from the *tableau* and the cost of idleness.

Step 5 Obtain the table of functional minimisation versus actual costs in the inflationary conditions

1 list all the formulations along both the vertical and horizontal axes

2 observe that no entries could be obtained under formulations 2, 3 and 4 along the vertical column while considering model 1 along the horizontal column.

also, no entries are possible for all models along the vertical columns while considering formulation 2 along the horizontal column. Again, no entry calculations are possible for models 2 and 4 along the vertical axis while considering model 3 along the horizontal axis.

3 Model application

The organisation whose data is analysed in this work is categorised into five branches: accounts and budget, logistics, materials, operations and personnel. In order to obtain reliable data used in this work, two main approaches were adopted. The first concerns historical records collected from the accounting and engineering units as well as the dockyard where actual maintenance of ships are carried out. The second approach is the information gathered from interviews with all levels of staff in the organisation. Using the second approach, both direct and indirect questions were posed to administrative staff, engineering employees and craftsmen. Information obtained through instructions was validated by ensuring that supporting data are sighted. However, some difficulties were encountered in doing this, primarily, the reluctance of some personnel in revealing vital information for the study.

The analysis of data was carried out according to four models:

Model 1: MC

Model 2: MC and inflation factor

Model 3: MC and opportunity cost

Model 4: MC, opportunity cost and inflation factor.

3.1 Solution to model 1

In setting up facilities-periods, final transportation *tableau* for model 1, the first requirement is to compute the cost values (see Table 1), which would be minimised for each facility and period. These cost values are positioned in the northeast corner in the transportation *tableau*, which may consist of positive numbers and the symbol, ∝, representing infeasible. The formula utilised is obtained from the objective function of model 1, that is, Equation (1). The value of y_{ij} is either 1 or 0, j is the period counter at the instance where the calculation is to be made, while k_i represents the arrival time of the facilities for maintenance. The correction factor is guided by the decision to have realistic values. For instance, certain calculations that should be placed in particular cells are not feasible unless time adjustment is made that would put the values in the proper place. For the dockyard whose data is collected and analysed, j varies from 1 to 24, k_i is the arrival time for ith ship.

Table 1 Computation of period-dependent cost (a_i)

Description	Year 1											
	Jan (₦)	Feb (₦)	Mar (₦)	Apr (₦)	May (₦)	Jun (₦)	Jul (₦)	Aug (₦)	Sep (₦)	Oct (₦)	Nov (₦)	Dec (₦)
General servicing	192, 000	168,000	97, 500	280, 000	405, 000	180, 000	480, 000	390, 000	50, 000	130, 000	60, 000	97, 500
Valve servicing	600	700	250	260	855	708	243	1500	1440	525	800	170
Fixing strainers	200	135	120	225	200	300	30	125	140	100	60	375
Sand blasting	684, 000	180, 000	280, 000	112, 000	638, 000	105, 000	72, 000	144, 000	117, 000	300, 000	264, 000	324, 000
Paint spray	660, 000	136, 000	250, 000	220, 000	180, 000	600, 000	90, 000	330, 000	180, 000	140, 000	135, 000	780, 000
Weld area	475, 000	89, 000	364, 000	258, 000	292, 000	550, 000	306, 000	172, 500	240, 000	315, 000	360, 000	332, 500
Pump servicing	5200	108, 000	335, 400	80, 000	350, 000	270, 750	240, 000	540, 000	1,134,000	630, 000	450, 000	792, 000
Engine repair	1800	9100	4500	9200	6300	8750	11, 900	26, 000	2295	7380	4500	2400
Shaft	140	540	300	325	336	150	154	660	266	448	855	459
Propeller	1750	7800	3332	5550	5558	3999	6624	2800	11, 700	6600	2184	3000
Rudder	5700	10, 584	6400	8410	16, 562	14, 592	7742	6160	6432	19, 176	13, 360	16, 920
Docking	0.63 × 100000 = 63, 000	0.12 × 100000= 12, 000	0.48 × 100000= 48, 000	0.32 × 100000 = 32, 000	0.48 × 100000 = 48, 000	0.4144 × 100000 = 41, 440	0.585 × 100000 = 58, 500	0.5986 × 100000 = 59, 860	0.632 × 100000 = 63, 200	0.481 × 100000 = 48, 100	0.32 × 100000 = 32, 000	0.4 × 100000 = 40, 000
	2,089,390	721,859	1,390,302	1 005,970	1,942,811	1,776,139	1, 273,443	1, 667,605	1, 806,476	1, 597,329	1, 322,329	2, 388,824

