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# Integrated Linear Integer Model of a Fleet Allocation and Aircraft Routing Problem with Operational Constraints

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*ABSTRACT*

One of the topics that have been studied a lot in the field of airline industry optimization is related to flight planning, and air fleets, and how they relate to each other, which is called airline scheduling. Despite the high importance of this issue in the profitability of airline companies and the proper use of their resources, the high computational complexity of these models has led to considering each of them in a mathematical model separately, and as a result, the accuracy of the final decision will be decreased. So far, many articles have studied various relevant issues, in some cases, efforts to create integration in the process can be observed. However, there is a few operational views of the issue, and some key requirements were neglected due to the simplification of provided models. In this study, an integrated model of the two main stages of airline planning, including fleet allocation and aircraft maintenance routing, is considered simultaneously, and the performance of the developed model is investigated using real data from one of the airlines. Also, a sensitivity analysis of the model to some relevant parameters confirms the validity of the developed mathematical model and the solution algorithm. Then, a comparative study was investigated to compare the performance of the developed model with the operational method, including solving sub-problems stepwise. Also, the results are compared with the developed and similar method from the previous studies. The results confirm the superiority of the developed mathematical model.

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## NOMENCLATURE

| | | | |
|---|---|---|---|
| **Sets** | | | |
| $I\ (J)$ | Set of scheduled flight legs | $fd_k$ | Cumulative flight time of each aircraft at the start of planning. |
| $K$ | Set of all aircraft | $tp_i$ | Ticket price of flight leg *i*. |
| $M$ | Set of the maintenance stations | $pn_i$ | Number of flight leg *i* passengers. |
| $A$ | Set of airports | $cap_k$ | Capacity of aircraft *k*. |
| **Parameters** | | $op_{ka}$ | 1 if the aircraft *k* seating airports *a* at the start of scheduling; 0, otherwise. |
| $trt_k$ | Time needed for an aircraft *k* to prepare for the next flight. | $s_{ia}$ | 1 if the flight leg *i* departure from airport *a*; 0, otherwise. |
| $t_{max}$ | Maximum cumulative flight time of aircraft *k*. | $d_{ia}$ | 1 if the flight leg *i* ends in airport *a*; 0, otherwise. |
| $c_{max}$ | Maximum number of aircraft departures. | $ml_{ma}$ | 1 if maintenance station *m* is located in airport *a*; 0, otherwise. |
| $mt_k$ | Time needed for maintenance for aircraft *k*. | $O$ | Dummy start point |
| $v_{min}^k$ | Least number of maintenance has to be done for aircraft *k* in the planning horizon. | $D$ | Dummy destination point |
| $N$ | A big number. | **Variables** | |
| $dt_i$ | Departure time of flight leg *i*. | $x_{ijk}$ | 1 if flight legs *i* and *j* assign sequence to aircraft *k*; 0, otherwise. |
| $ft_i$ | Duration of flight leg *i*. | $y_{imk}$ | 1 if aircraft *k* going to maintenance station *m* after covering flight legs *i*; 0, otherwise. |
| $et_m$ | Time of closing the maintenance station *m*. | $z_{mik}$ | 1 if flight legs *i* covers by aircraft *k* in station *m*; 0, otherwise. |

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## 1. INTRODUCTION AND LITERATURE REVIEW

Aviation is one of the largest global industries, and in the modern era, the aviation industry has contributed greatly to the growth and development of the global economy, so the aviation industry has accounted for 3.5% of the world's gross domestic product [1]. Regardless of this issue, this industry indirectly affects economic growth by creating potential in creating employment. Nowadays, airports are not limited to only one place for air travel, and many recreational facilities such as dining, shops, rest, etc., are offered in them. Since the first commercial flights took off in the early 20th century, the industry has been growing at a tremendous pace. About 4.5 billion passengers traveled by the airlines in 2019, and more than 65 million people worldwide currently work in the airlines or related industries. Of this amount, about 10.2 million people are directly employed in full-time jobs in this industry [2].

Optimizing processes to increase revenues and reduce costs is one of the things that have been the focus of airline companies since their establishment. Considering that the main source of revenue for airlines is related to the movement of passengers, it is very important to have an optimal schedule of flights to meet the demand. On the other hand, the most important costs of airlines are related to flight operations and air fleets, which include about 10-20% of the total costs [3]. The next factor that has a significant impact on the profitability of organizations is related to lost sales, delays, and flight cancellations. In 2007, the airlines of the United States suffered a loss equivalent to 31.2 billion dollars due to delays [4]. This makes airline organizations seriously avoid situations that lead to delays or cancellations. To reduce this possibility, preventive measures are needed during flight planning.

Airline planning is usually divided into four steps including flight scheduling, fleet assignment, aircraft maintenance routing, and crew allocation. Air fleet planning, as an important and expensive resource of each airline, is carried out in fleet assignment and aircraft maintenance routing stages. In these steps, it is determined by which aircraft and in what sequence each flight will be made. There are many strict restrictions during this planning such as the maximum number and flight hours of each plane or the existence of a minimum time between two consecutive flights, which airlines are required to comply with in planning. Due to the sharp increase in the complexity of the model, these limitations are not considered in many studies, which makes it impossible to use them operationally.

