Dynamic Cargo Trains Scheduling for Tackling Network Constraints and Costs Emanating from Tardiness and Earliness

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Received 23 Apr., 2009; Revised 18 May., 2009; Accepted 15 Jun., 2009

Abstract

This paper aims to develop a multi-objective model for scheduling cargo trains faced by the costs of tardiness and earliness, time limitations, queue priority and limited station lines. Based upon the Islamic Republic of Iran Railway Corporation (IRIRC) regulations, passenger trains enjoy priority over other trains for departure. Therefore, the timetable of cargo trains must be determined based on certain passenger trains. In addition, the introduced model considers extra platforms in each station through the travel route. This model has been run in IRIRC and the results have illustrated a great improvement in comparison to status quo. The model has been verified and validated against the real system by conducting t-tests. Furthermore, sensitivity analysis of the model reveals a set of optimization alternatives for scheduling cargo trains. Reduced routing traffic, optimum number of cargo trains, enhanced customer lead times, maximum trains capacity are retrieved from the model in order to obtain an integrated scheduling for cargo and passenger trains.

Key words: Multi-objectives problem; Dynamic programming; Rail-way/Cargo train scheduling; Delivery decision.

1. Introduction

Railway freight loading is a complicated and multi-objective problem. The system overloads with continuing timetable changes and huge number of constraints. The traditional method of management and planning of the railway doesn't guarantee the optimal use of railways, locomotives. Therefore, the service level is low and hence much confusion regarding tardiness and miss-scheduling are commonplace. In addition, miss-scheduling the movement of the trains affects the productivity of the railway system and, in turn, it may deteriorate the country economy. For example, in the year 2000, IRIRC announced that seventy four percent of the capacity of the system has not been used and its customers have not received satisfactory services. This caused a loss of revenue close to 5.7 million dollars for IRIRC due to the failure to utilize maximum capacity. Development of the facilities is easier said than done because of shortages of resources. Therefore, the effective scheduling of the trains depends on the decrease of trains delay and related costs. At present, all passenger trains are pre-scheduled and must depart according to the corresponding timetables. However, cargo trains are not scheduled and the decision on their departure time is taken individually in each station.

2. Background and description of train scheduling

Train scheduling is one of the most challenging and difficult problems in railway planning which has attracted the attention of researchers for decades. Since the physical railroad network is shared by a large number of trains, it is, indeed, necessary to synchronize the use of the available resources. Moreover, the simultaneous scheduling of freight and passenger trains has an important impact on the quality and level of services provided to the public.

Train scheduling has been conducted based on individual judgments for more than a century. This

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causes ineffective use of trains and infrastructure and sometimes terrible accidents. It is worth mentioning in some countries this approach is still being practiced. In this process, rail network is first decomposed into a set of rail corridors. Each corridor typically consists of a set of lines connecting a sequence of stations together. Then, planners schedule a train at a time for each corridor separately according to scheduling requirements and later check to eliminate any conflicts. Resolving conflicts may require rescheduling of other trains. All these activities are rather time consuming as they take place based on trial and error tests and the output is, at best, only a feasible timetable .

The strong competition among rail carrier, the privatization of many national railroads, deregulation, the ever-increasing speed of computers, and the increasing role of railway in country's economy all motivate the efforts to develop and use more efficient scheduling techniques.

These techniques can be divided into three major groups: simulation, mathematical programming, and expert systems. In practice, these techniques are used in combination [23]. [13], [15], [14] are some examples in which expert systems are used. Simulation modeling approach may be the only ideal tool to resolve the complicated problems regarding scheduling cargo and passenger train in terms of priorities. In fact, due to the complexity of such problems, most of the previous research has been performed by utilizing computer simulation methodologies [3]. Simulation approach is used by [8], [20], [24], [21] among others.