Table 1 Computation of period-dependent cost (a_i) (continued)

Description	Year 2											
	Jan (₦)	Feb (₦)	Mar (₦)	Apr (₦)	May (₦)	Jun (₦)	Jul (₦)	Aug (₦)	Sep (₦)	Oct (₦)	Nov (₦)	Dec (₦)
General Servicing	216, 750	78, 000	225, 000	189, 000	120, 000	168, 000	382, 500	450, 000	182, 000	108, 500	105, 000	75, 000
Valve servicing	286	840	260	1550	720	882	324	675	250	190	1500	700
Fixing strainers	234	125	175	120	200	375	100	45	60	120	450	112
Sand blasting	91, 000	250, 000	117, 000	276, 000	190, 000	297, 000	297, 000	672, 000	319, 000	312, 000	300, 000	77, 000
Paint spray	220, 000	162, 000	240, 000	660, 000	330, 000	682, 000	627, 000	133, 000	225, 000	780, 000	150, 000	840, 000
Weld area	405, 000	98, 000	240, 000	315, 000	332, 500	240, 000	550, 000	172, 500	137, 500	255, 000	220, 000	390, 000
Pump servicing	385, 000	99, 000	1,032,750	306, 000	240, 000	540, 000	5200	600, 000	306, 000	108, 000	90, 000	243, 000
Engine repair	8800	19, 000	7470	2400	1800	8100	9200	9200	20, 000	6300	4500	8400
Shaft	150	693	513	570	300	348	280	280	435	476	510	540
Propeller	9000	3600	7000	11, 050	7200	2500	5500	1750	2320	12, 600	2940	6900
Rudder	6500	8120	16, 200	10, 080	8700	8352	13, 600	6270	16, 200	14, 952	16, 920	6432
Docking	0.1638 * 100000 = 16, 380	0.4484 * 100000 = 44, 840	0.595 * 100000 = 59, 500	0.48 * 100000 = 48, 000	0.632 * 100000 = 63, 200	0.4 * 100000 = 40, 000	0.48 * 100000 = 48, 000	0.455 * 100000 = 45, 500	0.819 * 100000 = 81, 900	0.64 * 100000 = 64, 000	0.32 * 100000 = 32, 000	0.4 * 100000 = 40, 000
	1,359,100	764,218	1,945,868	1,294,620	1,987,557	1,938,704	2,091,220	1,290,220	1,290,665	1,662,138	923,820	1,688,084

The ships arrived at the dockyard between months 1 and 20 for maintenance. Thus, in computing the value for cell (1, 1) that is, when ship 1 is considered in period 1, the cost value is [(i.e. [2089390/(24 – 1)](1 – 1 + 1) = 90, 843 = 0.09 million], that is, 0.09 unit of cost. However, to compute the values for cell (5, 2), we have [0/(24 – 14)](2 – 14 + 1) = 0, that is, 0 units of cost. C_{ij} is 0 and consequently, the value of cell (5, 2) is also 0 since the arrival time of ship 5 is 14 months and period 2 is before the arrival time. This gives an infeasible solution since maintenance and allocations cannot be made to a ship before its arrival at the dockyard. The next stage is to start with the iterations, which may be several depending on the magnitude of the values concerned and the number of periods and facilities considered. The first iteration is commenced by starting from the first row and then identifies the highest and the smallest value's cost. The difference between the highest and the smallest values now represents the value to be considered for this stage of iteration along the column. It is then written in the column created next, *Bi*, and listed as 1st. This same procedure is done for all the other seven rows (i.e. for ships 2–8).