So far, various articles and models have been published in the field of flight planning. Most of the primary proposed models have dealt with the tactical discussions of the issue and have refrained from examining the issue operationally. The maintenance requirements are the first things that must be observed for having an operational mathematical model in the field of airline planning. As mentioned earlier, three types of maintenance requirements, including the number of landings and take-offs, total flight time, and the number of days since the last maintenance, are defined in the airline safety rules, and any model that does not consider these items is not operational. In this section, the research done in the past on the topic of airline planning has been described and divided according to its characteristics.

The first group of articles takes a tactical look at airline scheduling. One of the first articles in this field was presented by Feo and Bard [5] who considered some maintenance constraints in a multi-commodity flow network model and tried to minimize the maintenance costs for a type of fleet. Daskin and Panayotopoulos [6] developed an integer model and used a combined method of Lagrangian simplification and a heuristic method to solve it. Kabbani and Patty [7] developed a new concept called "flight line" and scheduled a three-day schedule. They chose the night to do the scheduling and used an innovative two-step approach to the solution. Clarke et al. [8] used the salesman problem for modeling and planning an aircraft flight based on some maintenance constraints. Next, in 1998, the concept of the flight line was used by Gopalan and Talluri [9].

Barnhart et al. [10] defined a chain of flights and defined the objective function based on reducing the overall costs of this chain. Mak and Boland [11] have also used the salesman problem to model aircraft routing. They calculated the upper and lower bounds for this problem and then determined the optimal solution [11]. Sriram and Haghani [12] assumed that all maintenance activities are performed during the night. Therefore, they determined some pairs of origin and destination in such a way that the maintenance visits of each plane happen every four days. They used an innovative method to solve the model and developed another model at the end of the article, which was not solved [12]. Liang et al. [13] have developed a one-day aircraft routing planning model based on the time-space network. They focused on maximizing the revenue from flights and tried to prevent short connections in flights. They extended their paper by extending the planning period to one week on 2013 [14]. Jamili [15] has developed a mixed-integer programming (MIP) model by considering extra time for landing and take-offs to create robustness and has used a meta-heuristic method to solve it. Khanmirza, et al. [16] developed a model for fleet allocation and added restrictions to count the number and balance the planes and passengers. They used a developed method based on the genetic algorithm to solve the model. Next, Ozkir and Ozgur [17] developed a simple model of fleet allocation and aircraft routing and focused on developing an innovative solution method for it. The proposed method is two-stage, and the answers generated in the first stage are improved later.

Several developed models have incompletely included operational constraints in their models. Sarac, et al. [18] used the set partitioning problem to model the aircraft routing problem. Their goal was to minimize the remaining time of legal but unused repairs before repairs, and they tried to send the planes to repairs as late as possible [18]. Eltoukhy et al. [19] developed a linear integer model for the problem from a derivative method. In the next study by Eltoukhy et al. [20], they also developed a solution method. Wen et al. [21] focused a lot on the limited resources in maintenance stations. Due to the assumption of carrying out maintenance during the night, other constraints are implicitly included in the model. Saltzman [22] studied a daily recurring schedule for planning a fleet type and tried to satisfy the maintenance constraints by considering the maximum time interval of three days between two consecutive repairs.

The approach of creating integration in route planning is also very important in other fields, among which we can mention shipping. By converting the operating limits of cumulative flight hours and the number of cumulative flights into speed limits and the amount of ship fuel consumption and maintaining the minimum number of repairs in a period of time, we can mention the articles published in this field, including Pasha et al. [23]. The common operational and time requirements between these two issues are quite clear and the movement of this category of articles towards integration in decision-making can be seen. So that all kinds of operational, time, fuel consumption, speed, environmental and financial constraints have been investigated in an integrated problem.

As can be seen in Table 1, a few articles that have been published in the integration of airline planning stages have addressed the issues of mandatory restrictions on maintenance visits. Another point that is evident in this case is related to the shortness of the planning period in most of the articles. According to the existing conditions in the airlines, the results of the model that does not consider the mentioned topics, including mandatory maintenance visits and proper planning period, cannot be implemented in the operational environment. Therefore, one of the important weaknesses in this field is related to the non-operational nature of existing models, which exists due to the high complexity of airline planning stages.

This paper is attempted to provide an integrated model of the two main stages of the airline planning process, including fleet allocation and aircraft routing, which includes the constraints related to the requirements of periodic maintenance visits and has a long planning period. Also, the mentioned model deals with other relevant requirements, such as the initial location of the aircraft and the working hours of the repair stations.

## 2. PROBLEM DEFINITION

The main processes of airline planning include four steps flight scheduling, fleet assignment, aircraft maintenance routing, and crew scheduling. The high complexity of integrating and solving these problems at

**TABLE 1.** Summary of the literature review

| Authors | Planning period (day) | Maintenance constraits | | |
|---|---|---|---|---|
| | | **Take-offs number** | **Cumulative flight hour** | **Last day from the repair** |
| Feo & Bard [5] | _ | × | × | × |
| Daskin & Panayotopoulos [6] | – | × | × | × |
| Kabbani & Patty [7] | 3 | × | × | × |
| Clarke et al. [8] | _ | × | × | × |
| Barnhart et al. [10] | 7 | × | × | × |
| Gopalan & Talluri [9] | 3 | × | × | × |
| Mak & Boland [11] | _ | × | × | × |
| Sriram & Haghani [12] | 7 | × | × | ✓ |
| Sarac et al. [18] | 1 | ✓ | × | × |
| Liang et al. [13] | 1 | × | × | × |
| Hauari et al. [24] | 1 | ✓ | ✓ | ✓ |
| Liang & Chaovalitwongse [14] | 7 | × | × | × |
| Al Thani, et al. [25] | 7 | ✓ | ✓ | ✓ |
| Jamili [15] | 1 | × | × | × |
| Eltoukhy et al. [19] | 4 | ✓ | × | × |
| Safaei & Jardine [26] | 7 | ✓ | ✓ | × |
| Kenan et al. [27] | 1 | × | × | × |
| Eltoukhy et al. [20] | 4 | ✓ | × | × |
| Deng et al. [28] | 10 | ✓ | × | × |
| Ruan, et al. [29] | 4 | ✓ | ✓ | ✓ |
| Xu et al. [30] | _ | × | × | × |
| Wen, et al. [21] | 1 | × | × | × |
| Saltzman [22] | 1 | × | × | ✓ |
| **This paper** | **10** | ✓ | ✓ | ✓ |

