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Reducing the vehicles fuel consumption by using the optimization technique

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Abstract
Most modern searches are directed to alternative fuels and hybrid vehicles because the buffer stock from the petroleum oils reduces with time. On the other hand, there are millions from vehicles that already operates by petrol and diesel engines and not logic the searches neglect all these vehicles. This paper presents a solution of reducing fuel consumption for a branch from these vehicles especially works in public transport companies whereas these companies almost have thousands from the vehicles and these companies exist in all countries. The vehicles fuel consumption is function in the travelled kilometres. The aim of this paper reduces the fuel consumption of the public transport companies by minimizing the non-productive distance, where the non-productive distance are the distance between garages and first bus station to start the trip and inverse. The proposed model is based on using the transportation technique for minimizing the total non-productive distance by redistribution the vehicles of these companies on their garages. Using this model is powerful for minimizing the running cost of public transport companies, addition to reducing the bus emission and saving the energy. The results indicate that significant information gained for minimizing the total non-productive distance by redistribution the vehicles on garages that will save the extra driving that helps for saving the fuel consumption, oil consumption, spare parts,.., and reducing the emission and the congestion traffic problem.
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Keywords: Fuel consumption, Transportation model, Non-productive distance, Optimization.

1. Introduction
The most of recent researches related to the engine fuel consumption are directed to save the fuel consumption by modification injectors design, combustion chamber design, or alternative fuels as illustrated in [1-4]. These modifications have strong effect for saving the fuel but most of these modifications can't apply on the old vehicles where these modifications need changing some parts in the engines. These parts cost is not economic for fleet owners, so these modifications become more effectiveness in the new engines. On the other hand, the problem of fuel consumption for the old vehicles that already operate in the world still existence, the numbers of these vehicles reached to many millions vehicle. The fuel consumption of them is very high that affect the operating cost in the end. The companies that have such these vehicles want reducing the operating cost; therefore some of these companies resorted to replacement policy. Addition to, there are other companies don't have the ability on replacing their vehicles and want also reducing the operating cost from the fuel consumption, where this parameter has strong effect on the economic operation for these vehicles. This paper presents new

solution for this problem especially for public transport companies, whereas these companies almost have thousands from the vehicles and these companies exist in all countries.

The economic crisis has had a severe impact on the companies that run public transportation. Ways of solving this are of key importance in order to keep costs down. From analysis the problem, we found that the life of bus is one from the main reasons that affects operating economics of the fleet in the public transport field. Many papers studied this problem to determine the optimal vehicle replacement policy from these papers [5]. Studied how motor carriers should adjust their vehicle replacement policies when dramatic changes of vehicle re-sale values and insurance premiums were observed. This paper developed a model of vehicle replacement optimization, and solved the model by using the actual data obtained from a motor carrier [6]. Presented an application on the preventive maintenance and replacement vehicle engines using the sequential method. The main objectives determine the optimal policies when carrying out of the preventive maintenance action for an engine and when replacement it based on the minimization of: (i) Loss due to stoppage of an engine. (ii) downtime due to the sum repair and preventive maintenance times [7]. Presented a model to determine the optimal vehicle replacement using the multi-objective fuzzy integer programming technique, and applied it on a public transport company [8]. Proposed a model for determining the optimal vehicle replacement based on the linear integer programming and applied it on the Cairo Transport Authority in Egypt [9]. Presented an approach to vehicle replacement decision making for different types of vehicles in a vehicle fleet subject to budget and fleet age constraints [10]. Described a study focused on the discussion of the issues faced when developing a vehicle replacement model in practice. The main purpose of the paper is to describe the work of operation research project team aimed at establishing the acceptance and use of a common approach to vehicle replacement within the British Gas Corporation.

This paper presents another reason, has effect on the operating economics for a fleet of the public transport companies, this reason is non-productive distance where the non-productive distance is the distance between garages and bus stand to start the trip and inverse that affects fuel consumption for this fleet. The non-productive distance is loaded on a public transport company but it can't dispensable whereas the buses must go to garage after finished the day at day-end to rest, clean, repair and maintain,…etc. On the other hand, the bus must go from garage to bus stand to begin the trip at every morning. This distance is a very great distance if it is calculated on all the fleets. This distance consumes fuels, oils, spare parts …etc. This cost increases the total operating cost in addition it causes increasing the emission and the congestion traffic problem. This paper presents the solution for minimizing the total non-productive distance for a fleet as transportation problem.

