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Research Article

APS-CR: Assignment Problem Solver for Cost Minimization of Crew Routes

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Abstract

In this paper, crew scheduling problem is described on operational roadways. During our day-to-day operations, generalized monthly roadways, crew members are associated to solve the crew problems, which requires covering of all buses at minimal cost and also maximal profit. For selected crew members to prepare a simplified pairing, and classifying crew pairing problems in a constructive way, monthly assignments must be followed. In this work, we proposed the various problems in which the bus schedule and crew schedule are fixed in an optimized way by giving the input data. Hungarian method is applied as a case study that discusses the different routes and assignment problem solvation process, adopted by the routes from given sources to given destinations. From the case study taken, the minimum lay over time is found to be 33.30 Hrs.

Keywords: Allocation; Hungarian; Assignment; Routes; Crew scheduling, Vehicle Scheduling

1. Introduction

A linear programming relates to solve the complicated problem concerning distribution of various resources such as men, machine, money, material, and time quantity satisfying certain constraints in the form of algebraically represented linear equations/inequalities. In this paper, problem objective is solved to assign sources to destinations at a minimum cost to manage the listed routes in various path arrangements. Assignment problem arises while n jobs are assigned to m machines, where n may or may not be equal to m and the persons is intended to operate m machines or engage n number of cranes at m number of quarries. The assignment, employment or allotment is targeted with the goal to expend minimum cost or maximum effectiveness in the operation. The assignment problems are usually solved by using Hungarian method. In case, more restrictions or constraints are imposed in the jobs dimension or machines tool instruments' performance, or energy consumptions restrictions the assignment goal simplicity hampers and it

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becomes out of track. So, in spite of computational logistic flow diagrams availability, there is inadequate computer programming methods available to implement the assignment problem. The authors presenting Hungarian method applied case study that discusses the different routes and assignment problem solvation process adopted by a destinated routes from a given sources to a given Destinations. Despite the usefulness of operations research techniques in both manufacturing and service of designated routes. The assignment problem was formulated and solved with Hungarian method based on the data obtained from five routes in a different schedule.

In Public transport system crew and Vehicle scheduling are two main sources to solve the problems. Authors mainly focus about these two solved problems simultaneously. According to First in First out (FIFO) rule the vehicle scheduling problem comes first and afterwards the crew scheduling problem arises to solve the problems. It is mostly important that the time savings of transit system in suburban/extra-urban, which are also an integrated approach and also much more appropriate than in an urban transit system. It is mandatory for relief of one driver for another one savings of much or less opportunities that both drivers can avail their rest according to his own choice for starting/finishing their duties.

The major areas of research are stated as follows:

1. In this work, crew scheduling problem is solved by minimizing the route pairing cost. For analysis, the bus and crew schedules are fixed in an optimized way based upon the input data.
2. Hungarian method is applied as case study that discusses the different routes and assignment problem solvation process, adopted by the routes from given sources to given destinations.
3. From the case study, the minimum lay over time is found to be 33.30 Hrs.

The paper is managed as follows. In Section 2 related works is presented. In section 3 methodology is presented. In section 4 APS-CR technique is presented. In section 5, the effectiveness of the APS-CR technique is evaluated using a crew scheduling based problem. In section 6 we concluded the work.

2. Related Works

Several assignments have introduced by applying the concept of assignment model as well as the empirical framework. These are described as follows.