the same time, due to the volume of calculations and available calculation methods, causes that in most cases, as in Figure 1, these problems were examined and solved separately and sequentially. So that the output of each stage was used as the input of the next stage. This issue caused non-optimal solutions for problems to be delayed or even impossible [31].

The flight schedule is the first issue that should be questioned during the planning of an airline. The output of this step includes the origin, destination, take-offs, and landing time of all airline flights in a certain period. The purpose of this stage is to create a timetable to maximize the airline's revenue in relation to the expected demand from passengers. Usually, all other operations of the airline are based on the output of this stage. In most cases, these timetables are repeated daily or weekly [31].

The first issue that is addressed after the flight schedule is determined is the allocation of the fleet. The purpose of this stage is to allocate the types of the existing fleet of the airline to the flights planned in the previous stage [32]. According to the article of Al Thani and Haouari [25], the type of aircraft refers to a specific model of aircraft. Aircraft belonging to the same type have the same cabin style and equal seat numbers, and this is different from an aircraft family. An aircraft family includes different aircraft types with only the same cabin style. It should also be noted that at this stage, only the issue of allocating types of aircraft to scheduled flights is discussed, and the one-to-one allocation of existing aircraft is not an issue [32].

Another activity that must be put on the agenda for airline planning is the allocation of each aircraft to each scheduled flight. In other words, a sequence of flights that are required to be covered must be defined for each aircraft. During this stage, there are a large number of constraints that must be considered while solving the problem, the most important of which is related to meeting the requirements related to maintenance visits of each aircraft. Preventive maintenance visits are performed before the number of flights of each aircraft reaches a predetermined value [33]. A feasible route for an aircraft consists of several consecutive flights, each flight must be covered by one aircraft, and there is no time overlap between them. These paths must have the following conditions:

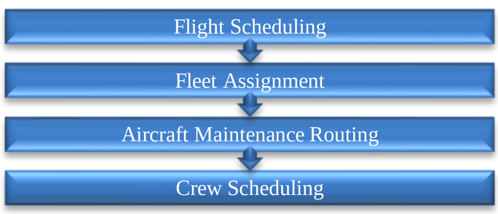


**Figure 1.** Airline's steps for flights scheduling

- The landing airport of the first flight must be the same as the departure airport of the second flight.
- The second flight request time must be greater than the first flight's seating time plus the time needed to prepare for the next flight.
- The cumulative flight time and take-off number of airplanes should not exceed a certain amount.
- It should not be more than a certain number of days since the last repair of the aircraft.

Because maintenance visits are required only after some flights and only possible in some airports (usually hub airports) when connecting two flights after a maintenance visit, the time and place of repairs are also It should be included in the above conditions. The problem of aircraft routing in all its forms is considered a very complex problem [34].

After the mentioned steps, it is necessary to plan how to serve the crew on the flights. This step involves assigning crew to each flight while complex work rules and reducing crew costs should be on the agenda [33]. Crew scheduling includes a sequence of duty periods with night rest between them, which starts at a specific location and ends at the same location, which is called the crew base. Carrying out this process step by step causes inefficiency and failure to achieve the optimal answer. This step-by-step process is used to help reduce complexity, which is somewhat successful in this matter, but this reduction in complexity comes at the cost of reducing the quality of the final solution. It seems that integrating the planning process can be very effective in improving the obtained response.

## 3. PROPOSED MATHEMATICAL MODEL

Assuming that the flight schedule is available, the purpose of the proposed model is to achieve an integrated model of two main processes with the high computational complexity of fleet allocation and aircraft routing. For this purpose, three types of arcs according to the connection network were used in this research. Flight vectors connect two consecutive flights to the flight flow of an aircraft, repair vectors direct the aircraft to the repair station after a flight, and auxiliary vectors are responsible for returning the repaired aircraft to the flight cycle.

This model is presented based on the connection network, in which flights are displayed as points and possible connections between them as vectors. Considering that it has been tried to make the model have the most features of an operational model, the flight cost of each plane has been considered different in each of the flights. Other things such as the capacity of each plane and the number of passengers on the route are also considered in this model. The objective function of the model is based on choosing the options that create the most profitability for the airline. The presented model has features that completely separate it from the previous models. The first feature is adding a decision variable as an auxiliary vector to the model, which is responsible for returning the aircraft to the planning cycle after completing the repairs. Another point that is considered in this model, unlike most of the previous models, is related to considering the initial location of the aircraft at the beginning of the planning period. This makes the planning operational. One of the most important strengths of this model is related to having control over the current state of the aircraft at every moment of planning. It should be noted that other things such as making a distinction between the time required for a maintenance visit and the time required to prepare the aircraft between two consecutive flights, separating the repair station from the airport, reducing the parameters related to the definition of scheduled flights, etc. Other features are added to the model. Using the nomenclature mentioned before the introduction, the mathematical model is presented as follows:

$$\text{Max}\, u = \sum_{k=1}^{K}\sum_{i=1}^{I}\sum_{j=1}^{I}\sum_{m=1}^{M}(pn_i * tp_i) * (x_{ijk}) \quad (1)$$

s.t.