No one can deny that the transportation problem plays an important role in all branches of our life, where the transportation cost for each unit is added to the total cost. Therefore, the unit transportation cost must be calculated exactly to minimize if possible. In general, the main objective for any decision maker minimizes the total transportation cost for any public transport project. Many books studied the transportation problems models and how can solve them as examples in [11-14]. The following section will show briefly construction of the transportation problem mathematical model and the steps of solution for this problem.

2. The mathematical model of the transportation problem

2.1 General

The transportation model is a special class of the linear programming problem. It deals with the situation in which a commodity is shipped from sources to destinations. The objective is to determine the amounts shipped for each source to each destination that minimizes the total shipped cost while satisfying both the supply limits and demand requirements. The model assumes that the shipping cost on a given route is directly proportional to the number of units shipped on that route. In general, the transportation model can be extended to areas other than direct transportation of a commodity, including, among others, inventory control, employment scheduling, and personnel assignment.

The general problem is represented by the network in Figure 1. There are m sources and n destinations, each represented by a node. The arcs linking the sources and destinations represent the routes between the sources and destinations. Arc (i, j) joining source i to destination j carries two pieces of information: (1) the transportation cost per unit, c_{ij} , and (2) the amount shipped, x_{ij} . The amount of supply at source i is a_i and the amount of demand at destination j is b_j . The objective of the model is to determine the unknowns' x_{ij} that will minimize the total transportation cost while satisfying all the supply and demand restrictions.

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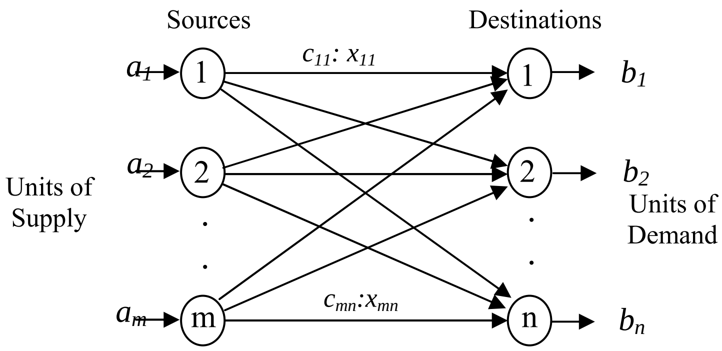

Figure 1. General transportation problem network

$$Min \sum_{j=1}^{n}\sum_{i=1}^{m} c_{ij}x_{ij} \qquad (1)$$

Subject to:

$$\sum_{j=1}^{n} x_{ij} = a_i, \quad i = 1,2,.....,m \qquad (2)$$

$$\sum_{i=1}^{m} x_{ij} = b_j, \quad j = 1,2,.....,n \qquad (3)$$

$$\sum_{i=1}^{m} a_i = \sum_{j=1}^{n} b_j \quad \text{(Balanced-Condition)} \qquad (4)$$

$$x_{ij} \geq 0, \quad i = 1,2,....m, \quad j = 1,2,....,n$$

where: c_{ij} : is the costs of transporting a unit from source *i* to destination *j*, x_{ij} : is the amount transported from source *i* to destination j, a_i : is the availability at *i* source and b_j : is the requirement at *j* destination.

The *m* constraints (2) represent the supplies and the *n* constraints (3) represent the destinations. The balanced condition (4) will lead to reduce the total number of constraints given by either (2) or (3) by one i.e., total number of constraints =*m*+*n*-1. This means that the number of optimal basic variables in the final optimal simples' tableau is equal to *m*+*n*–1.

The previous transportation problem model given by (1-4) can be put in matrix form as follows:

Min[CX] (5)

Subject to:

AX=B,X ≥ 0 (6)

where: C: is a matrix of *m* x *n* dimensional represents the objective coefficients, X: is a column vector of n dimensional represents the decision variables, A: is an (*m*+*n*-1) x (*m n*) matrix representing constraint matrix and B: is a column vector of (*m*+*n*–1) dimensional represents the right hand side constraints.