Assignment problem is a one case of transportation problem where jobs (or origins or sources) and number of facilities (or destination or machines or person and so on) are equal. It arises as a result of different decision making situation relating to job or task assignment in the day-to-day activities. Assignment Problem is a one-to-one matching problem. Assignment model comes under linear programming, which has to do with allocation of jobs to machines, personnel to location. Basically, assignment model has two objectives either to minimize or maximize. A.A. Bertossi et al. [1] proposed two bipartite similarity approaches arising in Vehicle Scheduling problems are considered. A. Gaffi et al. [2] describes scheduling of vehicle before crew in ex-urban mass transit system. Frimpong, O. S. et al. [3] used a linear programming to solve under allocation and over allocation of classroom in Premier Nurse’s Training College, Kumasi. Optimal solution was determined when solved with the help of POM-QM for Windows 4. G. Desaulniers. et al. [4] Performing locomotives and cars to a set of designated trains in a complex problem for passenger railways. Idris, E. M. et al. [5] applied assignment model to study the allocation of workers to different section in the store located at Alhram Plaza Centre in Saudi Arabia who specializes in the sales of clothes. Patrikalakis et al. [6] authors visualize a new decomposition of urban public transport scheduling problem. J. K. Sharma [7] proposed the number of jobs assigned to corresponding operators. Aircraft routing and crew scheduling problem is solved by J-F. Cordeau et al. [8] for determining a minimized cost. In assignment model of Kabiru, S., et al. [9] all tasks are to be performed must be assigned on one-on-one basis; two tasks or jobs cannot be assigned to machine or personnel. K. Haase et al. [10] proposed algorithm for the vehicle and crew scheduling problems in urban public transport systems. The multiple depot vehicle scheduling problem is also solved by M. Dell'Amicoet al. [11]. M. Fischetti et al. [12] argued about the fixed job working time constraints, where a bound is imposed total working time of each processor. P. Carraresi et al. [13] solves bus driver scheduling problem at the minimum cost. R. Freling et al. [14] designed a problem of integrating vehicle and crew scheduling is considered with in a sequential manner. An integrated approach to vehicle and crew scheduling is proposed by R. Freling et al. [15]. Simon, K. (2012) [16] used assignment problem to solve staff-subject allocation with the aim of maximizing quality on teacher's knowledge impact to students' lives. Optimal solution was obtained at end of the analysis. The assignment problem play a significant role in solving real life problem and it is acceptable and well utilized tool around the world. Srinivas, B. et al. [17] believe assignment problem is a management science tool that can be deployed to achieve optimization in both manufacturing and service system. Assignment problem is a technique in operation research that can be used to derive optimization, it has capacity to minimize and maximize depending on the objective of the model. It can be used in allocating jobs to machine, operators to machine, sales-personnel to territories, workers to supervisor, courses to lectures, engineers to construction sites among other with focus to minimize or maximize. Thongsanit, K. [18] have developed a mathematical model to solve course – classroom problem in FEIT at Silpakorn University in the First Semester, 2012. Optimal solution was determined, and total cost of classroom was reduced. Xian-ying, M. et al. [19] describes model in solving teachers' allocation problem in order to minimize the time to be spent in preparing lecturers for four teachers who are capable of teaching four different courses were selected for the study. Optimum solution was discovered with the help of Hungarian method employed to solve the assignment problem. Teaching schedule and learning [21-22] can be affective by adopting the game-based or fun learning and improving the communication factors. These all factors have negative impact during the pandemic [23] This can be improved by adopting the [24-25] the digital curriculum methodologies and latest assessment methods such as Rubric, etc.

3 Methodology

In this section, crew scheduling and multiple-depot vehicle scheduling processes are solved. To formulate different types of scheduling, a set of trips is mandatory to balance the crew costs and to find the total sum of vehicle cost, which corresponds a fixed planning period by balancing the feasibility condition of both the vehicle and the crew schedules. Every set of depots can be deployed to a crew member and a vehicle for visualizing the starting and ending times. Of course problem arises to a crew scheduling and single-depot vehicle, that decomposes if vehicle and crew members are assigned to every trip.

If we know locations of all travelling times between pair of routes then any bus schedule is feasible if the following points satisfy: (1) one vehicle must be assigned exactly all the trips (2) every depot is allowed to a vehicle to drive each trip.

The cost of the vehicle and travel time for every vehicle must be fixed, if there are lots of time between entry and exit trips of a vehicle then it must be fixed to returns the depot. Vehicle blocks have to be formed by the same vehicles from the vehicle schedule trips. These blocks are subdivided into relief points, mentioned in different locations in different times to enjoy the break of a driver and it is mandatory to engage another driver during the break time. Two consecutive relief points of a crew are utilized by using minimum portion. The crew responsibilities are engaged to the same crew member to fulfil the task. To perform crew schedule which can be feasible follows the conditions: if (1) One duty is assigned to each task and (2) for the sake of simplicity and for legal point of view, a single crew can be performed a sequence of duty for each task. To maintain workload regulation for crews each duty must be satisfying complicating constraints. Classical examples are without breaking maximum working hours with minimum break duration time, and also maximum duration and maximum total work time. So, different types of duties which can differ different constraints e.g. late duties early split. The duty cost is fixed and if a crew member perform overtime duty then their wages is calculated in payment basis. We have five assumptions for solving the problem, which are shown as follows:

1. For smooth Functioning of crew systems, if the number of vehicles entered into the depot is so large, at that time vehicles entered and exit in the same depot, so that travelling vehicles/crew must have its own depot.
2. If travelling vehicles/crew must have its own depot, which ensures that the vehicles from that depot must obey the task of a single crew member. However, every duty begins and closes in this depot is not mandatory.
3. For minimizing and maximizing limited piece length depends on its duration of feasibility to maintain piece.
4. If any vehicle remains present outside the depot a driver must stay inside the bus, and there continuous attendance must be maintained.
5. Any drivers remains absent during his duty, changeovers, are allowed to another driver during his absence.