The methodology of Mathematical programming was first applied to this problem by [2]. [7] presented a survey of relevant optimization models, although the mathematical programming approach is not limited to optimization models. There are studies using heuristic models such as [25]. Many models have been developed to schedule trains since decades ago. [26] Developed a branch and bound mathematical model to maximize the trains' speed in the route. He assumes a certain program for launching ten trains in five blocks. [11] Introduced an integer programming model for scheduling the trains in a single-track railway. The model seeks to minimize the aggregate tardiness of the trains and their operational expenses shown in non-linear goal function and the constraints such as trains' velocity, intersections, and surpass which are written as linear behavior.

Some published methods are related to the heuristic models which are combined with classical methods. For example, [17] proposed a heuristic branch and bound methodology for scheduling finite similar trains in the network assuming the dispatching time and trains constant speed are known. This model generates the timetable of train movements by minimizing the tardiness. He assumes that the duration of the travel for each train is a random variable with smooth distribution. [4] introduced a logical analysis to show that the problem of the trains is an NP Hard and developed an integer mathematical model for mono rail network based upon the rules of local decision making which submits the optimal local (not global) solution. Later in 1998, they proposed a more practical heuristic model ([5]) which presents an acceptable (not optimal) solution for the same problem.

[19] Uses the network concept and develops a non linear model in order to minimize the cost of tardiness and cost of fuel for cargo trains. He assumes that trains can have different speeds and he submits a heuristic algorithm to solve the potential inter-train conflict. In another attempt, [25] solved the same problem through applying a look-ahead method for scheduling trains in the network. In the first step, an initial timetable is produced. Then, the mathematical model endeavors to remove the inter-train conflict based upon minimizing the stoppage time. [9] Developed an expert system which can be used in local railway network for dispatching the trains in the blocks. Although this expert system does not produce the optimal solution, it can be used to increase the safety of the railway network in an automatic manner. [6] Also developed a knowledge-based model for Taiwan Railway called RSS. This model has two levels. At the first level, an initial figure is developed showing a global consideration like a master schedule. This global schedule does not consider local conflict. The second level relates to local scheduling. It seems that these two level work in separate environments; the first level searches for optimal operations while the second level modifies the schedule to avoid conflicts.

[16] Investigated the scheduling of the cargo train based on non-linear programming. In their model, the goal function is non-linear but all constraints are proposed in a linear figure. This model searches for minimum tardiness of trains in a 12-hour working day. [12] Also proposed a dynamic model which looks for maximum speed of the trains in the blocks with no priority of the trains. [18], in another attempt used a dynamic aspect of the movement of the trains in the network and took into account the time when the trains pass each block. Also, fuel efficiency, time and speed of the trains were considered as the major criteria in their model. [1] Investigated scheduling of passenger train based on the practical situations in Iran. He assumed that there is no certain program for launching trains in the blocks, the capacity of the station is limited and none of the train can bypass each other in stations or in blocks. [10] Also studied passenger train scheduling.

They developed a multi-objective model to schedule passenger train considering the consumption of the fuel and the time of travel. [22] Introduced a dynamic programming model to schedule cargo trains based on the timetable of passenger trains that have priority over cargo transportation. The objectives of the model are maximizing the capacity of cargo trains movement and minimizing the stoppage times in the blocks through the travel route.

The cargo trains scheduling have been determined based upon passenger trains timetables. Therefore, typical train scheduling models cannot be directly applied in Iran. Therefore, a model has been developed to deal with this specific problem. As it has been mentioned, based on top manager decision, all passenger trains have certain programs to launch and cargo trains must be moved among the free time of each block, i.e. the priority is always given to passenger trains. It is assumed that cargo trains are always ready to be launched among passenger trains. The proposed model is carried out in the route of Tehran-Mashhad and the results are reported in this paper. This route is more than 100 km long and bears the maximum traffic in the country.