$$\sum_{k=1}^{K}\sum_{j=1}^{I} x_{ijk} + \sum_{k=1}^{K}\sum_{m=1}^{M} y_{imk} = 1 \quad \forall\ i \in I - \{O.D\} \quad (2)$$

$$\sum_{i=1}^{I}\sum_{a=1}^{A} x_{oik} * s_{Oa} * op_{ka} + \sum_{m=1}^{M}\sum_{a=1}^{A} y_{omk} * s_{Oa} * op_{ka} \geq 1 \quad \forall\ k \in K \quad (3)$$

$$\sum_{j=1}^{I} x_{jik} + \sum_{m=1}^{M} z_{mik} = \sum_{j=1}^{I} x_{ijk} + \sum_{m=1}^{M} y_{imk} \quad \forall\ k \in K. i \in I - \{O, D\} \quad (4)$$

$$\sum_{i=1}^{I-D} y_{imk} = \sum_{i=1}^{I} z_{mik} \quad \forall\ k \in K. m\epsilon M \quad (5)$$

$$\sum_{m=1}^{M} z_{mik} \leq \sum_{j=1}^{I<i}\sum_{m=1}^{M} y_{imk} \quad \forall\ k \in K. i \in I \quad (6)$$

$$\sum_{i=1}^{I} x_{oik} + \sum_{m=1}^{M} y_{omk} = 1 \quad \forall\ k \in K \quad (7)$$

$$dt_i + ft_i + trt_k - dt_j \leq N * (1 - x_{ijk}) \quad \forall\ k \in K. i \in I. j\ \epsilon\ I \quad (8)$$

$$\sum_{k=1}^{K} x_{ijk} \leq \sum_{a=1}^{A} d_{ia} * o_{ja} \quad \forall\ i \in I. j\epsilon I \quad (9)$$

$$dt_i + ft_i + mt_k - et_m \leq N * (1 - y_{imk}) \quad \forall\ m\epsilon M. i \in I. k \in K \quad (10)$$

$$\sum_{k=1}^{K} y_{imk} \leq \sum_{a=1}^{A} d_{ia} * ml_{ma} \quad \forall\ m\epsilon M. i \in I \quad (11)$$

$$\sum_{k=1}^{K} z_{mik} \leq \sum_{a=1}^{A} o_{ia} * ml_{ma} \quad \forall\ m\epsilon M. i \in I - \{D\} \quad (12)$$

$$\sum_{i=1}^{I}\sum_{j=1}^{I} x_{ijk} \leq c_{max} \quad \forall\ k \in K \quad (13)$$

$$\sum_{i=1}^{I}\sum_{j=1}^{I} ft_j * x_{ijk} + fd_k \leq t_{max} \quad \forall\ k \in K \quad (14)$$

$$\sum_{i=1}^{I}\sum_{m=1}^{M} y_{imk} = 1 \quad \forall\ k \in K \quad (15)$$

$$x_{ijk}\epsilon\{0.1\} \quad \forall\ k \in K. i \in I. j\epsilon I \quad (16)$$

$$y_{imk}\epsilon\{0.1\} \quad \forall\ k \in K. i \in I. m\epsilon M \quad (17)$$

$$z_{mik}\epsilon\{0.1\} \quad \forall\ k \in K. i \in I. m\epsilon M \quad (18)$$

In this model, the objective function maximizes the total revenue of the airline by selling tickets to passengers. Constraint (2) tries to ensure that all flights are covered by exactly one aircraft. Constraint (3) ensures that the flight path of each aircraft starts from the airport where it was based at the beginning of the planning period.

Constraints (4) to (7) are used to create balance in planning. The purpose of constraint (4) is to logically switch between decision vectors so that if an aircraft is sent to the repair station, the next vector should return the aircraft to the planning cycle. While the previous vector was a flight vector, the next vector is only allowed to take two states, a flight vector or a repair vector. Constraint (5) causes correct change between the repair vector and auxiliary vector in repair stations. In Constraint (6), it is only possible to use the auxiliary vector to return the aircraft to the flight cycle if the related repair vector has already been set. Despite Constraint (7), the use of the entire fleet is guaranteed during the planning of at least one flight or one repair.

Constraints (8) and (9) are used to ensure the consistency of consecutive flights during the planning process. In this way, in Constraint (8), the coincidence of two consecutive flights in terms of time is checked in such a way that the landing time of the first flight plus the minimum time required for the preparation of the plane is before the time of the next flight. While in Constraint (9), their compatibility is examined in terms of origin and destination airports.

Constraints (10) to (12) are responsible for the correct planning of the repairs of an aircraft in terms of time and place of repairs. In such a way, Constraint (10) of the working time of the repair station and the completion of the repair visits before the end of the working time has been examined. While Constraint (11) examines the sameness of the scheduled repair location with the destination airport of the previous flight. Constraint (12) examines the coincidence of the origin airport of the next flight with the repair station.

