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CEMENT TRANSPORTATION LIMITED-FLEET MODELING AND ASSIGNING TO RATED DEMANDS

Summary. Transportation is an inseparable part of the supply chain, with a key role in product distribution. This role is highlighted when ratio of “the cost of transportation” to “the value of goods” such as cement is significant. Iran has recently become one of the main centers of cement production in the world. However, transportation is the most important challenge in cement distribution because of weak structure of the transportation fleet and its independent action. Independence of and lack of commitment on the part of transportation fleets to cement companies as well as lack of timely delivery due to shortage of transportation in some routes and seasons lead to customers` dissatisfaction and even market loss or lack of market development. One of the significant differences between the transportation system in Iran and that in developed countries is lack of complete productivity of the transportation fleet. It means that trucks are driver-based in Iran. This paper introduces a model considering some issues such as driver-based trucks, size of the transportation fleet based on the number of active trucks, and demand priorities in the cement company. Taking the relation between the number of active trucks and the cement company into account, this model assigns weekly demands to the transportation fleet. It also tries to minimize the delay to respond to demands and increases the efficiency of the transportation fleet. Finally, this current condition-based model is compared with two other models including “no constraints on different routes of trucks” as well as single-route model for trucks.

1. INTRODUCTION

Transportation plays a crucial role in supply chain management. Industrial units use different modes of transportation in raw material supply, production, and distribution of final products. Depending on the type of industrial unit, the role of transportation in each aspect mentioned above is highlighted. Transportation has a large role in distribution in the cement industry. Most of the cement-manufacturing plants are founded near mines and other sources of raw materials. The internal transportation system is defined as being close to machineries. Distribution is crucial because the ratio of transportation cost to “goods value” is high. Therefore, transportation and distribution have a mutual relationship with the target markets so much so that market development depends on access to a proper transportation fleet.

Several studies conducted in different modern and developing countries have highlighted the role of advanced transportation systems. Modern transportation companies take advantage of a multi-driver system to maximize transportation efficiency. Further, no constraints exist in terms of destination. Transportation is possible to all destinations by trucks. These two fundamental distinctions with the current condition in Iran make it necessary to apply some constraints.

Iran has become one of the three main cement producers in the world. However, transportation facilities are inadequate and poor. The independent nature of functioning of transport vehicles causes problems, such as final price change due to change in transportation cost in the short run, untimely delivery, project breaks, unexpected costs, customer dissatisfaction, and sometimes losing target markets. Incorporating the fleet as a part of the supply chain is an undeniable need. Right now, delay is not measurable in terms of demand because the transportation fleet functions independently of the cement companies. The high level of customer complaints in this regard is the most important assessment criterion. Absence of complaints does not necessarily mean timely delivery. Therefore, this paper intends to study the transportation fleet under current conditions and optimally assigned demands in order to minimize the delay in meeting demands as per the situation prevalent in the cement industry in Iran.

2. RESEARCH LITERATURE

Vehicle Routing Problem (VRP) is defined as finding the optimal route for delivery of goods from one or several depots to some cities or customers while considering constraints. Goods distribution, transportation of fuel tankers, snowplows, collection of household wastes, and postal package deliveries are some of the VRP applications [1]. Therefore, VRP plays a key role in distribution and logistics. After introduction of VPR as a generalized Traveling Salesman Problem (TSP) by Dantzig and Ramser [2], several studies have been published on various types of VRP, including Vehicle Routing Problem with Time Windows (VRPTW), Vehicle Routing Problem with Pick-Up and Delivery (VRPPD), and Capacitated Vehicle Routing Problem (CVRP). VRP is a combinational optimization and integer programming problem. Toth and Vigo [3] reported that using computational methods in the distribution process leads to 5%-20% reduction in transportation cost. In addition, Barker [4] explained that VRP algorithms lead to noticeable savings [5].