To maintain feasibility of crew, the last two characteristics satisfying that no changeovers are allowed to drivers i.e. before starting and after ending break and also same driver must drive the vehicle, there is only possibilities that another driver remain present on this vehicle during the break period of the other driver. We have to conform to every drivers should maintain two types of task i.e dh-tasks and, trip task. A trip task corresponds to the trips of any goods/passengers, and deadheading corresponds to dh-tasks. A deadhead represent to a commercial driver, who complete trips in a bus or other vehicles with no passengers/cargo. A crew member must be present for every trip task, which covered all the passengers. Vehicle schedules must depend on two types of tasks, which calculates the feasibility of crew schedules and vehicles. In general, each dh-task must be given to a crew if the particular vehicles must be assigned the deadhead.

So, the vehicle-based crew assignment problem can be solved using Hungarian assignment technique, that gives maximum effectiveness of changeover times of the designated vehicles to the designated routes. The total effectiveness of cost minimization of every vehicles assigned to corresponding designated routes can be calculated by changeover times.

4. APS-CR Assignment Technique

APS-CR mainly apply the Hungarian method for assignment to solve the crew scheduling problem. Assignment model or mathematical model for assignment problem [20] is a branch of linear programming that requires n buses or vehicles to m routes. Also let C_{ij} be the cost of assigning i^{th} vehicle (i=1,2,3,…,n) to j^{th} route (j=1,2,3,…,m). The main focus is to determine the vehicles to the routes at least total cost or the maximum total profit or efficiency. The problem can be formulated in this canonical form as follows:

$$Z = \sum_{j=1}^{n} \sum_{i=1}^{m} C_{ij} X_{ij} \qquad [1]$$

with following constraints:

$\sum X_{ij} = 1$ i = 1,2,3…. n (A vehicle assigned to a route)

$\sum X_{ij} = 1$ j = 1,2,3….m (A route must be assigned to the vehicle)

$X_{ij} = 1$ or 0 (1 = Vehicle assigned; 0 = Vehicle not assigned)

where,

n = Number of vehicles for moving on the routes

m = Number of routes to covered by vehicles

C = Vehicle effectiveness

i = row number representing route

j = Column number representing vehicle

X = 1 if the route is assigned to a vehicle, 0 if not assigned

C_{ij} = vehicle i effectiveness taking route j

X_{ij} = 1 if vehicle i will cover route j, (0 if vehicle i will not cover route j)

Z = Objective Function (Maximize)

$Z = C_{11}X_{11} + C_{12}X_{12}$

The mathematician from Hungary, D. Konig in 1955 developed a method for calculating an optimal solution without any direct comparison of every solution due to the special structure of assignment model, known as Hungarian method.

The steps involved for computational procedure to obtain optimal solution are described as follows and also represented in Fig. 1.

Step 1: Create a given cost matrix, formulate the problem in a square matrix form by introducing dummy row or column (if the job m is not equal to machine n) to make it balance and form square matrix, the cost of dummy row/column is zero (0).

Step 2: Convert the problem to minimization problem in case the problem objective is maximization, by subtracting the maximum entry in the matrix from all the entries in the matrix. In case of minimization problem, move to step 3

Step 3: Perform row reduction by the smallest entry by subtracting every row from that row. If zero is occurred in that row of a matrix which is referred to the first reduced cost matrix.

Step 4: Perform column reduction by the smallest entry in every column subtracting from all the entries of the respective columns. So, there would be zero in every elements of the given matrix.

Step 5: Procedure for determining an optimal assignment.

(i) Starting with first row of the reduced matrix, examine all the rows of this matrix that contains only one zero in it. Mark this zero within the circle and cross out the columns containing these assigned zeros. This process will be going on until all the rows have been examined. If any row deals with more than one zero, then that row will not be considered and it will move to the next row.