In this paper, a multi-objective model for the scheduling of cargo trains faced by the costs of tardiness and earliness, time limitations, queue priority and limited station lines is presented. Furthermore, this paper introduces an integrated scheduling model of cargo trains with the above-mentioned limitations via mathematical approach. Time limitations means that a cargo train is permitted to travel from station i to station j if scheduled passenger trains have completed their travel from station i to station j. Queue priority has been calculated based on passenger trains timetable. Due to minimizing the cost of tardiness and earliness arrival of goods, the absolute deviation of planned delivery time must be minimized in the model. In addition, each station has a limited platform. This model has been run in IRIRC and the results are reported in this paper. The model was verified and validated against actual system using t-tests. In summary, the unique features of this study include: an integrated modeling and scheduling of cargo trains with complex limitations such as time constraints, queue priority and limited track storage. Furthermore, sensitivity analysis of the model reveals a set of optimizing alternatives for the scheduling of cargo trains. In this paper, the following assumptions have been taken into account:

- The train timetable for the passenger trains is taken as constant in this model, but it can be changed easily according to future policies.
- The sequence order for the passenger trains is taken as constant at the start of journey and throughout the trip.
- There is a limit in terms of the number of platforms at each station.

3. The Proposed Model

This section illustrates how the problem is formulated in a mathematical technique. To do so, the following steps have to be taken.

3.1. Notation and Variables used in mathematical model

In the mathematical model, the following notations will be used.

to_{ij}	the time cargo train j dispatches from station i
ts_{ij}	The time cargo train j passes i (the block is placed between station i and i+1, i.e. each block is known as the starting point)
tp_{ij}	Pre- calculated time required for loading and unloading train j in station i (this parameter is constant and known)
Td_j	Pre- calculated time taken for delivering the products of cargo train j
To_{ij}	the time passenger train j dispatches from station i (this parameter is constant and known)
Ts_{ij}	the time cargo train j passes i (the block is placed between station i and i+1, i.e. each block is known as the starting point)
x_{ij}	the distance between station i and j
$Vmax_i$	the maximum speed for cargo train in block i
$Vmin_i$	the minimum speed for cargo train in block i
J	number of cargo trains to be programmed
n	number of stations in the route
m	number of passenger trains which are programmed for that route
a	the total number of cargo trains ready for scheduling
$buffer_i$	the index of the cargo trains held in station i. these trains are arranged as FIFO rules in which for example train with the index $buffer_{i,1}$ is the first train held in station i
Cap_i	the capacity of the station i for holding trains, i.e. number of secure railways
Num (.)	this function illustrates the desirable numbers of member of the group

C_1 cost of tardiness per minute

C_2 cost of earliness per minute

It must be mentioned that all time series like To_{ij} are considered as ordered set. So the following inequalities hold: $To_{i1} \leq To_{i2} \leq \ldots \leq To_{im}$

3.2. The Goal Functions

The first objective of this model is to minimize the aggregate stoppage time (or delay) of planned cargo trains in all stations along the route. If the stoppage time is illustrated in this manner, the following equation will be derived:

The stoppage time of planned cargo train *j* in station *i*= $to_{i+1,j} - to_{ij} - ts_{ij} - tp_{ij}$

Then this goal function can be defined as follows:

$$Min. \quad \sum_{i=1}^{n}\sum_{j=1}^{J}\left(to_{i+1,j} - to_{ij} - ts_{ij} - tp_{ij}\right) \qquad (1)$$

The second objective of the model is to maximize the number of cargo planned trains in the route based on the capacity of the railway in that route. Since the number of cargo trains is shown by character *J*, the second goal function is defined as follows:

$$Max. \quad J \qquad (2)$$

The third objective of the model is to minimize the costs emanating from the actual deviation of planned train schedule from real delivery time (i.e. costs of tardiness and earliness) in order to avoid delivery penalty and keeping inventory costs in the final destination of the packages such as, insurance, warehouse, etc. It is clear that by minimizing the total stoppage time of cargo trains among the stations of the travel route, the cost of holding inventory in the station (not in the final destination) will be minimized. This goal function is defined as follows:

$$Min. \sum_{j=1}^{J} C \cdot \left|to_{n,j} - Td_j\right| \qquad (3a)$$

$$Min. \sum_{j=1}^{J} z_j \cdot C_1 \cdot \left(to_{n,j} - Td_j\right) + \left(1 - z_j\right) \cdot C_2 \cdot \left(Td_j - to_{n,j}\right) \qquad (3b)$$

