Development of the Contiguous-cells Transportation Problem

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Abstract—**The issue of scheduling a long string of multi-period activities which have to be completed without interruption has always been an industrial challenge. The existing production/maintenance scheduling algorithms can only handle situations where activities can be split into two or more sets of activities carried out in non-contiguous sets of work periods. This study proposes a contiguous-periods production/maintenance scheduling approach using the Transportation Model. Relevant variables and parameters of contiguous-cells scheduling problem were taken from the literature. A scheduling optimization problem was defined and solved using a contiguous-cells transportation algorithm (CCTA) which was applied in order to determine the optimal maintenance schedule of a fleet of ships at a dockyard in South-Western Nigeria. Fifteen different problems were solved. It is concluded that the contiguous-cells transportation approach to production/ maintenance scheduling is feasible. The model will be a useful decision support tool for scheduling maintenance operations.**

Keywords- Contiguous-cells Transportation Model; Production Maintenance Scheduling; Linear Optimization;

I. Introduction

One of the oldest problems of human societies is the allocation of limited resources. This problem is multifaceted in nature because it can still be divided into several sub-problems. Distribution of goods and commodities from one point to another has been a major issue encountered in day–to-day activities. Its cost implication as well as satisfying the needs of clients and customers is of prime importance. The above problem is described by the term transportation problem or TP. However, this term in general also includes other important applications such as scheduling, production planning, inventory control, employment scheduling, production mix problem etc. The transportation problem has been the focal point of many researchers because of its wide application and usefulness to solving real life problems. The extensions of Transportation Problem are given in [1].

Some manufacturing processes have to be carried out without interruption to get the intended end product at the required composition e.g. casting processes, forging processes and most steel making processes. Steel making process requires some processes which have to take place systematically in a definite order. The heating, soaking, and cooling processes must not be interrupted in order to achieve the required composition and quality for the product.

Pre-emption may not be feasible or allowed in the maintenance of certain types of equipment because of the size of the equipment, the limited maintenance facility, the set up cost and time associated with loading and unloading equipment in and out of maintenance facility. In ship maintenance, the moment a ship is loaded into the dockyard, it has to stay there for the required period to carry out maintenance activities until completion. To permit pre-emption in the maintenance of ship, the ship have to be unloaded from the dockyard, load another ship of higher priority and then bring in the former to complete its maintenance activities later. There are situations, however, where non-preemptive execution is preferable that is in situations where the cost required in the operating system to handle the preemption may be regarded as too large or if the system needs to support critical sections where preemption is not allowed. This calls for a model that can handle non-pre-emptive scheduling problem using Transportation Model.

Contiguous-cells transportation model is proposed to solve non-preemptive scheduling problem using the Transportation problem. It differs from the traditional transportation model used in scheduling in that it has a uniform period and once the process or operation starts at the beginning of a period, it must be completed at the end of a period without interruption. The beginning of a period to the end of a period which represents the period used to carry out the process or operation is depicted with cells that are connected together without a break within a common boundary called contiguous-cells. Also, the demand constraint is distributed across the blocked cells i.e. contiguous-cells.

II. Literature Review

Scheduling is a decision-making process that is used on regular basis in many manufacturing and service industries and this form of decision-making process plays an important role in procurement and production, in transportation and distribution and in information processing and communication. Scheduling rely on mathematical techniques and heuristics methods for allocation of limited resources which must be done in such a way to optimize the objectives and achieve the goals of the organization [2].

Pre-emption is the act of temporarily interrupting a task being carried out in order to run a higher priority task with the intention of resuming the task later. Non-preemptive scheduling when compared with preemptive scheduling has received considerable less attention in the research community [14]. However, non-preemptive scheduling is widely used in industry practice, and it may be preferable to preemptive scheduling for a number of reasons [8, 18, 30].

Non-preemptive scheduling algorithms are easier to implement and have lower runtime overhead than preemptive scheduling algorithms; the overhead of preemptive scheduling algorithms is more difficult to characterize and predict than that of non-preemptive scheduling algorithms due to inter-task interference caused by caching and pipelining. Work with non-preemptive scheduling algorithms has typically been confined to consideration of models where processes are invoked only once, there is a precedence order between the processes, and each process requires only a single unit of computation time and must be completed before a deadline [10, 12]. Several approaches have been used to solve production and maintenance scheduling problems [11, 13, 16-17, 19-22, 27, 31]. Researchers have developed algorithms applicable in models with variables and structure similar to the standard Transportation Problem that is extensions of transportation model [3, 5-6, 15, 23-26, 28-29].