Similar procedure is carried out along the columns where the value for the 1st iteration is written next to the capacity constraint A_j. The decision on the 1st iteration is taken based on the minimum values for either row or column in the 1st iteration. This minimum value is then traced along the row or column and a value of 1 is assigned to the cell along this row or column representing the first ship. As the assignment of '1' is made, a reduction in the value of B_i and A_j is effected. This is done concurrently. Iteration 2 now commences with the same procedure implemented. It should be noted that if either or both B_i and A_j are exhausted in any allocation, the row or column is stricken out. This makes the next iteration to exclude those stricken out rows or columns in computation. Following these procedures, a stage is reached where all assignment of values have been made. This is then the stage at which computations concerning the maintenance, operations and idle periods can be made. All the assigned values of '1' are made in cells that represent maintenance activities being performed. A comparison between when the ship arrived at the dockyard and when it is maintained would give information about the idle periods. Excluding this time and maintenance period from the planned period of operation is the actual operations period utilised.

3.2 *Procedures for the computation of overall cost of schedule*

After setting up the final transportation *tableau* for the facility scheduling problem, four main stages of calculations should be embarked upon before arriving at the final result. These are explained in the following section.

3.2.1 *Calculation of the total MC from the transportation tableau*

Depending on the model of the problem solved (i.e. models 1–4), the heading for this subsection 1 may be 'calculation of the total MC', 'calculation of maintenance and opportunity cost' or 'calculation of maintenance, opportunity and inflation costs'. The idea of this subclassification is to find out the behaviour of cost in practice. The first case refers to a situation, which currently exists. Maintenance managers and researchers measure maintenance scheduling cost based on the adapted model from developed economies, which assumes an insignificant effect of inflation on the results. This may not be true since in the third world countries and other developing economies where inflation is of the order of double digits as opposed to single digits experienced in developed economies. When inflation is not incorporated into the model framework, it becomes model 2. Obviously, values obtained may be different from when MC alone is used for the computation. The question relating to these values being significantly different from each other would be tested with the use of student's t-test statistical tool. This statistical tool is useful in this situation since the normal distribution is not the appropriate sampling distribution, and we are estimating the population standard deviation when the sample size is 30 or less. In this case, six data sets were used.

Model 3 is obtained when only the maintenance and opportunity costs are integrated. This case assumes that there is no inflation but there is an idle period, which could be classified as avoidable and non-avoidable. It is this idle period that is transformed into opportunity cost. This is based on the understanding that usually the ship is supposed to be in operation all the time, according to the investor's desire. Unfortunately, since it may break down, there is a need for maintenance to restore it to 'as-good-as-new' state. Thus, the alternative revenue forgone, becomes a penalty on the system, when it is being maintained. When the ship is being maintained, the equivalent cost of idleness is computed. Likewise when the ship is at the dockyard, awaiting attention of maintenance staff, it incurs cost of idleness. Although several reasons may be given for the ship's delay for service, these excuses are not acceptable.

Model 4 is an integrated model of maintenance, inflation and opportunity costs. It is a situation where the maintenance manager is aware of the possible period changes in the prices of resources utilised to obtain the output. The accumulation of all input changes would significantly affect the cost obtained in computation. This is the inflationary component of the problem. In addition, the opportunity cost component of the problem is considered in terms of avoidable and non-avoidable delays. This has been described for model 3. However, using model 1 to compute the MC, the transportation *tableau* should be viewed to observe the portions where ships are maintained. These areas are indicated by an assignment of '1' in each of the cells. From the *tableau* for model 1, the cells concerned are cell (1, 4), cell (1, 5), cell (1, 6) and cell (1, 7) for ship 1 (Table 2). The same interpretation is given to ships 2–8.

None of the cells where maintenance is marked out has an infeasible value (i.e. ∞). Cells that have this infeasible value indicate that no allocation could be made on them. This is synonymous to the 'big M' concept in simplex algorithm procedure where the value of 'M' is too large. In this particular case, the values obtained are negative and hence, could not be considered in the computation. For example, consider cell (2, 1) that has an infeasible value. If the value of the cost unit (Z) is to be computed using Equation (1), the notation y_{ij} is 1, $j = 1$, $c_{ij} = 0$, k_i is the arrival period of ship 2 at the dockyard is 6 units. Thus, $Z = [0/(24 - 6)](1 - 6 + 1) = 0$. This zero value is interpreted as infeasible in the model framework.

Computation of the cost for all ships using model 1 is presented as:

Model 1 (MC alone) (see Table 2) (₦ million).