In which z_j can be defined as follows:

$$z_j = \begin{cases} 1 & if\ to_{n,j} \geq Td_j \\ 0 & if\ to_{n,j} \leq Td_j \end{cases}$$

With the following unequal relation:

$$z_j \cdot \left(to_{n,j} - Td_j\right) \geq 0 \qquad \forall j \qquad (4)$$

$$\left(1 - z_j\right) \cdot \left(Td_j - to_{n,j}\right) \geq 0 \qquad \forall j \qquad (5)$$

Since the model has three objectives, the Goal Programming has been applied to solve this problem.

3.3. The main constraints related to the actual existing system

The first group of constraints (overall constraints): Constraints occurring throughout the time of the schedule:

- The time taken by a cargo train to dispatch must be longer than the time taken by a passenger train to dispatch
- The time a cargo train enters must be between the times two passenger trains enter.
- The time taken by a cargo train to enter each station must be longer than the time taken by the train to dispatch from that station.
- The time of movement into the block (the route between two stations) must be feasible, i.e. the speed of the train must be acceptable.
- In emergency situation it is possible to postpone the dispatching timetable.
- The model is capable of restricting the number of scheduled cargo trains.

The second group of constraints: the following constraints relate to a conditional situation:

- There is at least one secure or extra platform in all stations.
- The constraints in the number of platforms in some stations (due to occupation by other trains) must be checked before the train entering into the block reaches the mentioned station.
- If the platform is occupied in any station, the planned trains must be stopped in the previous station.

3.4. Constraints of the model

3.4.1. Overall constraints

- The dispatching time of scheduled cargo train *j* from station *i* must be adjusted to be after the movement of programmed passenger train *k (k=1,2,3,…,m*) from the same station. Therefore:

$$to_{ij} \geq To_{ik} + Ts_{ik} \qquad k = 1,2,\ldots,m \quad i = 1,2,\ldots,n \qquad (6)$$

- During the time of traveling, the cargo train *j* in block *i* must be planned in such a way that no passenger train enters the block *i* while train *j* has not been received by the same block (i.e. when the cargo train is still in block *i*) Therefore:

$$To_{i,k+1} \leq to_{ij} + ts_{ij} \leq To_{i+1,k} \qquad k = 1,\ldots,m \quad i = 1,\ldots,n \qquad (7)$$

- Similarly, the above mentioned consideration must be taken for already programmed cargo trains, so there is:

$$to_{i+1,j-1} \le to_{ij} + ts_{ij} \quad i=1,\dots,n \quad j=1,\dots,J \tag{8}$$

- When a cargo train is scheduled, the index of the number of programmed cargo train must be increased by one:

$$J = J + 1 \tag{9}$$

In order to update the changes, the following equation must be added to the model.

$$\text{Initial number} \begin{cases} J = 1 \\ to_{i+1,0} = \infty \end{cases}$$

- The next constraint relates to the maximum and minimum speed of the cargo trains entering the block (it must be mentioned that all trains must travel in the block based on the regulation of IRIRC:

$$\frac{x_{i,i+1}}{V\,max_i} \le ts_{ij} \le \frac{x_{i,i+1}}{V\,min_i} \qquad i = 1,2,\dots,n \tag{10}$$

- In emergency condition, management asks for certain stoppage for a train. In this situation the model will not allow for the delay time for mentioned train more than the time requested by management:

$$to_{i+1,j} - to_{ij} - ts_{ij} \ge tp_{ij} \qquad i=1,2,\dots,n \quad j=1,2,\dots,J \tag{11}$$

- The total number of programmed cargo trains must be equal or smaller than the total number of cargo trains ready for scheduling:

$$J \le a \tag{12}$$

3.4.2. Conditional constraints

As it was mentioned earlier, the dispatching of the cargo train from station *i* must be after the time the passenger train enters the station *i+1*. if there is any need to stop the train in the next station, at least one free platform must be available in that station. Otherwise, the dispatching time for that train has to be postponed for security reasons. In order to guarantee the above rule and to provide for the safety of the train in the route, the following three conditions have to be taken into account.