The first heuristic was introduced by Dror and Trudeau [6] for The Split Delivery Vehicle Routing Problem (SDVRP). Thereafter, Archetti, Speranza & Hertz [7] introduced an algorithm for Tabo. Mota, Campos & Corberan [8] used scatter search algorithm. Dergis, Li & Vogel [9] added a local search-based heuristic to SDVRP. Studies conducted by Archetti, Savelsbergh, and Spranza [10] as well as those by Gulczynski, Golden, and Wasil [11] are good sources for understanding the recent advances in SDVRP modeling and solutions [12].

In addition, two case studies were selected:

1. Al-Yakoob & Sherali [13] introduced mathematical programming models to assign professors to classes under certain criteria and schedules in the University of Kuwait. Since the beginning, class scheduling was assumed to follow the Course-Faculty-Assignment Model (CFAM), helping to minimize individual and collective dissatisfaction, with dissatisfaction being measured through a function after faculty assignment to classes. In order to enhance the quality of results obtained, the model is modified with Enhancing Satisfaction of CFAM (ECFAM) so that the time-tables for the classes can be changed, however with consideration given to efficient facility utilization and permitting an administratively regulated maximum number of changes. On the other hand, a gender-based model was also introduced to follow the policies of the University. Computational results based on direct application of the model with CPLX-MIP (version 7.5) as well as LP-based heuristics were used. The faculty schedules based on the proposed approach as applied in a number of studies in the Departments of Mathematics and

Computer Science in the University of Kuwait showed that this approach leads to fair scheduling and enhanced satisfaction among faculty members.

2. This paper based on a new approach of operation research introduced by Hertz et al. [14] considers a cement delivery problem involving a heterogenous transportation fleet with different depots. Customers' demands are generally greater than the capacity of the trucks. This means that most customers are visited several times. This is a separate delivery with additional limitations. First, a two-phase solution is proposed, which assigns demands to trucks. Then, it determines the routes. Both sub-problems are formulated as integer linear programming problems followed by introduction of a mixture of both phases in an integer linear programming. Finally, both models are calculated on the basis of real-world issues.

3. CONDITIONS AND CONSTRAINTS

This paper aims to establish a model for transportation fleet assignment in the real world. This model takes different situations into account: truck dependency or driver-based trucks, importance of orderly response to cement company demands according to the competitions, and current condition of truck transport, which is the impossibility of transportation in all directions. Each of the aforementioned issues is carefully analyzed as follows:

3.1. Driver-based trucks

As trucks are driver-based, the resting hours of the drivers should be taken into account in their hours of operation to calculate real working hours. In Iran, there is no standard for resting hours of drivers. Therefore, a generally applied Australian standard for resting hours is used in this study. Considering the resting hours, delivery time was calculated as follows:

δ_i= the distance from factory to i destination;
L= the average speed of the truck with load;
U= the average speed of the truck without load;
L_{i}= delivery duration with resting hours;
U_{i}= back duration with resting hours;
TL_{k}= loading time of k-type truck;
TU_{k}= unloading time of k-type truck;
R_{ik}= total round-trip duration needed for i$^{\text{th}}$ trip by k-type truck with resting hours, determined by Eq. (1).

$$R_{\mathrm{ik}} = L_i + U_i + TL_k + TU_k \tag{1}$$

To calculate L_i (in hours), we have:

The same procedure is used to calculate U_i.

3.2. The importance of various demands

The two main indicators for customers are the region they belong to and the type of customer group they are from. Customer groups are categorized into three: 1. constructional material sellers (public consumption); 2. building and development projects; and 3. cement-using industries. Moreover, in this case study there are 14 different regions.