Ship 1: 0.50; Ship 2: 0.25; Ship 3: 0.21; Ship 4: 0.44; Ship 5: 0.41; Ship 6: 0.16; Ship 7: 0.08 and Ship 8: 0.13. This gives a total of ₦2.18 million.

Table 2 Final transportation *tableau* matrix (Set 1) – model 1 (₦ million)

	Period j												
Ship i	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*B*
1	0.09	0.06	0.18	0.08 1	0.20 1	0.12 1	0.10 1	0.15	0.14	0.11	0.10	0.20	4
2	∞	∞	∞	∞	∞	0.03 1	0.04 1	0.09 1	0.09 1	0.09	0.08	0.18	4
3	∞	∞	∞	∞	∞	0.01 1	0.02	0.04	0.04 1	0.04 1	0.04 1	0.08 1	5
4	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	3
5	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	2
6	∞	∞	∞	∞	∞	∞	∞	∞	∞	0.02	0.03	0.09	2
7	∞	∞	∞	∞	∞	∞	∞	∞	0.03 1	0.05 1	0.06	0.14	2
8	∞	∞	∞	0.03 1	0.10 1	0.07	0.07	0.12	0.11	0.10	0.09	0.18	2
S	0	0	0	0	0	0	0	0	0	0	0	0	
A_j	3	3	3	3	3	3	3	3	3	3	3	3	

Table 2 Final transportation *tableau* matrix (Set 1) – model 1 (₦ million) (continued)

	Period j												
Ship i	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24*	*B*
1	0.12	0.06	0.17	0.12	0.20	0.20	0.23	0.13	0.14	0.18	0.11	0.20	4
2	0.12	0.06	0.02	0.16	0.21	0.22	0.26	0.15	0.16	0.22	0.13	0.25	4
3	0.05	0.03	0.08	0.06	0.09	0.10	0.12	0.07	0.07	0.10	0.06	0.11	5
4	∞	∞	∞	∞	∞	∞	∞	0.04	0.08	0.16	0.12	0.28	3
								1			1	1	
5	∞	0.01	0.07	0.07	0.13	0.16	0.21	0.13	0.15	0.22	0.14	0.27	2
											1	1	
6	0.07	0.04	0.12	0.09	0.17	0.18	0.22	0.13	0.14	0.20	0.12	0.23	2
		1	1										
7	0.10	0.05	0.16	0.12	0.21	0.23	0.27	0.16	0.17	0.24	0.14	0.28	2
8	0.12	0.06	0.17	0.12	0.20	0.21	0.24	0.14	0.14	0.20	0.11	0.22	2
S_i	0	0	0	0	0	0	0	0	0	0	0	0	
A	3	3	3	3	3	3	3	3	3	3	3	3	

3.2.2 Setting up the summary table for ship maintenance, operation and idle periods

In setting up Table 3, three critical issues are of major concern to the analyst. The first relates to the computation of idle periods. This is observed from the table. Once a ship is at the dockyard, the idle period starts counting. Concern is shown for those periods where the ship is not maintained, but unattended to. This is monitored until the ship is released from maintenance.

Table 3 Model 1: Ship maintenance, operation, and idle periods (months)

Ship	*Idleness*	*Maintenance*	*Operation period*
(1)	(2)	(3)	(4) = 24 – [(2) + (3)]
1	3	4	17
2	0	4	20
3	2	5	17
4	2	3	19
5	9	2	13
6	4	2	18
7	0	2	22
8	0	2	22
Total	20	24	148
Mean			18.5

The second critical issue of concern relates to the maintenance period. This is observed from the transportation *tableau*. It is the sum of all cells where '1' is assigned to. The third critical issue relates to the computation of operations period. Granted that the total planned period for the shipping firm is 24 months, the operations period is the difference between the planned period and the sum of idle periods and maintenance period. In summary, the computation is as stated below. From the table, the total operations period for all the ships is 148 months while its mean is 18.5 months. The information gathered so far are useful inputs in calculating the total cost of schedule, as displayed in the next section.