(ii) Start from first column and examine all the uncovered columns to find the columns containing exactly one remaining zero. Mark this zero within the circle as an assignment will be made there. Cross out the rows containing this assigned zero.

Steps (i) and (ii) will be repeated until all zeros are either crossed out or assigned.

Step 6: If the order of the matrix is equal to the number of assignments, then the assignment made in step 5 is the primal solution otherwise go to next step.

Step 7: Revised the matrix as follows. Choosing smallest element among the uncovered elements and that element can be subtracted from all uncovered elements and adding them at the point of intersection of two crossed lines whereas the other element never be changed.

Step 8: Proceed to step 5 until primal solution is obtained.

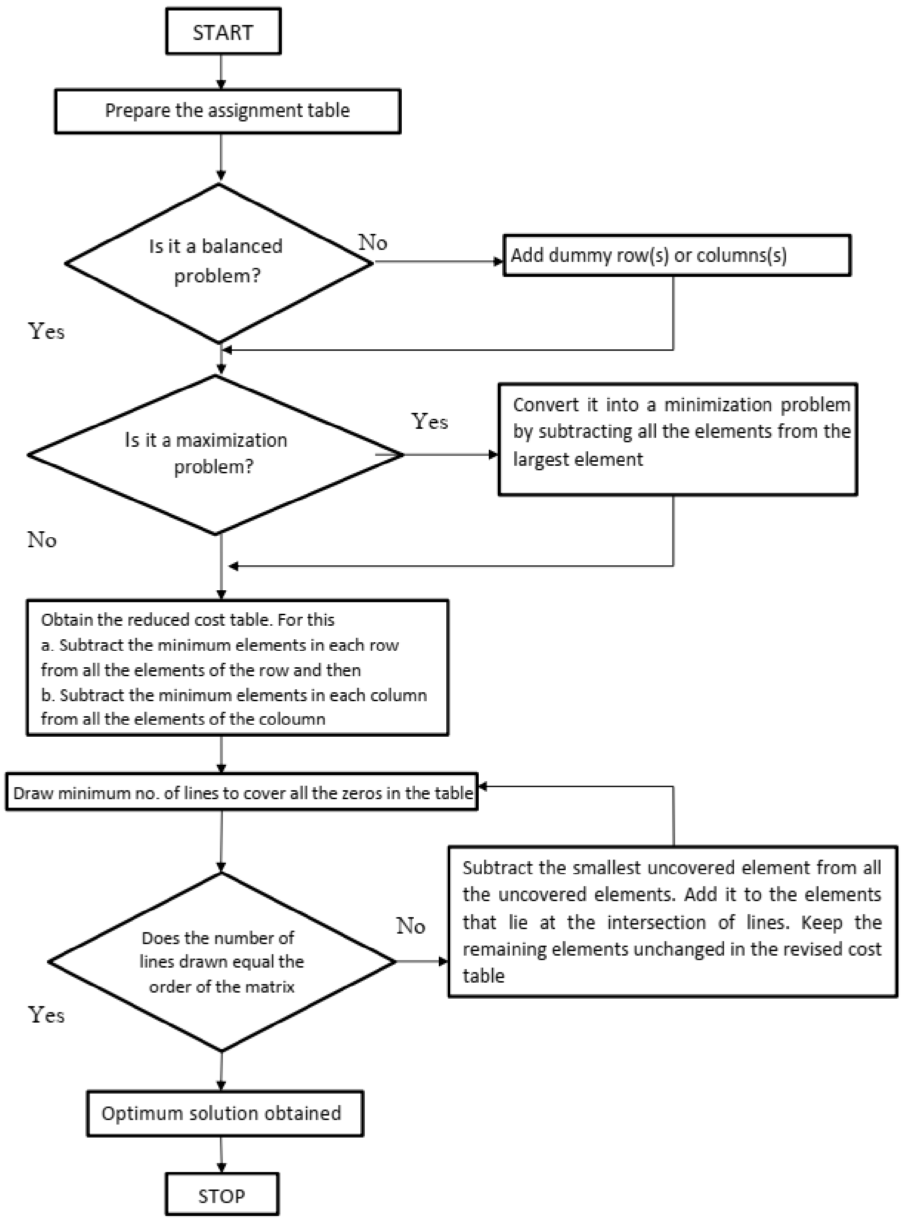

Figure 1: Flowchart for Hungarian assignment method for course Timetabling.