As the cement-using industries were rated low in terms of demands, such demands were merged with “Building and Development projects”. Then one-day delay cost (by day) was considered for each group. Finally, one-day delay cost was obtained for each sub-indicator using the Simple Additive-Weighting (SAW) method, expressed by Eq. (2) as follows [15]:

$$P_{gd} = W_g P_g + W_d P_d \qquad \forall g = 1,2,3 \quad , d = 1, \dots ,14 \tag{2}$$

Table 1

The link between resting hours and distance (in hours)

L_i	δ_i/L (hours)
δ_i/L	≤ 5
$\delta_i/L + 0.25$	$5 < \quad \leq 7$
$\delta_i/L + 0.5$	$7 < \quad \leq 10$
$\delta_i/L + 1$	$10 < \quad \leq 12$
$\delta_i/L + 7$	$12 <$

where: W_g = the weight of customer type g; W_d = the weight of region type d; P_g = the delay cost of customer type g; P_d = the delay cost of every customer in region d; and P_{gd} = the delay cost of customer type g on region d.

3.3. Compliance with current condition

As the transportation fleet has to be based on the current conditions of cement trucks, such compliance was studied on the basis of the most active trucks. It means that truck-related constraints are written by assuming collaboration with the most active trucks.

4. MODEL DEFINITION

The model consists of three sections as follows:

4.1. Variables

4.1.1. Demand

l_c= day of the c^th^ demand;
A_c= importance coefficient of c^th^ demand (P_{gd}) with no delay to respond to the demand;
C: request number (depending on timetable for C=1,…..)

4.1.2. Delivery

j: transportation day;
i: number of trips in one day for a truck;
k: truck code (you can define a specific code based on the number of trucks; in this case there are 88 active trucks);
$X_{i,j,k,c} = 1$ if k truck transports c demand in j day at i^th^ order; otherwise it is considered 0.

4.2. Limitations

4.2.1. Single route / multi-route

According to the current data on fleet in a certain period, single-route or multi-route condition is determined by active trucks.

4.2.2. Responding to the demand

Each demand is responded to only once, represented by Eq. (3) as follows:

$$\sum_i \sum_j \sum_k X_{i,j,k,c} = 1 \qquad \forall c \tag{3}$$

4.2.3. Transportation of a maximum of one demand in each trip

A truck can meet a maximum of one demand in a day, as defined by Eq. (4):

$$\sum_c X_{i,j,k,c} \leq 1 \qquad \forall i, j, k \tag{4}$$

4.2.4. Customers` warehouse capacity limitation

Responding to customers' demands is not possible prior to demand because of lack of customers` warehouse capacity. This capacity is defined by Eq. (5) as follows:

$$\sum_i \sum_j \sum_k (j.X_{i,j,k,c}) \geq l_c \qquad \forall\ c \tag{5}$$

4.3. Objective function

The objective function aims to minimize the delay in response to demands based on the importance of demand (customer group and requested region), which is calculated by Eq. (6) as follows:

$$Min\ \ \sum_c A_{c(d)} \left(\sum_i \sum_j \sum_k j.X_{i,j,k,c} - l_c\right) \tag{6}$$

5. SOFTWARE

In this model, Excel software was used to categorize primary data and determine errors. In addition, ILOG CPLEX (version 10.1) was used to solve assignment models in C#.NET.

6. ASSESMENT OF THE TRANSPORATION FLEET’S CURRENT CONDITION

The months of April and May, 2012 were selected for better assessment as the demands during this period were higher compared with those during other months. The basis is that the fleet capable of meeting the demand during peak months will be able to satisfy the needs in other low-demand months. As the fleet is influenced by factors such as periodic attractive spots in some seasons, fewer number of such attractive spots are advised in the course. A total of 7844 data or cement deliveries were evaluated in a 61-day interval.

As many as 5771 out of 7844 deliveries are associated with domestic trucks. This paper also focused on such trucks.

In order to study the current condition, the following steps were undertaken:

Step 1: Human error elimination and data classification according to license plate numbers.

Step 2: Calculation of useful business hours for each trip.

Step 3: Calculation of useful business hours for the fleet.