- The first condition: In this condition, there is no available free platform in the next station and therefore cargo train must not stop in the next station. So the formula is developed as $Num(buffer_{i+1}) = 0$. It means that the written constraint is adequate.
- The second condition: In this situation, the above formula is changed to $Num(buffer_{i+1}) \le P_{i+1} - 1$. So, in this condition the planned cargo train does not need another constraint and the following order will be considered for future test.

$$buffer_{i+1,Num(buffer_{i+1})+1} = j$$

- The third condition: In this condition, the above formula will be changed to $Num(buffer_{i+1}) = Cap_{i+1}$. In this case, the cargo train *j* can enter the station *i+1* provided that the first train entering this station has left that station. So, the following constraints for future tests must be added to the model:

$$\text{Initial number} \begin{cases} L = 1 \\ First = buffer_{i+1} \end{cases}$$

s.t.

$$to_{ij} + ts_{ij} \ge to_{i+1,buffer_{i,First}}$$

$$L = L + 1$$

$$First = buffer_{i,L}$$

In order to manage the above statements, it is beneficial to change all of them into constraints in a general model. So, the following lemma has been applied in this model: Lemma: if *a*, and *b* has been integer number and $a \le b$ then:

$$\left[\frac{a}{b}\right] = \begin{cases} 0 & a < b \\ 1 & a = b \end{cases}$$

Therefore, given this definition, the above conditions are converted into the following constraints in model:

$$y_{ij} = \left[\frac{Num(buffer_i)}{Cap_i}\right] \tag{13}$$

$$y_{ij} \cdot (to_{ij} + ts_{ij}) \ge y_{ij} \cdot (to_{i+1,buffer_{i,First}}) \tag{14}$$

$$y_{ij} \cdot L = y_{ij} \cdot (L+1) \tag{15}$$

$$y_{ij} \cdot First = y_{ij} \cdot buffer_{i,L} \tag{16}$$

$$buffer_{i+1,Num(buffer_{i+1})+1} = j \tag{17}$$

Considering the above explanations, the whole mathematical model is as follows:

$$Min.\quad \sum_{i=1}^{n}\sum_{j=1}^{J}\left(to_{i+1,j} - to_{ij} - ts_{ij} - tp_{ij}\right)$$

$$Max.\quad J$$

$$Min \sum_{j=1}^{J} \begin{matrix} z_j \cdot C_1 \cdot (to_{n,j} - Td_j) + \\ (1 - z_j) \cdot C_2 \cdot (Td_j - to_{n,j}) \end{matrix}$$

s.t.

$$to_{ij} \ge To_{ik} + Ts_{ik} \qquad k = 1,2,\dots,m \quad i = 1,2,\dots,n$$

$$To_{i,k+1} \le to_{ij} + ts_{ij} \le To_{i+1,k} \qquad k = 1,\dots,m \quad i = 1,\dots,n$$

$$to_{i+1,j-1} \le to_{ij} + ts_{ij} \qquad i = 1,\dots,n \quad j = 1,\dots,J$$

$$J = J + 1$$

$$\frac{x_{i,i+1}}{V\,max_i} \le ts_{ij} \le \frac{x_{i,i+1}}{V\,min_i} \qquad i = 1,2,\ldots,n$$

$$to_{i+1,j} - to_{ij} - ts_{ij} \ge tp_{ij} \quad i = 1,2,\ldots,n \quad j = 1,2,\ldots,J$$

$$J \le a$$

$$y_{ij} = \left[\frac{Num(buffer_i)}{Cap_i}\right]$$

$$y_{ij} \cdot (to_{ij} + ts_{ij}) \ge y_{ij} \cdot (to_{i+1,buffer_{i,First}})$$