2.1 Steps of solution the transportation problem

As the transportation problem is a special case forms the general linear programming problem, therefore the definitions and theorems for the general linear programming problem are also applicable for the transportation problem. Some important definition will be stated to understand the steps of solution. In the end of this section, there is an algorithm to illustrate the steps for check of optimality.

- Feasible solution (F.S.)

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A set of non-negative allocations $x_{ij} \geq 0$ which satisfies the row and column restrictions is known as feasible solution.

- Basic feasible solution (B.F.S.)

A feasible solution to a *m*-origin and *n*-destination problem is said to be basic feasible solution if the number of positive allocations are (m+n–1). If the number of allocations in a basic feasible solutions are less than (m+n–1), it is called degenerate basic feasible solution (DBFS) (otherwise non-degenerate).

- Optimal solution

A feasible solution (not necessarily basic) is said to be optimal if it minimizes the total transportation cost.

In order to find the solution of this transportation problem, we must find the initial basic feasible solution and check of optimality for basic feasible solution.

Finding the initial basic feasible solution (I.B.F.S.):

There are many different methods to obtain the initial basic feasible solution from these methods North-West corner method, least cost method, and Vogel's approximation method all of these methods explained in [11-14]

Check of optimality for this solution:

A basic feasible solution that was obtained from the previous step may be optimal or not, so it becomes essential for us to check for optimization. There are two methods are used to check of optimality Stepping stone method and (u-v) modified method [11-14].

Algorithm for optimality test

In order to test of optimality, the following procedure illustrates the steps for check of optimality as given below and there is the flow chart for this algorithm in Figure 2.

Step 1: Start with B.F.S. consisting of m+n–1 allocations in independent positions.

Step 2: Determine a set of $m+n$ numbers u_i (i=1,2,....m) and v_j (j=1,2,...n) such that for each occupied cells(r,s) $c_{rs} = u_r + v_s$

Step 3: Calculate cell evaluations (unit cost difference) d_{ij} for each empty cell (i, j) by using the formula $d_{ij} = c_{ij} - (u_i + v_j)$

Step 4: Examine the matrix of cell evaluation d_{ij} for negative entries and conclude that

(i) If all $d_{ij} > 0 \rightarrow$ Solution is optimal and unique.

(ii) If all $d_{ij} \geq 0 \rightarrow$At least one $d_{ij} = 0 \rightarrow$ Solution is optimal and alternate solution also exists.

(iii) If at least one $d_{ij} < 0 \rightarrow$ Solution is not optimal.

If it is so, further improvement is required by repeating the above process. See step 5 and onward.

Step 5: (i) See the most negative cell in the matrix [d_{ij}].

(ii) Allocate θ to this empty cell in the final allocation table. Subtract and add the amount of this allocation to other corners of the loop in order to restore feasibility.

(iii) The value of θ, in general is obtained by equating to zero the minimum of the allocations containing – θ (not + θ) only at the corners of the closed loop.

(iv)Substitute the value of θ and find a fresh allocation table.

Step 6: Again, apply the above test for optimality till you find all $d_{ij} \geq 0$

3. Case study

3.1 Collected data

Our case study was carried out on four garages in east of Cairo city. There are two garages contiguous and the others are separated. The collected data were obtained from the public transport company. This data include on the number of the required buses for each bus stand that considers as a start point for the trip of these buses is given in Table 1, the garages capacity is presented in Table 2, and the distance

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between these garages and those bus stands were measured by using the distance meter of speedometer of the buses and are tabulated in Table3.