After calculating the hours of operations for trucks, the average number of hours of operation for each truck was calculated using Eq. (7) as follows:

$$\bar{T}_u = \frac{T_{\mathrm{u}}}{\mathrm{k}} \tag{7}$$

$$\bar{T}_u = \frac{37321.315}{605} = 61.68$$

Finally, the number of working hours of a truck was calculated for a period of 61 days on the basis of the standard for maximum weekly working hours of a driver. Then the efficiency of the cement transportation fleet was calculated using Eq. (8) as follows:

$$R\% = \frac{\bar{T}_u}{T_t} = \frac{61.68}{627.42} = 9.8\% \quad (8)$$

This number shows the operation of the cement transportation fleet. It showed that trucks were not present for 90% of working hours. This is because the trucks work in other businesses or drivers have no commitment for regular attendance.

Fig. 1 shows the efficiency of each truck in the current condition. The steps taken for calculation have been already explained in the previous paragraphs.

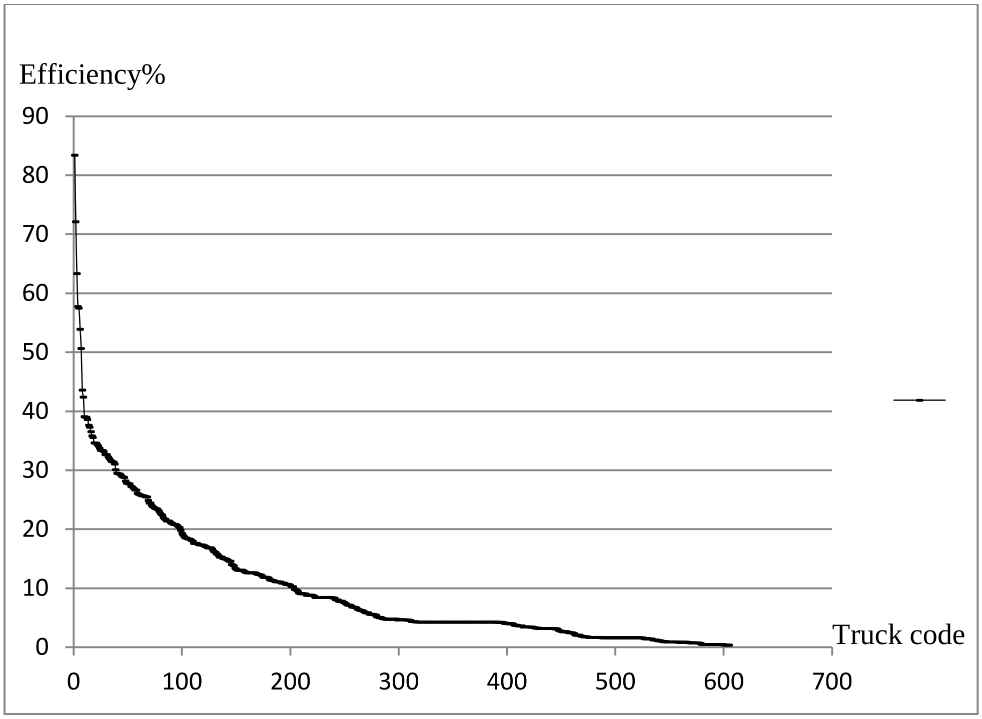


Fig. 1. Current condition of cement transportation fleet versus efficiency (%)

7. DETERMINATION OF TRANSPORTATION TIMES IN A DAY

Using the data and the standard for drivers, we calculated the maximum number of times a truck could travel to each of the i destinations. This estimated the actual usage of truck capacity.

It is obvious that, concerning the sixth, seventh, and eleventh destinations, the process of coming back to the factors must start one day in advance because of the requirement of more than 24 hours for delivery to meet the demand for the next day.

8. INPUT DATA

The model is run on a weekly basis, with related demands to various regions and the demands from these destinations. It is noteworthy that we are not supposed to reach zero-delay response in this model because demands differ in various months. We should also try to take maximum advantage of the new fleet, defined on the basis of the current condition. Thus, the objective is to create a trade-off between efficiency enhancement and delay reduction. Managers define the importance order between these two indicators on the basis of their priorities and conditions.