$$y_{ij} \cdot L = y_{ij} \cdot (L+1)$$

$$y_{ij} \cdot First = y_{ij} \cdot buffer_{i,L}$$

$$buffer_{i+1,Num(buffer_{i+1})+1} = j$$

$$z_j \cdot (to_{n,j} - Td_j) \ge 0 \qquad \forall j$$

$$(1 - z_j) \cdot (Td_j - to_{n,j}) \ge 0 \qquad \forall j$$

$$y_{ij}, z_j \in \{0,1\} \quad \forall\, i, j$$

4. Operationalizing the model for Tehran-Mashhad route

This study considers one of the major double–line tracks with eight major stations (including the origin and the destination). This route is 1000 km long and has the heaviest traffic in the country. Due to government policy of the Iran's North-South corridor development (to encourage business with Tajikistan, Kazakhstan and Uzbekistan), the traffic will be even much more in the near future. In the existing situation, all passenger trains are pre-scheduled and have priority to dispatch. At the moment, the decision regarding the movement of the cargo trains are taken individually in every single station independently by the local authority. The only consideration in this situation is that the next block is empty and the next stoppage place has available secure railway. Lack of clear plans and discipline causes lots of delays and confusion. Therefore, there is a need to develop a scheduling plan for the cargo trains. Figure 1 presents the overview of the system.

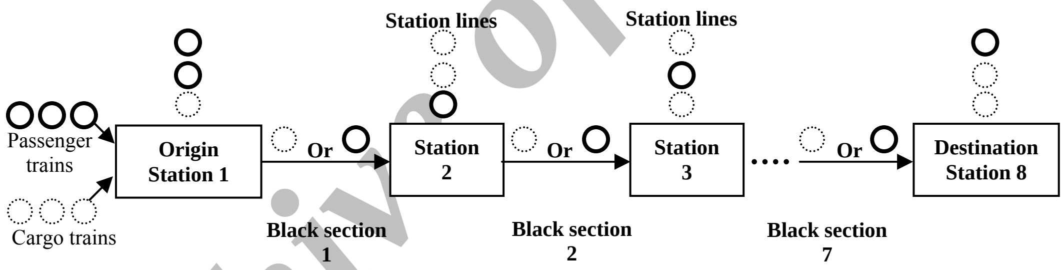

Fig. 1. Schematic representation of the cargo and passenger trains

Figure 2 shows the limitations associated with stations and blocks. A train (cargo or passenger) is permitted to travel from station *j* to station *k* if the block between *j* and *k* is empty and maximum queue capacity (station lines) is not reached in station *k*. In addition, a cargo train is permitted to travel from *j* to *k* if it does not cause a delay in travel of passenger trains from *i* to *j*. The objective of this study is to develop a model for the above system in order to identify optimum scheduling of the cargo trains.

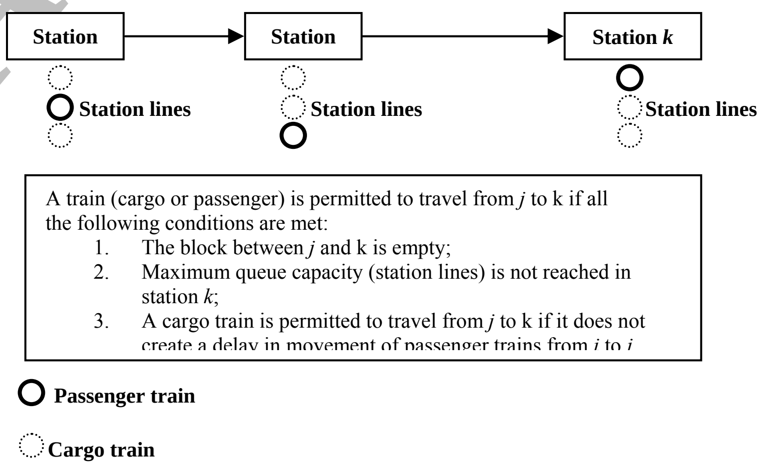

Fig. 2. Schematic representation of the model limitations

5. Numerical Tests and Results

Following the development of this model, the required data on the route of Tehran-Mashhad were gathered in order to test the model. With the help of IRIRC personnel, the following data were gathered:

- type of trains
- departure timetables of passenger trains
- number of stations in the route and their names
- the time passenger trains enter and leave each stations
- the block distance between two stations
- maximum and minimum speeds of two type of trains
- pre-determined stoppage time of trains in the stations

Table 1 depicts the time of arrival and departure of the passenger trains for all major stations which show the stoppage times for each train in each station as well. Table 2 also illustrates the maximum and minimum time required to pass every blocks in the route. This table is prepared according to the minimum and maximum authorized speed for each block.

Table 1
Timetable of arrival and departure of passenger trains (Time is written in minute)

No	Tehran	Garmsar		Semnan		Damghan		Shahrood		Neghab		Nishaboor		Mashhad
	Departure	Ariv.	Dep.	Ariv.	Dep.	Ariv.	Dep.	Ariv.	Dep.	Ariv.	Dep.	Ariv.	Dep.	Arrival
1	1.00	2.17	2.17	3.40	3.42	5.27	5.52	6.33	6.43	9.05	9.10	10.37	10.39	12.15
2	9.00	----	----	----	----	----	----	13.40	14.05	----	----	----	----	19.10
3	12.00	13.55	14.00	15.36	15.45	17.48	17.53	18.41	18.50	22.03	22.22	00.03	00.06	1.55
4	14.00	15.26	15.30	16.56	17.00	18.49	19.14	19.58	20.08	22.50	23.10	00.45	00.48	2.25
5	16.00	16.00	----	18.40	19.00	----	----	21.21	21.30	23.53	24.00	1.27	1.30	3.05
6	16.30	16.30	----	19.19	19.39	----	----	22.12	22.22	00.55	00.57	2.28	2.30	4.05
7	17.00	17.00	18.23	20.09	20.11	----	----	22.44	22.54	1.27	1.47	3.18	3.20	5.55
8	18.00	18.00	----	22.09	21.11	----	----	23.44	23.54	2.27	2.47	4.18	4.20	6.15
9	19.00	19.00	----	22.09	22.11	----	----	00.44	00.54	3.27	3.47	5.18	5.38	7.15
10	20.00	20.00	----	22.49	22.51	----	----	1.24	1.34	4.07	4.27	6.08	6.10	7.55
11	21.00	21.00	22.23	23.51	23.53	----	----	2.26	2.36	5.09	5.29	7.00	7.02	8.40

Table 2
Maximum and minimum time need to pass through each block

Block number	Minimum Time to pass (minute)	Maximum time to pass (minute)
1	120	135
2	125	155
3	145	160
4	70	90
5	215	230
6	110	125
7	120	135

The model WAS run with WinQSB software and the code of C for the above the results are shown in Table 3. It must be mentioned that all Pentium (III/VI) computers are able to calculate the scheduling problem with the size of 50 stations, 15 passenger trains and up to 10 cargo trains. This type of problem can be run in less than 90 seconds

Table 3
Proposed timetable of arrival and departure of cargo trains derived from the developed model (minute)

No	Tehran	Garmsar		Semnan		Damghan		Shahrood		Neghab		Nishaboor		Mashhad
	Dep.	Ariv.	Dep.	Ariv.	Dep.	Ariv.	Dep.	Ariv.	Dep.	Ariv.	Dep.	Ariv.	Dep.	Ariv.
1	132	259	275	403	421	581	615	694	710	934	1063	1181	1200	1335
2	259	388	407	546	581	728	823	907	979	1196	1218	1335	2197	2327
3	388	514	688	837	889	1055	1141	1225	1744	1972	2067	2190	2327	2461
4	1338	1462	1477	1638	1655	1807	1842	1924	1975	2196	2215	2335	2593	2713