Bowman [7] was the first to suggest solving the production scheduling problem by a transportation method framework. And he further stated that many transportation problems could be extended to include a multi-time period. However, several extensions of the TP [3, 6-7, 9, 25-26, 28-29] have the structure of the traditional Transportation Problem which only solves problems where preemption is allowed. Charles-Owaba [9] mentioned the contiguity concept in scheduling of operation and maintenance periods of machines on Gantt charts (the Gantt charting problem) which was formulated, defined and solved as a transportation model. Though, the contiguity concept was mentioned in Gantt charting problem but it was formulated, defined and solved as that which is pre-emptive. The stringency attached to some real life situation as earlier illustrated may not allow pre-emption. This brings about the development of a contiguous-cells transportation model. Therefore, the Contiguous-cells Transportation Model (CCTM) formulation is the main subject of this study.

III. MODEL FORMULATION

A. Notations

The following are the notations used in the model:

i: index indicating source identity

j: index indicating destinations identity which is time period for contiguous-cells TM

M: total number of supply sources

T: total number of demand destinations (i.e. number of periods in time horizon for CCTM)

B_i : Number of periods required to process demand source i

t_i : the number of periods source i stays in the system

H_i : period at which activities was completed on source i

s_i : period at which activities commence on source i

m_i: period that precedes the commencement of activity on source i

k_i : the period source i is ready for processing

I_i : the number of periods source i waited before being processed or attended to

c_{ij} : unit cost of processing source i at period j

y_{ij} : a contiguous variable and it is defined as:

$$y_{ij} = \begin{cases} B_i, \textit{ numbers contiguous cells commencing} \\ \textit{from } \left(j - B_i + 1\right)^{th}, \textit{ if cell } j \textit{ is the last cell} \\ \textit{among the contiguous cells assigned for} \\ \textit{the task} \\ \\ 0, \textit{ otherwise} \end{cases}$$

B. Mathematical Model Formulation

The model is developed as an LP transportation model for problems that do not allow pre-emption such that cost is minimized under the following assumptions:

1. The total numbers of periods (T) are fixed and contiguous.
2. The problem parameters are known.
3. A ready source has its activities commenced only when resources are available. Otherwise, it waits.
4. A source is either on queue or in for processing at any moment.
5. When a source is ready, activities commenced at the beginning of a period while completion is at the end of a period.
6. Ready times are known.
7. The unit cost of source i is given for the contiguous period required.
8. The span of a period may be in seconds, minutes, hours, days, weeks, months, e.t.c..
9. There is no pre-emption; that is a running task is executed till completion; it must not be interrupted.

C. Development of Cost Objective Function, Constraint and Problem Definition

The unit cost of source *i* at period *j* without contiguous-cells consideration, is given as c_{ij}. The total cost for item i in T periods is given by the expression:

$$C\left(T, y_{ij}\right) = \sum_{j=1}^{T} c_{ij} y_{ij} \qquad (1)$$

For all M items, the total cost is given as

$$C\left(T, M, y_{ij}\right) = \sum_{i=1}^{M}\sum_{j=1}^{T} c_{ij} y_{ij} \qquad (2)$$

The cumulative cost over the contiguous period is given as e_{ij} and it is defined as follows:

$$e_{ij} = \begin{cases} \sum_{j=k}^{H} c_{ij} \quad , \; if \;\; j \geq H \\ \\ - \quad , \; if \;\; j < H \end{cases} \qquad (3)$$

The symbol "–" in (3) implies "not applicable", that is the cell does not form a contiguous-cells. The definition of cumulative cost over the contiguous period in (3) is described as follows and shown in Table I. The horizontal movements on Table I indicate destination which is the period for contiguous-cell TP while the vertical movement across the table shows the source identity with the supply for each source *i* (where *i* = 1, 2, 3,…,z) and demand for each destination *j* (where *j*=1,2,3,…, x). e_{ij} implies the cumulative cost over the contiguous period which is the summation of cost from the start of operation at the beginning of period to the completion of operation at the end of period.