In this paper, we studied one-week data on transportation fleet. The results can be generalized to other weeks. Finally, the organization takes a decision pertaining to the transportation fleet using the processed information.

Table 2

Transportation times for a truck in a day for various destinations

Destination	Number of transportation times in a day	The possibility of transportation in the day before
01	3	Yes
02	2	Yes
03	1	Yes
04	2	Yes
05	1	Yes
06	1	No
07	1	No
08	1	Yes
09	1	Yes
10	1	Yes
11	1	No
12	1	Yes
13	1	Yes
14	1	Yes

A total of 88 trucks were selected under the supervision of experts (Table 3). Active trucks covering the demands of various destinations were selected. One of the assumptions is that weekly demands are responded to within a maximum of 3 days during the coming week. Therefore, a 10-day period was defined as the response period.

Table 3

The number of trucks in multiple routes

Multiple routes	Number of trucks
01	7
06-01	22
02-01	8
06-04-01	2
08-02-01	1
10-06-01	1
10-01	1
14-01	1
09-01	1
06-03	1
07-06	1
05	29
13-12	1
13	1
12	9
14-07-06	1
11-06	1

9. ASSIGNMENT MODEL BASED ON CURRENT CONDITION

Based on the assumption that all demands are met within three days of the following week, responding to the demand in the eleventh route took more than 10 days with this fleet. Thus, based on the sensitivity analysis and optimization possibility of the model based on real data, the following changes (Table 4) were made by maintaining the initial number of trucks:

- Eliminating 7 single-route trucks in route 01.
- Adding a truck to routes 01 and 02.
- Converting 9 single-route trucks of route 12, 1 single-route truck of route 13, and 1 truck in routes 12 and 13 to 8 single-route trucks for route 12 and 3 trucks for routes 12 and 13.
- Adding 6 trucks to the collection of single-route trucks for route 05.
- Reducing the demand in destination 11 to a maximum of one daily demand.
- Applying these changes, we were able to develop the market and raise demands in destination 05 by a maximum 17% (Table 3 shows that 29 trucks were increased to 35 trucks. Table 2 shows that daily trucks could respond to destination 05, resulting in 17% improvement in infrastructure)

The above changes aimed to optimize the objective function (Section 4.3) under an assumption of a fixed number of trucks (88).

Table 4

The number of trucks in multiple routes after optimization

Multiple routes	Number of trucks
06-01	22
02-01	9
06-04-01	2
08-02-01	1
10-06-01	1
10-01	1
14-01	1
09-01	1
06-03	1
07-06	1
05	35
12-13	3
12	8
14-07-06	1
11-06	1

10. ASSIGNMENT MODEL OPTIMIZATION BASED ON CURRENT CONDITIONS

After redefining the model on the basis of the new conditions, the results were as follows:

- Efficiency based on standard= 69.23%
- Efficiency based on considered capacity for trucks= 81.28%

Table 5

Delay (day-demand) for cities after applying the model based on current conditions

Destination	Delay (day-demand)
05	8.84
10	2.58
11	1.21
12	8.47
Total delay (objective function)	21.1

This model has more than 1.500.000 variables and more than 5.700 limitations. The software solved it in 16.5 minutes. The model provides details of weekly schedules: namely, which demand is to be met by each truck on which day, and the frequency of transportation.

11. ASSIGNMENT MODEL ASSUMING THE PROBABILITY OF TRANSPORATTION IN ALL ROUTES

In the optimal state, which is the focus of many research studies, the best conditions include imposing no limitations in transportation to various destinations for trucks. The results of this model comprising 88 trucks without limitation of transportation in comparison with the assigned model based on current conditions are as follows:

- Efficiency based on standard= 69.46
- Efficiency based on considered capacity for trucks= 81.54%
- Total delay (day-demand)= 2.21 (it occurs in route 05)

12. ASSIGNMENT MODEL ASSUMING SINGLE ROUTES FOR TRUCKS

In this case study, most of the managers believed that operation planning was optimal with a single-route fleet. Therefore, in this section we consider single-route truck assignment.