3.2.3 Computation of the total cost of schedule

The total cost of schedule has provisions for cost from the *tableau*, cost of idleness and cost of schedule. The computation of cost of idleness has two aspects: avoidable cost of idleness and unavoidable cost of idleness. For the model 1 considered, cost from *tableau* ranges from 0.08 to 0.5 units. Avoidable cost of idleness is 0 for ships 2, 7 and 8 since no idle period is observed for any of these ships while it ranges from 0.028 to 0.54 for other ships based on their idle periods. However, the unavoidable cost of idleness, which may be due to maintenance, ranges from ₦ 0.032 to ₦ 0.085 million. This is dependent on the tonnage of the ship, which ranges from 800 to 2000 tonnes (Table 4).

Table 4 Ship's description and preventive maintenance data

Ship	*Max. running time (months)*	*Size*	*Max. passengers allowed on board (no. of people)*	*Type of operation*	*Tonnage*	*Arrival (k_i) period (months)*
1	80	Large	70	Oil carrier	1500	01
2	75	Large	70	Cargo transport	1800	06
3	40	Medium	25	Cargo transport	800	06
4	77	Large	70	Cargo transport	1700	20
5	57	Large	70	Oil carrier	1900	14
6	55	Large	70	Oil carrier	1650	10
7	70	Large	65	Cargo transport	2000	09
8	70	Large	70	Cargo transport	1600	04

From the section of the table that describes the tonnage of each ship, calculations are made on the cost of idleness as follows.

3.3 Determination of depreciation cost of ships

In the calculation of the opportunity cost for idle ships or those in maintenance, the comparative analysis of the economic loss of revenue by not operating the ship and the depreciation cost of ship is considered. The lower of the two values is adopted in the computation of opportunity cost.

Thus, in this section, the depreciation costs of ships are calculated. These will be used as input values for the computation of opportunity cost utilised for the cost of schedule as shown in the section that follows. From Table 5, the breakdown of depreciation cost is shown.

Table 5 Breakdown of depreciation costs

Ship	*Tonnage*	*P ($)*	*N (years)*	*S (years)*	*Depreciation cost (P – S)/N ($)*	*Depreciation cost (₦)*
1	1500	4831	35	0	138.03	17,943.71
2	1800	5797	50	0	115.94	15,072.20
3	800	2576	20	0	128.80	16,744.00
4	1700	5475	50	0	109.50	14,235.00
5	1900	6119	50	0	122.38	15,909.40
6	1650	5314	35	0	151.83	19,737.71
7	2000	6441	50	0	128.82	16,746.60
8	1600	5153	35	0	147.23	19,139.71

Note: $1 = ₦130. Service life for: 1700–2000 tonnage = 50 years; 1500–1699 tonnage = 35 years. Below 1500 tonnage = 20 years. *P* = investment cost; *N* = service life; *S* = salvage value.

For all the eight ships (ships 1–8), tonnages, investment cost of ship (*P*), service life (*N*), salvage value (*S*) and the depreciation cost (in dollars and Naira values) are shown. For instance, ship 1 which has a tonnage of 1500 with investment cost of $4831 is expected to have a service life of 35 years and a salvage value of zero. Using the straight-line depreciation method which is used in practice for asset valuation, a depreciation cost of $138.03 is obtained. This is equivalent to ₦ 17,943.71 at an exchange rate of $1 = ₦ 130. Thus, the result obtained for ships 1–8 ranges from ₦ 14,235 to ₦ 16,744. These values are used as the opportunity costs in the computation of the total preventive MC as given in Table 5.

3.3.1 *Computation of opportunity cost (d_i) utilised for the cost of schedule*

In order to compute the opportunity cost used for analysis in this work, two approaches were adopted and a reasonable minimum value of the choices was adopted in the computation of the total preventive MC utilised in the study. The first approach considered the price charged for commercial activities for the various tonnages of ships. The second approach is the use of depreciation value of the particular ship of interest. These two approaches aim at obtaining the market values of the services rendered by the ship per period. From investigation and proper analysis, it was observed that ₦2.5 million is charged for two weeks for an oil carrier vessel. This is a possible opportunity cost. An alternative is to consider the depreciation cost, which is the minimum cost incurred as the opportunity cost. Depreciation cost of ships varies according to tonnage.

Thus, the cost of schedule is as given in Table 6.