Constraints (13) to (17) are related to the review of aircraft maintenance and repair requirements. In this regard, Constraint (13) examines the number of flights made by each aircraft since the last repair. At the same time, Constraints (14) examine the cumulative time of flights performed by each aircraft. It is necessary to explain that the amount of previous flights made by each aircraft is counted. Constraint (15) determines the minimum number of maintenance visits of each aircraft on the planning horizon. Constraints (16) to (18) are related to determining the binaryness of the decision variables of the model.

## 4. COMPUTATIONAL RESULTS

To check the validity of the presented model, it tried to analyze the real data of an airline company, and for this purpose, the available flight and fleet data of Ata Airlines Company (as Appendices 1 and 2) were used[1], which information is stated in Table 2. The used information includes the origin, destination, time, and duration of the planned flights during a week. Other required information, including the type and number of air fleets, operating costs, etc., was also collected from the company's website[1]. In addition to the proposed model, the collected data were solved with the conventional step-by-step method and the work conducted by Ruan et al. [29] as an updated and similar article, and the results were used to confirm the performance. The reason for choosing the mathematical model [29] is the high similarity of its features and constraints to our model proposed in this paper So that both models are modeled using the connection network and the objective function of both is based on increasing the profitability of the airline. Also, the constraints used to maintain the balance and sequence of flights (constraints 2 to 10) and operational constraints (constraints 11 to 15) provide a similar function. The main difference between these two models is the absence of one of the decision variables (decision variable *z* to return the plane to the flight schedule) in [29], as well as how the restrictions are set differently, and these differences do not hinder the possibility of comparing the two models. For similarity in comparison results, the objective function of the mentioned paper was also replaced, despite the high similarity. The comparison with the stepwise method was also done by solving the fleet allocation problem and transferring its results as input data to the aircraft routing problem, as explained in section 2. The presented model was solved according to the information provided in the previous section and three modes. In the first case, the scheduled flights of this airline in 2 days, including 110 flights and 15 separate destinations, were examined under the title of small statistical population. The second studied mode was related to 4 days of the flight schedule of this airline, including 220 flights and 18 separate destinations, and at the end, the statistical population with a large size was related to 1 week of the flight schedule with 347 flights to 18 flight destinations.

All these three statistical populations were solved with a precise method using GAMS software, and the results are shown in Table 6. Also, all three assumed cases are solved by the stepwise method, and a comparison of the amount of the objective function and its solution time with the exact solution method has been made. To increase the validity of the proposed integrated model, a comparison with one of the new articles by Ruan et al. [29] was also made, and the results were reported. This article was chosen due to the similarity in key features to the proposed model, including considering all the repair limitations and also the solution time of four days. By using the mentioned comparisons, the performance of the proposed model can be compared with the most important related cases. The first comparison with the step-by-step method shows how the proposed model performs in our comparison of the common practice method in airline scheduling, while the comparison made with the selected paper compares the performance of the model with the latest research achievements. It should be mentioned that the selected article related to Ruan et al. [29] should have presented several features similar to the proposed model, the most important of which are similar repair restrictions (considering all repair requirements), relatively similar parameters, and The solution time indicated the appropriate ratio. To compare the two models from the point of view of the amount of the objective function and the non-identity of the models in this matter, the objective function of the model proposed in this article was replaced, and the models were solved with the same input information. The things that are comparable in the mentioned comparison are related to the two key issues of the value of the objective function (here, the profitability rate) and the solution time.

As shown in Table 2, despite the 28% increase in solving time in the large sample compared to the stepwise method, an improvement of more than 18% is seen in the final answer. In medium and small samples, despite the improvement of 20% and 12%, respectively, in the value of the objective function compared to the stepwise method, the solution time is also in a suitable range. Meanwhile, the comparison of the proposed method with the paper of Ruan et al. [29] indicates an improvement of between 1.5 and 4.5 percent in the obtained answers, and the solution time has also improved significantly compared to this paper. It should be noted that meta-heuristic methods have been used in the article by Ruan et al. [29] due to the long time needed to solve the model accurately. One of the most important reasons for this improvement is the return of repaired planes to the planning cycle. This has caused flights to be reassigned to the aircraft at the correct time

[1] https://www.ataair.ir

**TABLE 2.** Performance comparison of the proposed model

| Problem Size | | Small | Medium | Large |
|---|---|---|---|---|
| Aircraft number | | 21 | 21 | 21 |
| Maintenance Station | | 15 | 18 | 18 |
| Flights number | | 110 | 207 | 347 |
| Objective Function Value | * | 2,987,985 | 27.187.168 | 33.793.258 |
| | ** | 2,629,426 | 21.749.707 | 22.722.487 |
| | *** | 2,943,164 | 25.963.745 | 33,318,585 |
| Solution Time | * | 4.664 | 33.637 | 87.938 |
| | ** | 10.635 | 31.126 | 68.438 |
| | *** | 3255.032 | 5869.866 | 9014.326 |

* Proposed model ** Stepwise model *** Selected model from [27]

and place after the repairs. Also, the improvement created in modeling, including reducing the number of parameters used to define flights and replacing complex constraints with simpler constraints, has caused a significant reduction in model-solving time.

In addition to the above analysis, several related sensitivity analyzes were conducted to determine the accuracy of the model's performance. In the first case, the state of change of the objective function relative to the changes in the allowed flight time of the aircraft was investigated. For this issue, two different parameters, including $t_{max}$ to show the maximum allowed flight hours of each plane and $c_{max}$ for the maximum number of landings and take-offs allowed in the model are used. To determine the correctness of the model's performance, it is expected that by reducing the allowed time or the number of landings and take-offs of the aircraft, the operating costs will increase, and as a result, the amount of the objective function will decrease. Therefore, to measure this issue by keeping one of these two parameters constant, the value of the other parameter is changed. The result of these changes can be observed in Figure 2.