The following criteria are essential to assign 88 single-route and optimum trucks:

- The upper limit of the number of trucks in each route: delay is zero in this condition. As much as one unit reduction in the number of trucks leads to a delay.
- The lower limit of the number of trucks in each route: there is at least one truck in each route. In addition, responding to all requests does not exceed more than 10 days.

Then, the following steps are taken:

Step 1: The upper limit of trucks is considered the starting point for each route.
Step 2: For each unit truck reduction in each route, the increase in delay in responding is calculated;
Step3: Minimum delay rise is selected as decline unit in total number of trucks;
Step 4: The same procedure is applied on all 88 trucks.

Note: If the number of trucks reaches the lower limit during calculations, it is considered the final and optimum number of trucks for the route.

Table 6 presents the mathematic algorithm for the sensitivity analysis.

As the algorithm shows, reduction in the number of trucks is always performed by considering the minimum increase in delay, leading to optimum solution.

According to the algorithm, the number of assigned trucks for different routes is calculated on the basis of the criteria presented in Table 7.

Table 6

Sensitivity analysis in two sequential steps

Destination	Delay in the i^{th} step	Delay resulting from one decline in i+1 step	Delay difference	Selecting a unit of reduction with the minimum delay difference in each route
1 2 ….. N	$d_{1,i}$ $d_{2,i}$ . . . $d_{n,i}$	$d_{1,i+1}$ $d_{2,i+1}$ . . . $d_{n,i+1}$	$d_{1,i+1} - d_{1,i}$ $d_{2,i+1} - d_{1,i}$ . . .	$Min\left\{d_{\mathrm{c},i} - d_{c,i}\right\}$

Table 7

Optimum assignment of 88 trucks to various routes

Destination	The number of assigned trucks
01	8
02	9
03	1
04	1
05	29
06	21
07	1
08	1
09	1
10	2
11	1
12	10
13	2
14	1

Then, a single-route model was applied. The results are presented in Table 8 as follows:

- Efficiency based on standard= 69.12%
- Efficiency based on considered capacity for trucks= 81.15%
- Total delay (day-demand)= 58.51

13. COMPARISON OF THREE MODELS

Considering 88 trucks in the model, the delay (day-demand) in the single-route model, under the current conditions, and without limitation models was, respectively, 58.51, 21.1, and 2.21 (Fig. 2).

Furthermore, efficiency improved in “comparing with standard” and “comparing with determined capacity” states in the three models: single route, current condition, and without limitation (Fig. 3).

14. CONCLUSION

In this paper, first we studied the current situation prevalent in the transportation fleet of a cement company in Iran. The period from April to May was considered as it a peak season for cement distribution. With 5771 deliveries in domestic transportation by this company, the fleet efficiency was about 10%. This efficiency was calculated on the assumption of driver-based trucks because multiple-driver-based trucks are used in international research because of advanced transportation companies and company ownership. However, trucks are driver-based in some countries and it is an inseparable part of this model. Customers belonged to 14 destinations and were of different types. The importance of these groups was calculated on the basis of one-day delay. Then, an 88-truck fleet was studied considering the fleet condition and the most active trucks as well as their working history. This model does not aim to reach zero delay, but to reduce the delay and increase the capacity of the new fleet according to current conditions. It means that demands are responded to by creating a balance between efficiency capacity and reduction in delay in responding to the needs according to the importance of demands.