Table 6 Model 1 – computation of cost of schedule (Naira) (non-inflationary condition) (₦ million)

Ship	*MC (from tableau)*	*Cost of idleness*		*Cost of schedule*
		Avoidable	*Unavoidable (maintenance)*	
(1)	*(2)*	*(3)*	*(4)*	*(5) = (2) + (3) + (4)*
1	0.50	3 × 0.018 = 0.054	4 × 0.018 = 0.072	1.112
2	0.25	0 × 0.015 = 0	4 × 0.015 = 0.06	0.310
3	0.21	2 × 0.017 = 0.034	5 × 0.017 = 0.085	0.329
4	0.44	2 × 0.014 = 0.028	3 × 0.014 = 0.042	0.510
5	0.41	9 × 0.016 = 0.144	2 × 0.016 = 0.032	0.586
6	0.16	4 × 0.020 = 0.08	2 × 0.020 = 0.04	0.280
7	0.08	0 × 0.017 = 0	2 × 0.017 = 0.034	0.114
8	0.13	0 × 0.019 = 0	2 × 0.019 = 0.038	0.168
Total				3.409

Thus, overall, the computation is as shown below for model 1. The total cost for all the 8 ships is ₦ 3.409 million. The cost we have obtained here so far is the cost due to model 1 of the problem. This is referred to as MC under non-inflationary condition. Computation is made using the same procedure but with the inflation cost of model 2 utilised (Table 7). The transportation *tableau* obtained for this model 2 is then used to interpret the result of model 1. The result obtained from this interpretation is called MC in an inflationary condition. This is carried out as follows. Firstly, the table for the transportation *tableau* of model 2 is considered without assigned values of maintenance.

Table 7 Functional minimisation versus actual costs in inflationary and non-inflationary conditions (₦ million) (data set 1)

	Model 1 (non-inflationary)	*Model 2 (inflationary)*	*Model 3 (non-inflationary)*	*Model 4 (inflationary)*
Model 1	3.41	3.53	15.79	16.61
Model 2	×	3.22	×	16.11
Model 3	×	×	15.44	16.15
Model 4	×	×	×	16.15

For an extensive investigation into the maintenance scheduling practice, it is necessary to consider a wide range of data such that reliable conclusions are made on the data pattern. Statistical tools such as student *t*-test may not be feasible by considering only one set of data. In this regard, samples from the population of data are essential for analysis. As stated earlier, the final transportation *tableau* should consist of unit cost parameters, maintenance capacity B_i and docked capacity, A_j, among others.

Since it is difficult to collect real life data when all these parameters are changed, it is necessary to simulate data that will reflect these instances. Clearly, it is difficult and expensive to increase the dockyard capacity. As such, parametric changes are made in the system relating to manpower, since manpower changes may occur with little or no difficulty. Thus, only the manpower maintenance period is simulated while other factors remain constant. For example, for the first data set, the maintenance capacity for ships 1–8 is 4, 4, 5, 3, 2, 2, 2 and 2, respectively. The same interpretation is given to data sets 2–6.

Based on these simulated data (data sets 2–6), the procedure for the computation of the cost of schedule is adopted for all data sets generated and for all problem models. In other words, computation of values that form the final transportation *tableau* is made possible when the assigned positions for maintenance are considered. After assigning maintenance periods to appropriate cells, the idle time generated is studied with the total operation hours for the month calculated. It is this idle time that forms an important component of the cost in this work. Thus, the total cost for all the models are computed using algebraic sum. For student *t* statistic test, data generated for model 1 alone in terms of cost of schedule are extracted per data base number (i.e. model 1 data for data sets 1–6). This is compared with values obtained from other models. Then, *t*-test is carried out to determine the significance of the differences in the values obtained.