TABLE I. STRUCTURE OF CONTIGUOUS-CELLS TRANSPORTATION TABLEAU MATRIX FOR COST FUNCTION

	Destination j							
Source i	**1**	**2**	**3**	**4**	**.**	**.**	**X**	**Supply**
1	-	e_{12}	e_{13}	e_{14}	.	.	e_{1x}	**M**
2	-	-	-	e_{24}	.	.	e_{2x}	
3	-	-	e_{33}	e_{34}	.	.	e_{3x}	
.								
.								
Z	-	-	-	-			e_{zx}	
Demand	**N**							

Here are the mathematical expressions of some values of e_{ij} given in Table I:

$$e_{12} = \sum_{j=1}^{2} c_{1j} \;,\; e_{24} = \sum_{j=1}^{4} c_{2j} \;,\; e_{33} = \sum_{j=1}^{3} c_{3j} \;,\; e_{zx} = \sum_{j=1}^{x} c_{zj}$$

The "-" in some cells show that the cell cannot form a contiguous-cell yet. For example, for source 1, 2 cells form the contiguous-cells, thereby making the first cell not applicable. Also, for source 2, 4 cells form the contiguous-cells, thereby making cell 1, 2, and 3, for that row not applicable.

The actual cost of processing source *i* in the contiguous period is given as o_{ij}

$$o_{ij} = e_{iH} - e_{im} \qquad (4)$$

where m is the period that precedes the start of activity on source *i* and *m* is given as *(H-B_i)*

$$o_{ij} = e_{iH} - e_{i(H-B_i)} \qquad (5)$$

The average cost of source *i* in period *j* taking into consideration all the B_i contiguous-cells is given as $\overline{o}_{ij}$ and it is defined as follows:

$$\overline{o}_{ij} = \frac{o_{ij}}{B_i} \qquad (6)$$

The total cost for item *i* in T periods for contiguous-cells transportation model is given by the expression:

$$C\left(T, y_{ij}\right) = \sum_{j=1}^{T} \overline{o}_{ij} y_{ij} \qquad (7)$$

The total cost for all M items for contiguous-cells transportation model is given as:

$$Minimise \;\; C\left(T, M \;\; , y_{ij}\right) = \sum_{i=1}^{M} \; \sum_{j=1}^{T} \overline{o}_{ij} y_{ij} \qquad (8)$$

The demand constraint is expressed mathematically as:

$$\sum_{i=1}^{M} \frac{y_{ij}}{B_i} \leq A_j \quad (9)$$

The supply constraint which also caters for the non pre-emption constraint is given as:

$$\sum_{j=1}^{T} y_{ij} = B_i \qquad (10)$$

Equation (10) implies that the constraint must be satisfied at once which depicts the contiguous cells for non- pre-emption.

The contiguous-cells transportation problem model is given as:

$$Minimize\ C = \sum_{i=1}^{M}\sum_{j=1}^{T}\bar{o}_{ij}\,y_{ij}$$

Subject to $\sum_{i=1}^{M}\frac{y_{ij}}{B_i} \le A_j$ and $\sum_{j=1}^{T} y_{ij} = B_i$

where B_i, A_j ,M, and T are as defined earlier.

D. Contiguous-cells Transportation Algorithm (CCTA)

The approach to solve the CCTP is adapted from revised distribution method of finding optimal solution of TP [4]. This solution approach will make use of allocation by minimum supply. The procedure is as follows:

Step 1: Start with the minimum value in the supply column; if tie occurs select the supply with the least cost.

Step 2: Allocate all the supply in that row and also meet the demand constraint that can be met alongside. It should be noted that all the supply constraint is first met at once for it to be contiguous.

Step 3: If all the supply in the row and demand in the column are satisfied, repeat the procedure from step 1. But, in case there is no demand to accommodate the supply for the least cost on supply row, select the next minimum cost that can accommodate the demand constraint for the supply on that row. It should be noted that the minimum cost to be considered is non-zero least cost.

E. Solution Procedure for the Contiguous-cells Transportation Model

Step 1: Determine the value of problem parameters: $\{B_i, k_i, A_j, c_{ij}.M, T, N_i\}$

Step 2: Set up the transportation tableau by computing e_{ij} which defines the cumulative cost over the contiguous period to find the optimal y_{ij} and this cumulative cost is defined as follows:

$$e_{ij} = \begin{cases} (3), \ if\ source\ \ i\ \ is\ ready\ in\ period\ \ j \\ \infty\ ,\ otherwise \end{cases}$$

Step 3: Solve the cost minimizing transportation problem with the above defined cost using the algorithm given above to determine the optimal value of y_{ij} for the contiguous period.