Table 8

Delay (day-demand) in reaching destinations after applying
the model based on single-route assumption

Destination	Delay (day-demand)
01	3.21
02	-
03	-
04	2.14
05	27.6
06	8.47
07	-
08	-
09	-
10	2.58
11	1.21
12	12.1
13	1.17
14	-

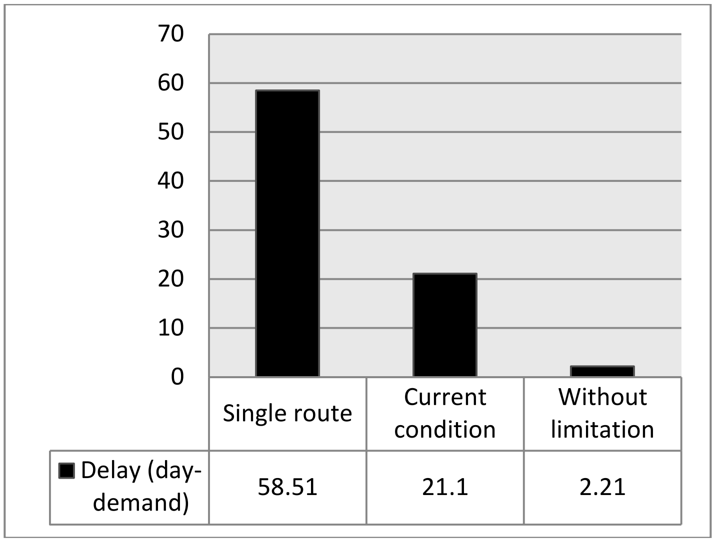
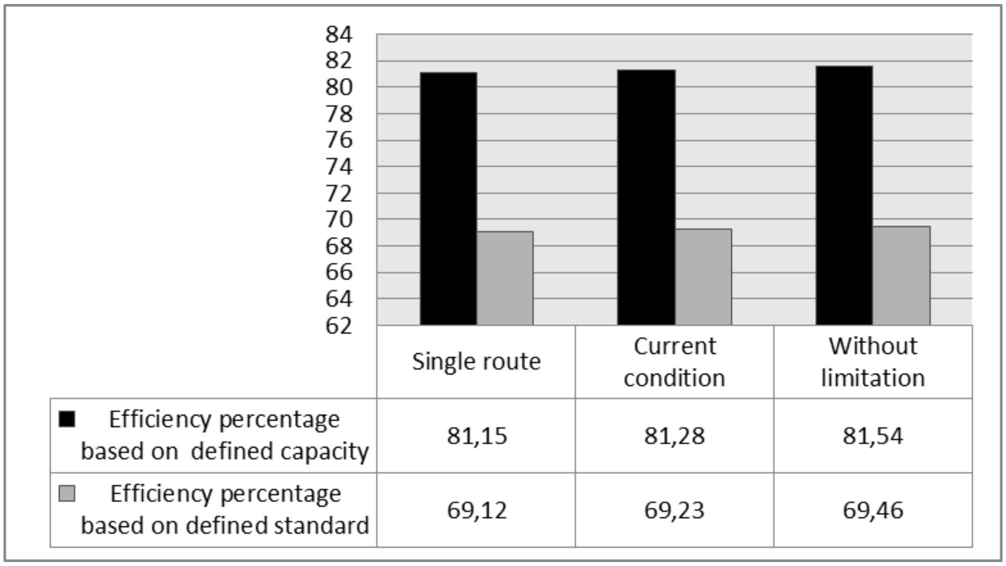


Fig. 2. Delay comparison in three model (day-demand)



	Single route	Current condition	Without limitation
■ Efficiency percentage based on defined capacity	81,15	81,28	81,54
▨ Efficiency percentage based on defined standard	69,12	69,23	69,46

Fig. 3. Comparison of utilization percentage (compared to capacity and standard) in three models

This model is a tool for programming and estimating the necessary capacity of the fleet and the delay while responding to demands. To this end, a one-week period was considered from two-month demands and the current condition of the selected fleet. The model assumes that all requests are met within three days in the coming week; otherwise the fleet needs revising. This assumption is changeable and depends on the opinions of the executive managers. This assumption was rejected after applying the model. Thus, the optimum model and conditions of trucks were determined using the sensitivity analysis and maintaining the same number of trucks. After applying the model and assigning demands, efficiency was calculated under two conditions: considered capacity and standard. The delay in each route was obtained. To decrease the delay in route 11, a maximum of one demand per day was proposed (it is advised to reduce the demand in a route that is facing a delay when it is impossible to increase the fleet, in order not to face reneging and maintain the market for future development). Considering the two-way relationship between transportation and market development, the route demand can increase by a maximum of 17% for route 05 by applying optimization changes.