3.4 *The concept of true cost in functional analysis*

True cost is determined based on the inclusion or non-inclusion of a particular function in the functional minimisation exercise. If a function is not included, it is obvious that no analysis is carried out on it to minimise cost relative to it. Take model 1 (data set 1), along the horizontal axis, which involves an expression to minimise the MC. The result indicated as ₦3.41 million is the true cost for that situation since the only expression considered is minimised. Now, consider model 3 along the horizontal axis. Here, the functions involving maintenance and opportunity cost are minimised. Thus, it reflects a situation where the maintenance crew do not bother on the ship that has the highest opportunity cost, hence incur high cost. In the real sense, when opportunity cost is incorporated into the function and minimised, the true cost of ₦15.79 million is obtained (data set 1). It should be noted that this is truly better than what is obtained when only MC is considered. Now consider formulation 4 along the horizontal axis. This function minimises maintenance, opportunity cost and inflation cost. However, if we consider the intercept of model 1 with model 4 along the vertical column, a value of ₦16.61 million is obtained if opportunity and inflation costs are to be incorporated into the MC.

3.5 Inflation and non-inflationary environments

The functions developed in the work were carried out under both inflationary and non-inflationary environments. It is observed that some of these functions could be analysed under either one or both environments. Inflation refers to a change in the price of a service without a corresponding change in its value and quality. It is observed that the various resources utilised in the system in which its maintenance activities are to be scheduled could be analysed under inflationary and non-inflationary environments. Consider the first function, MC. This function could be analysed under the non-inflationary period only since the functional development did not incorporate inflation. The second function, maintenance and inflation could be categorised under inflationary environment. This is because of the inflationary factor that it contains. The third factor, maintenance and opportunity cost could be classified under non-inflationary periods. The reason advanced for this is that no element of inflation is contained in the formulation. The fourth function formulated, maintenance, opportunity cost and inflation, could either be considered in non-inflationary period or inflationary period.

3.6 Statistical test and analysis of the models

Scientific research all over the world is usually tested statistically in order to explore the characteristics of the data utilised in model frameworks. Consequently, the data collected from the shipping organisation, which is presented here, is statistically tested using student's t-test statistical tool. The focus of the test is to find out the relationship between pairs of models for all the four models considered. For example, for the six data sets utilised in the current work, it may be interesting to find out the statistical significance between models 1 (MC alone) and 2 (maintenance and inflation costs). If significant differences exist, it then implies that variations in results are large enough not to be neglected. Although if the differences are not significant, it does not infer that one method is not better than the other. However, it may be that enough data have not been collected or an error may exist in the data collection.

In comparing results, attention is focused on comparing pairs of models 1–4. In analysing these models and comparing them in order to make conclusions, t-test was employed since only a sample of the population is studied. In this case, only six data sets (sample size) are studied out of over 120 months of data which represent the data of the organisation for over a decade. Since manual analysis of the data using t-test would be computationally challenging, Microsoft Excel software package was used in the analysis.

The data analysis part of the software, with main focus on *t*-test: paired two samples for means, was used with the appropriate result displayed in Table 8 (see model 1 analysis).

Table 8 *T*-test results between models 1 and 2 (while model 1 is horizontal)

Data set	*Model 1 (1)*	*Model 2 (2)*	*% changes [(1) − (2)]/(1)*	*Statistical descriptions*		
					Model 1	*Model 2*
1	3.41	3.53	−3.52	Mean	3.95	4.19
2	4.14	4.73	−14.25	Variance	0.17	0.25
3	4.14	4.33	−4.59	Observations	6	6
4	4.09	4.27	−4.40	Correlation	0.94	
5	4.45	4.63	−4.04	Hypo. mean	0	
6	3.49	3.62	−3.72	df	5	
				t-Stat	−3.19	
				$P(T < +t)$ one tail	0.0121	
				t Critical one tail	2.02	
				$P(T < +t)$ two tail	0.0243	
				t Critical two tail	2.57	
				Decision	Accept null hypothesis	

3.6.1 *Statistical analysis for models 1 and 2*

By considering Table 8 that contains all the information needed, explanations are given on how these values are obtained. The first column contains labels for all the six data sets used in the study, that is, data sets 1–6. The value obtained from the cost of schedule of model 1 is recorded in front of data set 1. Five other scenarios are obtained from the simulated cost unit factors of MC alone. These five results obtained from the cost of schedule of these cost inputs are inserted in the appropriate columns of the table. The values to be written under data set 1 of model 2 are those obtained when the solution of model 1 is interpreted from the values obtained in computing model 2. Notice that at this stage, there is no need to compute the optimal schedule for model 2: only the values of the cost units are used. Given that five other values from five data sets have been obtained, the two columns (2nd and 3rd) are then compared.