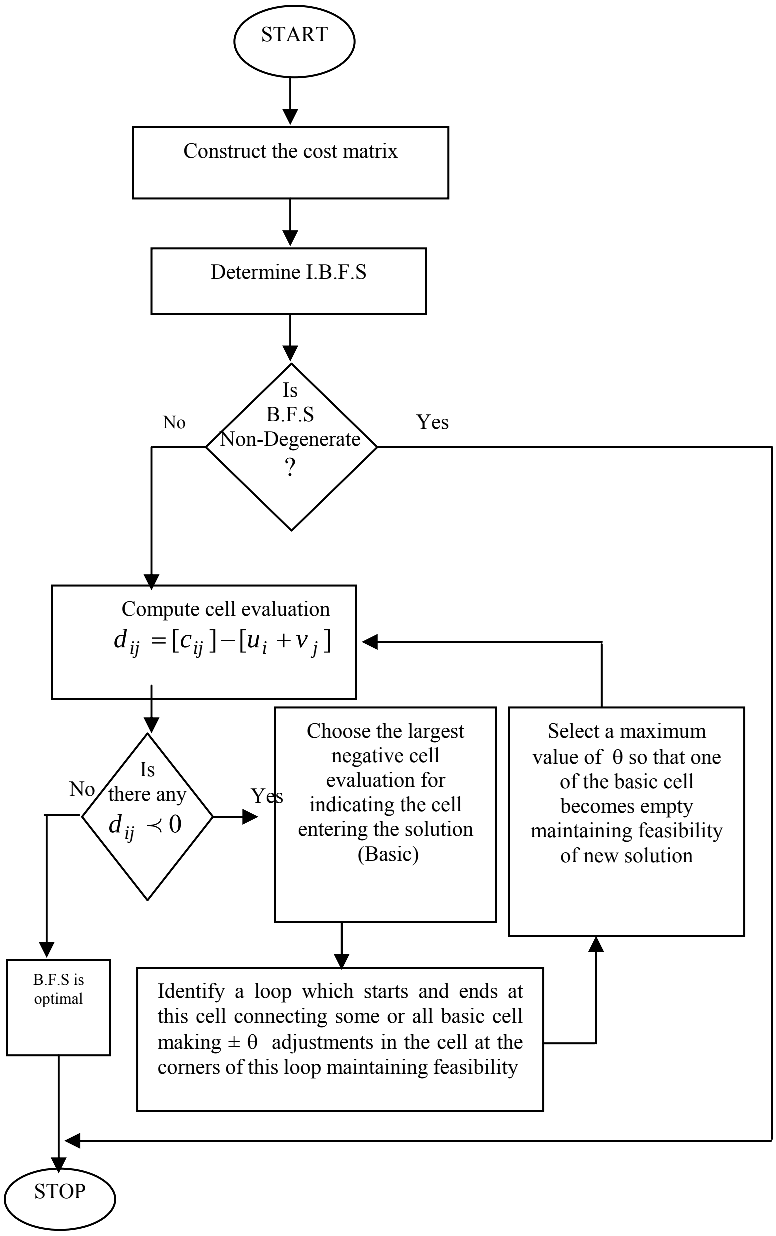

Figure 2. Flow chart of finding an optimal solution

Table 1. The numbers of required buses (b_j) for each bus stand

Bus stand No.	b_j	Bus stand No.	b_j	Bus stand No.	b_j	Bus stand No.	b_j
1	21	11	20	21	9	31	6
2	26	12	26	22	27	32	20
3	24	13	6	23	12	33	8
4	25	14	20	24	13	34	17
5	26	15	19	25	24	35	11
6	13	16	53	26	29	36	19
7	6	17	7	27	10	37	14
8	8	18	27	28	8	38	9
9	11	19	6	29	25	39	15
10	8	20	17	30	3	40	9

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Table 2. The garages capacity (a_i)

Ser.	Garage No.	Capacity (bus)
1	G1	160
2	G2	170
3	G3	159
4	G4	168

Table 3. The distance in Kilometers (c_{ij}) between the garages and the bus stands

Garage No Bus Stand	G1	G2	G3	G4	Garage No Bus Stand	G1	G2	G3	G4
1	5.5	12.5	10	10	21	8	7.5	12	12
2	1	9.5	8.3	8.3	22	12	18	15	15
3	3.5	8.5	11.5	11.5	23	8.5	2.75	12	12
4	5	4.5	10	10	24	5.5	13.25	7.7	7.7
5	4.5	6.25	11	11	25	12	15	8	8
6	6.5	3.9	12	12	26	8.6	15.05	6	6
7	5.8	9	2.75	2.75	27	7.5	11.5	3.5	3.5
8	5.5	11.75	6	6	28	6	12	1	1
9	3	10.5	7.5	7.5	29	4	10.5	5	5
10	16	20.25	16.3	16.3	30	6.3	10	7	7
11	6.5	5	12.75	12.75	31	6.5	12.9	6.5	6.5
12	13.5	7.5	17.4	17.4	32	7.5	10	2.25	2.25
13	11.5	13.5	20	20	33	11.5	10.5	15	15
14	8.5	3	12	12	34	11.5	18	12	12
15	7.5	0.5	14.75	14.75	35	2.4	9.65	7	7
16	19.5	11	25	25	36	7	1.65	10	10
17	20.5	20	27	27	37	13.75	18.7	9.75	9.75
18	9.5	9	16	16	38	8.75	12.6	11.5	11.5
19	2.7	7	8	8	39	6.75	15	12.5	12.5
20	10	18.5	12.75	12.75	40	4.75	7.2	7	7