Step 4: Compute $\bar{o}_{ij}$ the average cost of source i in period j from the optimal value of y_{ij} and then the total cost of source i in T period for contiguous-cells and the total cost of M sources for contiguous-cells transportation model as given by expressions (6), (7) and (8) respectively

IV. MODEL APPLICATION

The model developed was applied to schedule the maintenance of a fleet of ships for a shipping company in South-Western Nigeria. The company has a successful operation record of transporting goods outside Nigeria and importing other goods into Nigeria from distant and near countries. The company engages majorly in crude oil transportation to refineries outside Nigeria. It also imports petroleum products from these refineries in to the country. This shipping company is faced with the challenge of lacking an effective methodology for maintenance and operation scheduling for optimum profitability. Due to the operation of the shipping company, an effective maintenance system is required to avoid breakdown which may lead to loss of profit, good will, and towing charges.

The ship maintenance activities include sand blasting, welding of damaged ship parts and bodies, pump servicing, generator servicing, fixing strainers, raider repair, engine repair, ship reconstruction, propeller fabrication, rudder fabrication, electrical system maintenance. The company's total maintenance cost is influenced by the period it takes to carry out the maintenance task, the labor cost which increases with time, the amount of consumables item, spares and other materials used. The contiguous-cells transportation model is defined as maintenance scheduling problem for a fleet of ships.

The problem parameters are:

- the number of visits per machine (N_i) within the T periods,
- the duration per maintenance visits (B_i),
- number of ships (M)
- the maintenance capacity in period j (A_j)
- the arrival period of ship i (k_i)
- the number of periods in planning horizon (T)
- the direct maintenance cost of ship (a_{ij})

The operations period in a planning horizon is given as the difference in the total number of periods on planning horizon and the actual maintenance period and this given as:

$$P_i = T - B_i \qquad (11)$$

$$TP = \sum_{i=1}^{T} P_i \qquad (12)$$

In case where the machine waited before being serviced, the actual operations period is given as the difference in the total number of periods on planning horizon and in time spent in maintenance system which is expressed mathematically as:

$$O_i = T - t_i$$

$$O_i = T - (J - k_i + 1)$$

$$O_i = T - J + k_i - 1 \qquad (13)$$

$$TO = \sum_{i=1}^{T} O_i \qquad (14)$$

Idle period is the difference in the period spent in the maintenance system and the period for maintenance activities on ship *i* and it is given as:

$$I_i = t_i - B_i \qquad (15)$$

$$I_i = P_i - O_i \qquad (16)$$

$$TI = \sum_{i=1}^{T} I_i \qquad (17)$$

V. RESULTS

Table III illustrates the ships-periods final transportation tableau matrix with y_{ij} indicated for the contiguous-cells Transportation model. The total maintenance cost of ships; operation and idle period in months for the ships were computed and the results are shown in Table II.

TABLE II. TOTAL MAINTENANCE COST (TMC) OF SHIPS, TOTAL OPERATION PERIOD (TOP) AND TOTAL IDLE PERIOD (TIP)

Problem	TMC (million Naira)	TOP (month)	TIP (month)
1	74.45	168	0
2	87.33	164	0
3	81.85	164	0
4	91.24	160	0
5	83.01	163	0
6	53.24	167	0
7	86.31	165	0
8	93.19	161	0
9	90.76	162	0
10	93.36	160	0
11	91.86	159	1
12	82.39	157	11
13	59.00	168	0
14	109.78	168	0
15	118.98	163	5