According to Table 3, which shows the timetable of the cargo trains in every block, cargo train 1 leaves Tehran at 2:12 AM and arrives in Mashhad at 22.15 PM on the same day. Another example relates to the train 3 which departs from Tehran at 6:28 and arrives in Garmsar at 8:34 waiting in this station for 174 minutes, then leaves

for Semnan and finally arrives in Mashhad at 17:01 PM on the following day.
The cargo train number 1 and 3 encountered the tardiness time of 225 and 450 minutes, respectively. Assuming C_1= 5 Rials/Mins, then, for one ton the cost of tardiness equals 5×675=3375 Rials. The cargo train number 2 and 4 has earliness time of 165 and 750 minutes, respectively. Assumimg C_2=4 Rials/Mins. For one ton; then, cost of earliness equals 4×915=3660 Rials for one ton.
According to Table 3, the table of stoppage time for cargo trains can be obtained as it is illustrated in Table 4 below.

Table 4
The stoppage time of the cargo trains in each station (minute)

No.	Garmsar	Semnan	Damghan	Shahrood	Neghab	Nishaboor	Total stopage time
1	16	18	34	16	129	19	232
2	19	35	95	72	22	862	259
3	174	52	86	549	95	137	1003
4	15	17	35	51	19	258	446

The average performance for one week has been taken into account against the real existing performance in order to examine the introduced model. Table 5 illustrates the stoppage times of cargo trains for real existing system and the timetable suggested by the proposed model. As it is clear in the proposed model, the number of scheduled cargo trains during a day increased to 4 and, simultaneously, the total stoppage time decreased to 487.25 minutes. In the real situation, only one cargo train travels in the route with the total stoppage time of 535 minutes. This means that the efficiency of the system increased by 4.36 times.

Table 5
The average stoppage time in the current real system and the proposed model of the cargo trains in each station (minute)

	Garmsar	Semnan	Damghan	Shahrood	Neghab	Nishaboor	Average stoppage time
Proposed model	56	30.5	62.5	164.5	66.25	107.5	487.25
Existing system	50	61	25	120	130	150	535
t_0				0.215			

Based on IRIRC management viewpoint, the total traverse time from station 1 to 8 has been selected as the most important performance measurement of the railroad system. So, accumulation time of the actual system and the mathematical model were selected, respectively. An Independent *t-test* was utilized to compare the existing system with the mathematical model with respect to total traverse time from 1 to 8. The null hypothesis H_0: $\mu_1 = \mu_2$ was tested at α = 0.01 level of significance. It is concluded that with respect to the total traverse time, the two systems have the same performance (See Table 5). In addition, the equality of variance was tested prior to the *t-test* and the null hypothesis of H_0: $\sigma_1^2 = \sigma_2^2$ was confirmed at α = 0.05.

6. Discussion and Conclusions

In this paper, a dynamic linear mathematical (goal programming) model for scheduling of cargo trains among the pre-scheduled passenger trains is introduced. The model is tested in I.R. Iran Railway in Tehran-Mashhad route (over 1000 Km) using WinQSB software. The findings show that the timetable proposed by the model can increase the number of cargo trains in this route from 1 to 4 trains every running day and the stoppage time decreases from 535 minutes to 487.25 minutes. This indicates that efficiency of the system has increased as many as four times. For future research, the authors suggest the development of the model by adding such criteria as minimizing the operational cost or making the model more similar to the actual situation or minimizing the departure cost according to the maintenance costs or scheduling of goods transportation according to departure priorities such as emergency orders, etc. It is recommended that the model should be joined with the expert system or neural network to overcome the problem at large scales. This, in turn, can increase the security of the system and decrease the cost of running as well as the need for experts.
In summary, the unique features of this study are as follows: integrated modeling and scheduling of cargo trains with complex limitations which are time constraints, queue priority and limited track storage.

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