5 Results and Discussion

As already discussed earlier, linear programming relates to the problem concerning distributions of various resources (such as men, money, machine, material time etc.) satisfying some constraints, which can be algebraically represented as linear equations/inequalities. To study the effectiveness of the APS-CR we have solved a crew-based assignment problem which is discussed as follows.

Problem: In India, the travelling system from Mumbai to Goa must come back to Mumbai at the immediate next opportunity. It is further assumed that Bus service will make only forward and one return trip, and thus there must be Five Buses for Five forward and return trips. The problem is to determine optimum pairing. Our basic goal is to minimize the total layover time, let us at first instance determine the lay-over time both at Mumbai and at Goa for all possible pairings. For instance, for a Bus for travelling, Route *a* and Route *1* are paired, then the Bus leaves Mumbai at 06.00 reaching at 12.00 on Route *a*, and return from Route *1* at 05.30, next day, by making the layover of 24 hours at Goa. Similarly, for the same pairing, the Bus reaches at Mumbai at 11.30, and leaves for Goa at 06.00, next morning making layover of 35 hours at Mumbai. Likewise, we determine layover time at Goa and Mumbai for all possible pairings shown in Table 1.

Table 1: A trip data from Mumbai to Goa (presented in 24 hr scale).

Mumbai-Goa			**Goa-Mumbai**		
Route No.	**Departure**	**Arrival**	**Route No.**	**Departure**	**Arrival**
a	05.00 AM	11.00 AM	1	04.30 AM	10.30 AM
b	06.30 AM	12.30 PM	2	08.00 AM	14.00 (2 PM)
c	10.30 AM	16.30 (4.30 PM)	3	14.00 (2 PM)	20.00 (8 PM)
d	18.00 (6 PM)	00.00 AM	4	17.30 (5.30 PM)	23.30 (11.30 PM)
e	23.30 (11.30 PM)	05.30 AM	5	23.00 (11 PM)	05.00 AM

Any transport company calculating the cost of providing this service time must be satisfied by the bus crew. In different locations, some constraints arise such as before returning a crew member should take 4 Hrs of rest. It is mandatory that the crew members should not wait for more than 24 hours. Some companies have their residential facilities for the crew members. Our basic goal is to calculate pairing of routes so as to minimize the cost.

Solution: The above problem is solved using APS-CR. The assumption taken is the driver has to take rest for 4 Hrs, and he should not wait more than 24 Hrs. We also assume that 30 minutes = 1 Units. Firstly, we have found the crew based systems starting from Mumbai and reaching at Goa and vice versa at different designated times. From Table 3 to Table 9 we apply the APS-CR steps to solve the crew based vehicle assignments problem.

Crew based at Mumbai at 11.00	11.00-0.4.30 = 17.30 . Hrs = 35 Units
	11.00-08.00 = 21.00 . Hrs = 42 Units
	11.00-14.00 = 27.00 . Hrs = 54 Units*
	11.00-17.30 = 06.30 . Hrs = 13 Units
	11.00-23.00 = 23.00 . Hrs = 24 Units
Crew based at Mumbai at 12.30	12.30-0.4.30 =16.00 . Hrs =32 Units
	12.30-08.00 = 19.30 . Hrs = 39 Units
	12.30-14.00 = 25.30 . Hrs =51 Units*
	12.30-17.30 = 05.00 . Hrs = 10 Units
	12.30-23.00 = 10.30 . Hrs = 21 Units
Crew based at Mumbai at 16.30	16.30-0.4.30 = 12.00 . Hrs =24 Units
	16.30-08.00 = 13.30 . Hrs = 27 Units
	16.30-14.00 = 21.30 . Hrs =43 Units
	16.30-17.30 = 25.00 . Hrs = 50 Units*
	16.30-23.00 = 06.30 . Hrs = 13 Units
Crew based at Mumbai at 00.00	00.00-0.4.30 = 04.30 . Hrs =09 Units
	00.00-08.00 = 08.00 . Hrs = 16Units
	00.00-14.00 = 14.00 . Hrs =28 Units
	00.00-17.30 = 17.30 . Hrs = 35 Units
	00.00-23.00 = 23.00 . Hrs = 46 Units
Crew based at Mumbai at 05.30	05.30-0.4.30 = 23.00 .Hrs =46 Units
	05.30-08.00 = 26.30 . Hrs = 53 Units*
	05.30-14.00 = 08.30 . Hrs =17 Units
	05.30-17.30 = 12.00 . Hrs = 24 Units
	05.30-23.00 = 05.30 . Hrs = 11 Units
Crew based at Goa at 10.30	10.30-05.00 = 18.30 .Hrs =37 Units
	10.30-06.30 = 20.00 . Hrs = 40 Units
	10.30-10.30 = 24.00 . Hrs =48Units
	10.30-18.00 = 19.00 . Hrs = 15Units
	10.30-23.30 = 13.00 . Hrs = 26 Units
Crew based at Goa at 14.00	14.00-05.00 = 15.00 .Hrs =30 Units
	14.00-06.30 = 16.30 . Hrs = 33 Units
	14.00-10.30 = 20.30 . Hrs =41Units
	14.00-18.00 = 04.00 . Hrs = 8 Units