3.2 Problem formulation

The mathematical formulation of the redistribution policy for the buses of public transport problem on their garages is

$$Z = Min \sum_{j=1}^{40} \sum_{i=1}^{4} c_{ij} x_{ij} \quad ; \qquad (7)$$

Subject to:

$$\sum_{j=1}^{40} x_{ij} = a_i , \quad i = 1,2,....,4 \quad ; \qquad (8)$$

$$\sum_{i=1}^{4} x_{ij} = b_j , \quad j = 1,2,.....,40 \quad ; \qquad (9)$$

$$x_{ij} \geq 0, \quad i = 1,2,....4, \quad j = 1,2,....,40$$

where: c_{ij} : is the distance in kilometres between garage G_i to bus stands *j*. Table 3, x_{ij} : is the number of buses distributed from garage Gi to bus stands j, a_i : is the capacity of garage G_i . Table 2, b_j : is the number of required buses for the bus stands j Table 1.

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3.3 Solution of the practical problem

LINGO software was used for solving the practical problem to obtain the optimal distribution for the buses of the public transport company on their garages. Last but not least, the results of the total non-productive kilometres that are obtained it by the LINGO software must be multiple by 2 to obtain the total non-productive kilometres daily. The reason of multiple by 2 returns to that the buses make two strokes for every working day (one before beginning of the working day and another after the end working day). Table 4 presents the comparison of the total non-productive kilometres between the current buses distribution and optimal buses distribution. The current distribution doesn't use any scientific method but the proposal distribution bases on the transportation technique. Table 4 illustrates that some of garages will increase the non-productive kilometres due to the redistribution of the buses on garages as shown in garage 1 and garage 4. On the other hand, the other garages (i.e. garage 2 and garage 3) will decrease the non-productive kilometres due to the new distribution. But the total non-productive kilometres for all garages will decrease. The proposal redistribution policy doesn't deal with each garage as a sub-problem but it deals with all garages as one problem to minimize the total non-productive kilometres. That means that there are some garages may be the non-productive kilometres of them will be increased and other will be decreased, but the total non-productive kilometres must be decreased as shown in Table 4.

Table 4. Comparison of the non-productive kilometers daily of the buses on their garages between the current and optimal distribution

Garage No	Non-productive kilometres daily		Different between current & optimal	Different percent %
	Current distribution	Optimal distribution		
1	1668	1891	-223	-13.37
2	2978	2005	973	32.67
3	3381	2340	1041	30.79
4	2811	3261	-450	-16.00
Total	10838	9497	1341	12.37

The solution of proposal model illustrates that the total saving for the non-productive kilometres is 1341 Km per day. By using the collected data about the average working days per year for each bus that equals 300 working days per year. That means, the total saving kilometres is 402300 Km per year approximately. From the collected data, the average fuel consumption for a bus is 0.5 l/km that means we will save 201150 liter per year from the consumed fuel. The proposed solution will save extra driving that helps the public transport companies for saving the fuel consumption, oil consumption, spare parts,.., and lastly in releasing some of the traffic and emission problems. The proposed redistribution policy model is powerful for all public transport companies that have more than a garage and more than a bus stand, whereas, this model helps in saving the operating cost, reducing the emission and the congestion traffic problem.

4. Conclusion

- The proposal redistribution policy for buses on their garages can be generalized on the public transport companies that have more than a garage and more than a bus stand.
- The optimal distribution for the 657 buses on four garages will reduce the total non-productive kilometres by 12.37 %, this percent is equivalent to 1341 Km/day or 402300 Km/year. This distance will save 201150 liter per year from consumed fuel.
- The proposed model is powerful for all public transport companies for saving the extra driving that helps for saving the fuel consumption, oil consumption, spare parts,.., and reducing the emission and the congestion traffic problem.

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