As shown in Figure 2, the amount of the objective function has an increasing trend with an increase in the parameters of the allowed flight time. It can also be seen that for the trend line, fixed parameters with lower values have a lower objective function value than higher values in both parameters. As a result, in this analysis, the correct performance of the model is observed for changes in the allowed flight time.

The next analysis that can be examined in this regard is related to the number of scheduled repairs per change in the amount of allowed flight time. It is expected that the number of repairs will decrease as the flight time increases. For this purpose, the sensitivity analysis of the model was done, and the results are shown in Figure 3. In this figure, it is evident that the

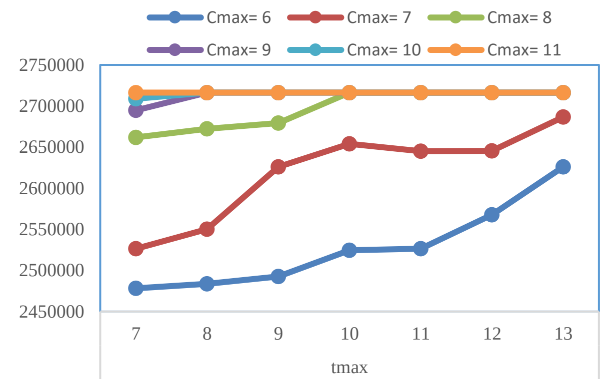


**Figure 2.** Changes of the objective function for parameter $t_{max}$ for different values of parameter $c_{max}$

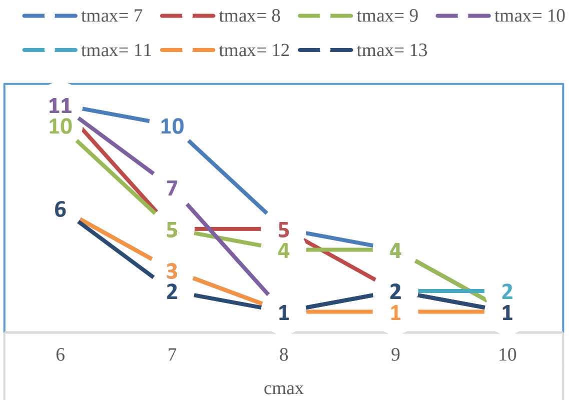


**Figure 3.** Changes of the planned maintenance number for $c_{max}$ for different values of $t_{max}$

number of planned repairs of the model decreases due to an increase in time and the number of allowed flights of each plane.

- Improvement in the answers obtained compared to the conventional step-by-step method and reviewed articles, and as a result, increasing the profitability of the airline company.
- Consideration of all maintenance requirements and usability in all real issues.
- Long planning period and the possibility of using the model in operational mode.

Bringing repaired aircraft back into the planning cycle.

## 5. CONCLUSION

This article, while introducing the airline planning process, it was tried to focus on integrating the two main stages of this process. The presented integrated linear integer model is proposed for the ten-day scheduling of two major airline scheduling processes. These two stages, which include fleet allocation and aircraft routing, are presented in one model, unlike common mathematical models that analyze each stage separately. The presented model takes into account all operational limitations and maintenance visits, and as a result, it can be used operationally.

The presented model is solved using three different sizes of real data, and the result is compared with the stepwise solution method as one of the fastest available solution methods and one of the recent studies with a similar structure that produces one of the best possible solutions. According to the obtained results, it seems that the results of the proposed model have produced much better results and can be used in an operational mode so that the proposed model could improve the results by 12 - 20 percent improvement compared to the stepwise method and also could improve the results by 1.5 - 4.5 percent improvement compared to the model presented in the selected article. The numerical analysis confirms that solving the proposed model by GAMS software can compete with the stepwise model and has produced far better results than the selected model in terms of time efficiency.

One of the topics suggested for future research is the development of the level of integration in the model presented to other parts of planning. Another interesting topic is related to the development of the solving method for the presented model. Due to the widespread of heuristic and meta-heuristic algorithms, this potential method can be used to improve the time and quality of the achievable solution. Also, smartening the flight selection process and integrating it with the current model is another attractive direction for future study. Another interesting topic for future research is the use of studies conducted in the field of shipping in airline planning research or vice versa.

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**APPENDIX 1.** Ata airline flight schedule between 2022/04/12 to 2022/04/18