14.00-23.30 = 09.30 . Hrs = 19 Units

Crew based at Goa at 20.00
20.00-05.00 = 09.00 .Hrs =18 Units
20.00-06.30 = 10.30 . Hrs = 21Units
20.00-10.30 = 14.30 . Hrs =29Units
20.00-18.00 = 22.00 . Hrs = 44Units
20.00-23.30 = 27.30 . Hrs = 55 Units*

Crew based at Goa at 23.30
23.30-05.00 = 05.30 .Hrs =11 Units
23.30-06.30 = 07.00 . Hrs = 14 Units
23.30-10.30 = 11.00 . Hrs = 22 Units
23.30-18.00 = 18.30 . Hrs = 37 Units
23.30-23.30 = 24.00 . Hrs = 48 Units

Crew based at Goa at 05.00
05.00-05.00 = 24.00 . Hrs = 48 Units
05.00-06.30 = 25.30 . Hrs = 51Units*
05.00-10.30 = 05.30 . Hrs = 11Units
05.00-18.00 = 13.00 . Hrs = 26Units
05.00-23.30 = 18.30 . Hrs = 37 Units

Note: While solving the problem (*) mark values we cannot consider.

Table 2: The Table is drawn from the crew based at Mumbai (in Hrs)

Crew Routes	1	2	3	4	5
a	35	42	-	13	24
b	32	39	-	10	21
c	24	27	43	-	13
d	9	16	28	35	46
e	46	-	17	24	11

Table 3: The Table is drawn from the crew based at Goa (in Hrs)

Crew Routes	1	2	3	4	5
a	37	30	18	11	48
b	40	33	21	14	-
c	48	41	29	22	11
d	15	08	44	37	26
e	26	19	-	48	37

Table 4: Select minimum values from the Table 2 &Table

Crew Routes	1	2	3	4	5
a	35	30	18	11	24
b	32	33	21	10	21
c	24	27	29	22	11
d	9	08	28	35	26

e	26	19	17	24	11

Row wise operation (select the smallest element in a row and subtract from remaining row elements.

Table 5: Row wise allocation.

Crew Routes	1	2	3	4	5
a	24	19	7	0	13
b	22	23	11	0	11
c	13	16	18	11	0
d	1	0	20	27	18
e	15	8	6	13	0

Columns wise operation(select the smallest element in a column and subtract from remaining columns elements)

Table 6: Column wise allocation.

Crew Routes	1	2	3	4	5
a	23	19	1	0	13
b	21	23	5	0	11
c	12	16	12	11	0
d	0	0	14	27	18
e	14	8	0	13	0

Table 7: Row wise and Column wise assignments.

Crew Routes	1	2	3	4	5
a	23	19	1	$\boxed{0}$	13
b	21	23	5	0	11
c	12	16	12	11	$\boxed{0}$
d	$\boxed{0}$	0	14	27	18
e	14	8	$\boxed{0}$	13	0

If there is exactly one zero in a row, mark a square and draw a vertical line. If there are more than one zero then skip that row. Similarly, use the same rule for columns. From Table 7, still assigning is not completed (number of squares is not equal to number of rows). For that, at intersection (14, 27, 18) we have to add minimum value (1) with uncovered element and subtract minimum value from the uncovered element.

Table 8: Draw minimum number of lines.

Crew Routes	1	2	3	4	5
a	15	11	1	0	13
b	13	15	5	0	11
c	4	5	12	11	0
d	0	0	22	35	26
e	6	0	0	13	0

From Table 8, still assigning is not completed. For that, at intersection we have to add minimum value (1) of uncovered element and subtract minimum value from uncovered element.