The models were applied under academic and professional views based on the same number of trucks: the former is based on no limitations to select routes and the latter is based on single-route trucks. The results were compared with the current condition model. The results clearly showed that as trucks can select different routes, delays can be reduced and we have acted toward increasing the capacity efficiency of the fleet.

The current condition can be improved with different fleets and various weekly demands, providing solutions to executive managers in organizations. Schedules can be introduced for trucks, such as which truck will respond to which demand, on which day, and the frequency of response.

References

1. Choong Yeun, L. & Ismail, W.R. & Omar, K. & Zirour, M. Vehicle routing problem: models and problem. *Journal of Quality Measurement and Analysis*. 2008. Vol. 4(1). P. 205-218.
2. Dantzig, G & Ramser, J. The truck dispatching problem. *Management Science*. 1959. Vol. 6(1). P. 80–91.
3. Toth, P. & Vigo, D. (eds.). *The vehicle routing problem*. Volume 9 of SIAM Monographs on Discrete Mathematics. 2002. SIAM Philadelphia.

4. Baker, B.M. & Ayechew, M.A. A Genetic Algorithm for the Vehicle Routing Problem. *Computers and Operations Research*. 2003. Vol. 30. P. 787-800.
5. Eksioglu, B. & Vural, A. V. & Reisman, A. The vehicle routing problem: A taxonomic review. *Computers & Industrial Engineering*. 2009. Vol. 57(4). P.1472–1483.
6. Dror, M. & Trudeau, P. Split delivery routing. *Naval Research Logistics*. 1990. Vol. 37(3). P.383–402.
7. Archetti, C. & Speranza, MG, Hertz, A. A tabu search algorithm for the split delivery vehicle routing problem. *Transportation Science*. 2006. Vol. 40(1). P. 64-73.
8. Mota, E. & Campos, V. & Corberán, Á. A new metaheuristic for the vehicle routing problem with split demands. *Evolutionary Computation in Combinatorial Optimization*. 2007. P. 121-129.
9. Derigs, U. & Pullmann, M. & Vogel, U. Truck and trailer routing Problems, heuristics and computational experience. *Computers & Operations Research*. 2013. Vol. 40. P. 536–546.
10. Archetti, C. & Savelsbergh, M. & Speranza, M.G. To split or not to split: That is the question. *Transportation Research Part E*. 2008. Vol. 44. P. 114-123.
11. Gulczynski, D. & Golden, B. & Wasil, E. Recent developments in modeling and solving the split delivery vehicle routing problem. In: Chen, Z. & Raghavan, S. (eds.). *Tutorial in Operations Research: State-of-the-art Decision Making Tools in the Information-Intensive Age*. INFORMS, Hanover, MD. 2008. P. 170-180.
12. Gulczynski, D. & Golden, B. & Wasil, E. The split delivery vehicle routing problem with minimum delivery amounts. *Transportation Research Part E*. 2010. Vol. 46. P. 612-626.
13. S.M. Al-Yakoob & H.D. Sherali, Mathematical programming models and algorithms for a class – faculty assignment problem. *European Journal of Operational Research*. 2006. Vol. 173. P. 488-507.
14. Hertz, A. & Uldry, M. & Widmer, M. Integer linear programming models for a cement delivery problem. *European Journal of Operational Research*. 2012. Vol. 222. P. 623-631.
15. Asgharpour, M.J. *Multiple Criteria Decision Making.* University of Tehran Press. 12th edition. 2014. P. 232-234.

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