| Row | Date | Origin | Destination | Flight time | Flight duration |
|---|---|---|---|---|---|
| 1 | 2022/04/12 | Tehran | Tabriz | 5:00 | 01:00 |
| 2 | | Tabriz | Tehran | 6:02 | 01:00 |
| 3 | | Orumie | Tehran | 6:25 | 01:00 |
| 4 | | Tehran | Mashhad | 6:48 | 01:20 |
| 5 | | Tabriz | Tehran | 7:00 | 01:00 |
| 6 | | Tehran | Tabriz | 7:54 | 01:00 |
| 7 | | Tehran | Mashhad | 8:34 | 01:20 |
| 8 | | Mashhad | Tehran | 9:00 | 01:20 |
| 9 | | Mashhad | Sari | 9:04 | 01:10 |
| 10 | | Tehran | Ahvaz | 9:05 | 00:50 |
| 11 | | Tehran | Bandarabbas | 9:20 | 01:45 |
| 12 | | Tabriz | Mashhad | 9:57 | 02:00 |
| 13 | | Mashhad | Esfehan | 10:49 | 01:30 |
| 14 | | Ahvaz | Tehran | 10:55 | 00:50 |
| 15 | | Sari | Mashhad | 10:55 | 01:10 |
| 16 | | Tehran | Mashhad | 11:25 | 01:20 |
| 17 | | Tehran | Kish | 11:25 | 01:45 |
| 18 | | Bandarabbas | Tehran | 11:50 | 01:45 |
| 19 | | Mashhad | Tabriz | 13:00 | 02:00 |
| 20 | | Mashhad | Tehran | 13:00 | 01:20 |
| 21 | | Tehran | Sabzevar | 13:05 | 01:00 |
| 22 | | Esfehan | Mashhad | 13:10 | 01:30 |
| 23 | | Mashhad | Tehran | 13:40 | 01:20 |
| 24 | | Kish | Tehran | 14:00 | 01:45 |
| 25 | | Tehran | Kermanshah | 14:50 | 01:00 |
| 26 | | Sabzevar | Tehran | 15:00 | 01:00 |
| 27 | | Tehran | Shiraz | 15:05 | 01:20 |
| 28 | | Mashhad | Tehran | 15:40 | 01:20 |
| 29 | | Tabriz | Tehran | 16:00 | 01:00 |
| 30 | | Tehran | Kish | 16:35 | 01:45 |
| 31 | | Kermanshah | Tehran | 16:50 | 01:00 |
| 32 | | Tehran | Shiraz | 17:00 | 01:20 |
| 33 | | Shiraz | Tehran | 17:20 | 01:20 |
| 34 | | Tehran | Qheshm | 17:45 | 01:50 |
| 35 | | Tehran | Tabriz | 18:05 | 01:00 |
| 36 | | Kish | Tehran | 18:40 | 01:45 |
| 37 | | Shiraz | Kish | 19:10 | 01:00 |
| 38 | | Tehran | Kish | 19:50 | 01:45 |
| 39 | | Tehran | Mashhad | 19:50 | 01:20 |
| 40 | | Tabriz | Tehran | 20:00 | 01:00 |
| 41 | | Tehran | Ahvaz | 20:10 | 00:50 |
| 42 | | Qheshm | Tehran | 20:30 | 01:50 |
| 43 | | Kish | Shiraz | 20:50 | 01:00 |
| 44 | | Tehran | Mashhad | 21:30 | 01:20 |
| 45 | | Tehran | Tabriz | 22:00 | 01:00 |
| 46 | | Ahvaz | Tehran | 22:00 | 00:50 |
| 47 | | Mashhad | Tehran | 22:00 | 01:20 |
| 48 | | Kish | Tehran | 22:10 | 01:45 |