Table 9: Total elapsed time for crew routes.

Crew Routes	1	2	3	4	5
a	14	10	0	0	13
b	12	14	4	0	11
c	3	7	11	10	0
d	0	0	22	36	27
e	6	0	0	14	1

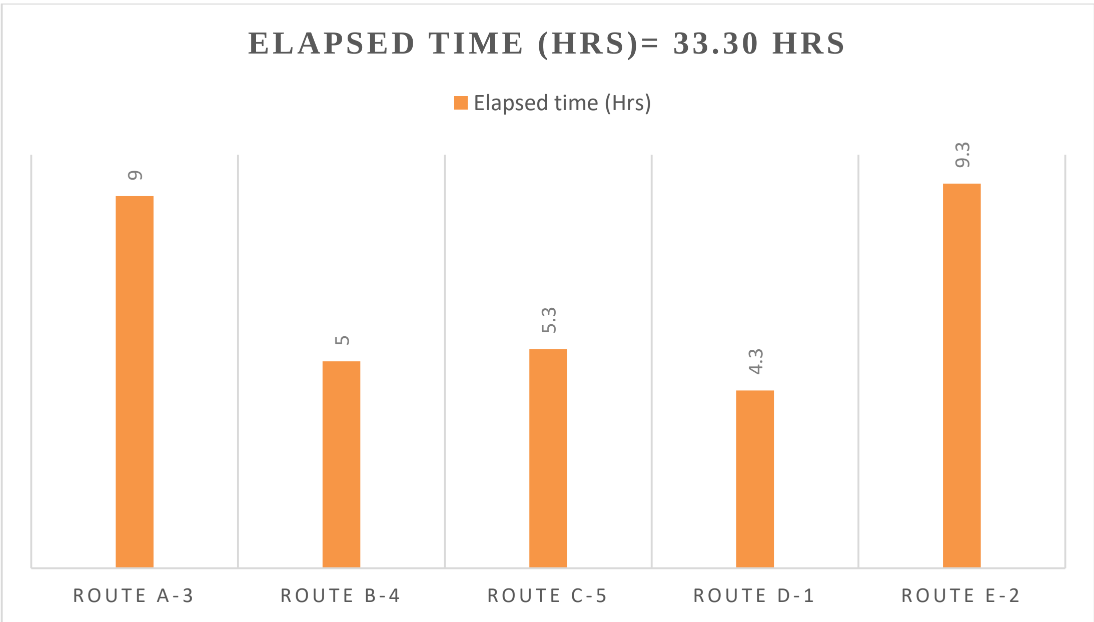

Figure 2: Pairing of routes for crew scheduling.

From Table 9, we get the optimal solution from route a paired with route 3, such that the elapsed time from route a to route 3 = 18 units = 9 Hrs. Similarly, the elapsed times for different paired crew routes are as follows: route b to route 4=10 units=5 Hrs, route c to route 5=11 units=05.30 Hrs, route to route 1=9 units = 04.30 Hrs, and route e to route 2=19 units = 09.30 Hrs. For our intuitions, we have to focus about that drivers plays an important role and also saved times by using its integration for different aspects the cost saving may allowed for increasing their service length that no drivers need to lose his or her job from Mumbai to Goa and return from Goa to Mumbai by assigning the routes, so that pairing of the routes so as to minimizing the cost is from routes a to routes 3 gives 9 Hrs. Again, routes b to routes 4 gives 5 Hrs, routes c to routes 5 gives 05.30 Hrs routes d to routes 1 gives 04.30 Hrs and lastly routes e to routes 2 gives 09.30 Hrs. From the assignment problem we conclude that A trip from Mumbai to Goa and vice versa gives routes d to routes 1, gives 04.30 Hrs, which is the minimum hours are required to reach from Mumbai to Goa. So, the total layover time=33.30 hours. It is also presented in Fig. 2.

6 Conclusion

In this work, we use Hungarian method as a case study of different routes by using crew members from a given source to a given destination for minimizing the pairing routes such that total effectiveness of layover times should be less from source to destination. We analyse the total effectiveness of APS-CR by considering a case where there are five pairing routes in different service times. It is solved using the Hungarian assignment method for choosing the best pairing routes for minimization of the cost. We found the optimal layover time to be 33.30 Hrs. So, from the results and discussion it is concluded that this method will be a better solution for solving the crew based scheduling problems.

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