By taking model 1 as a reference point (base period), the magnitude of the increase or decrease of model 2 over model 1 is then recorded in the third column. This gives values ranging from −14.25% to −3.52% for the six data sets. All the values of cost of schedule for model 1 are averaged, with results recorded adjacent to the column for mean. The same mean values for model 2 are computed and recorded on the rent column adjacent to the cell where 'mean' is inscribed. The variance between the two models is then calculated, with results stated adjacent the cell containing 'variance'. The number of observations is 6 since 6 data sets are concerned.

Correlation between these data sets is obtained as 0.94. The hypothesised mean is 0. This means that the hypothesis states that there are no differences between the means of the two models. The degree of freedom is 5. This relates to the number of data sets collected and analysed, and not the number of ships. Thus, for the same number of ships, the degree of freedom may increase to 9, if 10 sets of data were used. The t stat gives the reference value against which judgements are made. If we consider a one-tailed analysis, $P\ (T < +t)$ one tail gives 0.0121. When compared with t critical one tail value of 2.02, the decision is rejected. Also, for a two-tailed t statistical test, t stat is still used as a reference. Here $P(T < +t)$ two tail is 0.0243. Compared to t critical two tail value of 2.57, the decision still remains as: accept. Using the procedure in computing values given in Table 8 for comparative analysis of other pairs of models, it was found out that the decision made for all these pairwise comparisons is to accept the null hypothesis.

An important part of the analysis was to determine if model 1 underestimates the true ship MC when compared with the other three models, and if so, whether this underestimation was significant. For the original data, the ship MC was ₦3.4 million, which was underestimated by 3.5% when compared with model 2, underestimated by 363.1% when compared to model 3, and underestimated by 387.1% when compared with model 4. For the simulated scenarios, the mean ship MC was ₦4.1 million, and was underestimated by 6.2% when compared with model 2, underestimated by 344.2% when compared with model 3, and underestimated by 361.2% when compared with model 4. For all the samples, the costs of the model 1 were significantly ($p \le 0.05$) different from that of models 2–4.

4 Conclusion

The increasingly high customer demand for improved product and service quality in recent times has brought about the utilisation of high technology system to provide such products and services that meet and exceed the expectation of the customers. However, these facilities must be properly operated and maintained in order to recoup the high financial investment on them. For example, fleets of ship vessels, vehicles, aircrafts, heavy machine tools and heavy earth-moving equipment (e.g. caterpillars, cranes, etc.) require high cost of investments in purchase, operations and maintenance. The high investment cost, which may have been borrowed from the bank at an interest value that increases over time, must be cautiously expanded so as to recoup it within minimum time, while making profit for the organisation. In addition, modern manufacturing and service systems is becoming complex with multiple facilities to be managed in multiple periods by using limited maintenance resources under limited capacity of the plant.

Unfortunately, this challenge of coping with costs is compounded with inflation that causes periodic changes in the price of resources without changes in their values. Again, the seemingly difficult workforce requires close scrutiny in order to contribute their skills optimally to the improvement of the profit-making goal of the organisation. Thus, the maintenance workforce may be carefree in delaying facilities for maintenance due to unacceptable excuses such as lack of materials, insufficient labour availability or waiting for instructions from the higher authorities. Consequently, there is need for a scientific model that would incorporate costs, delays and inflation. This model has been formulated and solved in the current work. In particular, delay is viewed from the point of loss in revenue by the organisation, and christened opportunity cost. Primarily, four models of the problem were formulated and solved and the results compared with one another for decision making. Basically, in order to reduce costs and delays, decisions for scheduling preventive maintenance for fleet of facilities should be based on MC and opportunity cost in both inflationary and non-inflationary conditions.

The possible extensions of the current work are many-sided (Oke, 2004; Oke and Charles-Owaba, 2005a–c, 2007). Each of these aspects has the potential of becoming an important area on its own. These promising extensions are:

1 Sensitivity analysis and statistical tests

2 *Possibility of production or maintenance interruption*: a limitation of the model is that there is no guarantee that each maintenance activity is performed without interruption.

This is an important aspect that can be integrated into the existing framework in a future work.

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