TABLE III. SHIPS-PERIODS FINAL TRANSPORTATION TABLEAU MATRIX

ship i	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	∞				5.06 4	6.82	8.11	9.77	11.5	13.2	14.5	16.9	18.3	19.0	19.8	21.8	23.8	25.7	27.8	29.1
2	∞	∞	∞	∞	∞	∞	-	-	-	6.34 4	7.66	10.0	11.4	12.2	14.1	15.4	17.4	19.3	21.4	22.7
3	∞	∞	∞	∞	∞	∞	-	-	-	-	7.66 5	10.0	11.4	12.2	14.1	15.4	17.4	19.3	21.4	22.7
4	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
5	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	-	34.9 2	36.9	38.8	40.9	42.2
6	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	-	3.73 2	5.06	5.8	7.7	9.06	11.0	12.9	15.0	16.3
7	∞	∞	∞	∞	∞	∞	∞	∞	∞	-	6.3 2	11.7	15.5	18	25.1	31.1	39.5	48.2	58.1	64.5
8	∞	∞	∞	∞		6.62 2	7.9	9.56	11.3	12.9	14.3	16.7	18.1	19.3	20.0	21.9	23.2	25.2	27.1	29.2
9(D)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aj	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

TABLE III. (CONTINUED) SHIPS-PERIODS FINAL TRANSPORTATION TABLEAU MATRIX

ship i	21	22	23	24	Bi
1	30.4	32.1	32.9	43.6	**4**
2	23.9	25.6	26.5	28.2	**4**
3	23.9	25.6	26.5	28.3	**5**
4	-	-	3.83 3	6.2	**3**
5	43.5	45.2	46.5	48.9	**2**
6	18.3	19.9	20.9	28.3	**2**
7	71.2	80.0	85.1	94.6	**2**
8	30.5	32.1	33.1	34.7	**2**
9(D)	0	0	0	0	
Aj	3	3	3	3	

VI. DISCUSSION OF RESULTS

From the result it is seen that the algorithm gives the set of maintenance cost {74.45, 87.33, 81.85, 91.24, 83.01, 53.24, 86.31, 93.19, 90.76, 93.36, 91.86, 82.39, 59.00, 109.78 ,118.98} million naira with idle periods of {0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 11, 0, 0, 5}in months for the fleet of ship.

Elimination of idle time in the maintenance activities minimizes the period the ships spent in the maintenance system thereby increasing the operation period of the ships. The company' return on investment will also increase with increased operation period and the availability of the ships. Productivity is also increased when idle time is eliminated. It can be seen from the results that the little or no idle time in the maintenance of ships shows that the cost is reduced. Also, the little or no idle period will also increase the operation periods of the ship thereby increasing the return on investment.

The algorithm uses the revised distribution method of finding optimal solution of TP. The revised distribution method is based on allocating units to the cells in the transportation matrix starting with minimum demand or supply to the cell with minimum cost in the transportation matrix and then try to find an optimum solution to the given transportation problem. This gives an optimal solution as the existing Modified Distribution Method with less iterations.

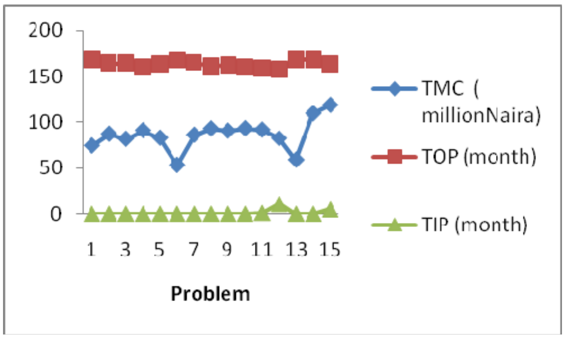

Fig. 1. Chart showing the total maintenance cost, total operation period and total idle period for problem parameters considered.

VII. CONCLUSION

This study proposes Contiguous-cells Transportation Model (CCTM) which is an extension of traditional transportation problem which aims at solving non- pre-emption scheduling problems. The study develops a mathematical model to define and solve CCTM with the criterion of minimizing the total cost. The approach defines the unit cost of activity per period with no pre-emption allowed for any set of activities to determine the set of contiguous cells for each set of activities. The tableau for the traditional transportation problem is first formed and then transformed into a non-pre-emptive tableau by combining sets of appropriate cells into one contiguous-cell. It turned out that the optimal solution procedure for the traditional also solves the contiguous-cell problem. The variables and parameters of the problem were identified and defined. Contiguous-cells transportation model was formulated, defined and applied to solve maintenance scheduling of a fleet of ships. Several scenarios for changes in the arrival period and maintenance activity duration were considered. The results show that the contiguous-cells transportation model formulation is feasible as demonstrated in its application to solve maintenance scheduling problem and this contiguity concept can be applied to real life situations.

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