| | | | | | |
|---|---|---|---|---|---|
| 49 | | Shiraz | Tehran | 22:40 | 01:20 |
| 50 | | Tehran | Orumie | 23:40 | 01:00 |
| 51 | | Tabriz | Tehran | 5:55 | 01:00 |
| 52 | | Tehran | Tabriz | 6:10 | 01:00 |
| 53 | | Orumie | Tehran | 6:23 | 01:00 |
| 54 | | Tehran | Kermanshah | 7:17 | 01:00 |
| 55 | | Tehran | Tabriz | 7:50 | 01:00 |
| 56 | | Tabriz | Tehran | 8:06 | 01:00 |
| 57 | | Kermanshah | Tehran | 8:50 | 01:00 |
| 58 | | Mashhad | Kish | 9:03 | 02:00 |
| 59 | | Tehran | Mashhad | 9:15 | 01:20 |
| 60 | | Tehran | Qheshm | 9:30 | 01:50 |
| 61 | | Tehran | Bandarabbas | 9:53 | 01:45 |
| 62 | | Tabriz | Tehran | 9:55 | 01:00 |
| 63 | | Tehran | Esfehan | 10:35 | 01:00 |
| 64 | | Mashhad | Esfehan | 11:00 | 01:30 |
| 65 | | Kish | Tehran | 11:00 | 01:45 |
| 66 | | Esfehan | Kish | 11:50 | 01:15 |
| 67 | | Tehran | Mashhad | 11:50 | 01:20 |
| 68 | | Tehran | Kish | 11:50 | 01:45 |
| 69 | | Kish | Esfehan | 12:00 | 01:15 |
| 70 | 2022/04/13 | Qheshm | Tehran | 12:20 | 01:50 |
| 71 | | Bandarabbas | Tehran | 12:40 | 01:45 |
| 72 | | Esfehan | Mashhad | 13:20 | 01:30 |
| 73 | | Kish | Esfehan | 13:35 | 01:15 |
| 74 | | Tehran | Kish | 13:45 | 01:45 |
| 75 | | Mashhad | Tehran | 14:10 | 01:20 |
| 76 | | Tehran | Tabriz | 14:20 | 01:00 |
| 77 | | Esfehan | Kish | 14:20 | 01:15 |
| 78 | | Kish | Tehran | 14:40 | 01:45 |
| 79 | | Tehran | Ahvaz | 14:50 | 00:50 |
| 80 | | Tehran | Mashhad | 15:20 | 01:20 |
| 81 | | Esfehan | Tehran | 15:30 | 01:00 |
| 82 | | Mashhad | Tehran | 15:40 | 01:20 |
| 83 | | Tabriz | istanbul | 16:00 | 01:15 |
| 84 | | Kish | Mashhad | 16:30 | 02:00 |
| 85 | | Ahvaz | Tehran | 16:50 | 00:50 |
| 86 | | Mashhad | Tehran | 17:40 | 01:20 |
| 87 | | Tehran | Mashhad | 17:40 | 01:20 |
| 88 | | Tehran | Kish | 17:45 | 01:45 |
| 89 | | Tehran | Tabriz | 18:00 | 01:00 |
| 90 | | Tehran | Ahvaz | 19:05 | 00:50 |
| 91 | | Mashhad | Tehran | 19:20 | 01:20 |
| 92 | | Tehran | Qheshm | 19:20 | 01:50 |
| 93 | | istanbul | Tabriz | 19:30 | 01:15 |
| 94 | | Tehran | Shiraz | 19:40 | 01:20 |
| 95 | | Tabriz | Tehran | 20:00 | 01:00 |
| 96 | | Mashhad | Tehran | 20:00 | 01:20 |
| 97 | | Kish | Tehran | 20:30 | 01:45 |
| 98 | | Ahvaz | Tehran | 21:00 | 00:50 |
| 99 | | Tehran | Mashhad | 21:40 | 01:20 |
| 100 | | Qheshm | Tehran | 21:50 | 01:50 |
| 101 | | Tehran | Tabriz | 22:00 | 01:00 |
| 102 | | Shiraz | Tehran | 22:00 | 01:20 |
| 103 | | Tehran | Orumie | 22:50 | 01:00 |
| 104 | | Tehran | Tabriz | 5:02 | 01:00 |
| 105 | | Tabriz | Tehran | 5:57 | 01:00 |
| 106 | | Tehran | Ahvaz | 6:09 | 00:50 |
| 107 | | Orumie | Tehran | 6:28 | 01:00 |
| 108 | | Tabriz | Tehran | 7:00 | 01:00 |
| 109 | | Tehran | Tabriz | 7:58 | 01:00 |
| 110 | | Ahvaz | Tehran | 8:06 | 00:50 |
| 111 | | Tehran | Mashhad | 8:40 | 01:20 |
| 112 | | Tehran | Bandarabbas | 9:05 | 01:45 |
| 113 | | Tehran | Mashhad | 9:35 | 01:20 |
| 114 | | Tabriz | Tehran | 10:00 | 01:00 |
| 115 | | Tehran | Kish | 10:20 | 01:45 |
| 116 | | Mashhad | Esfehan | 10:50 | 01:30 |
| 117 | | Kish | Tehran | 11:00 | 01:45 |
| 118 | 2022/04/14 | Bandarabbas | Tehran | 11:39 | 01:45 |
| 119 | | Mashhad | Tehran | 11:45 | 01:20 |
| 120 | | Tehran | Shiraz | 11:50 | 01:20 |
| 121 | | Kish | Esfehan | 12:00 | 01:15 |
| 122 | | Kish | Shiraz | 13:00 | 01:00 |
| 123 | | Tehran | Mashhad | 13:10 | 01:20 |
| 124 | | Esfehan | Mashhad | 13:30 | 01:30 |
| 125 | | Mashhad | Kish | 13:30 | 02:00 |
| 126 | | Tehran | Kish | 13:40 | 01:45 |
| 127 | | Shiraz | Tehran | 14:10 | 01:20 |
| 128 | | Esfehan | Kish | 14:20 | 01:15 |
| 129 | | Tehran | Esfehan | 14:30 | 01:00 |
| 130 | | Shiraz | Kish | 14:50 | 01:00 |
| 131 | | Mashhad | Tehran | 15:20 | 01:20 |
| 132 | | Mashhad | Tehran | 16:00 | 01:20 |

| | | | | | |
|---|---|---|---|---|---|
| 133 | | Esfehan | Kish | 16:20 | 01:15 |
| 134 | | Kish | Mashhad | 16:30 | 02:00 |
| 135 | | Kish | Tehran | 16:30 | 01:45 |
| 136 | | Tehran | Orumie | 16:35 | 01:00 |
| 137 | | Kish | Tehran | 16:50 | 01:45 |
| 138 | | Tehran | Kish | 17:45 | 01:45 |
| 139 | | Tehran | Mashhad | 17:45 | 01:20 |
| 140 | | Tehran | Tabriz | 18:00 | 01:00 |
| 141 | | Orumie | Tehran | 18:20 | 01:00 |
| 142 | | Kish | Esfehan | 18:30 | 01:15 |
| 143 | | Tehran | Qheshm | 19:05 | 01:50 |
| 144 | | Tehran | Kish | 19:15 | 01:45 |
| 145 | | Mashhad | Tehran | 19:20 | 01:20 |
| 146 | | Tabriz | Tehran | 20:00 | 01:00 |
| 147 | | Mashhad | Tehran | 20:00 | 01:20 |
| 148 | | Kish | Tehran | 20:10 | 01:45 |
| 149 | | Tehran | Shiraz | 20:15 | 01:20 |
| 150 | | Esfehan | Tehran | 20:40 | 01:00 |
| 151 | | Tehran | Mashhad | 21:30 | 01:20 |
| 152 | | Qheshm | Tehran | 21:40 | 01:50 |
| 153 | | Tehran | Tabriz | 22:00 | 01:00 |
| 154 | | Shiraz | Tehran | 22:20 | 01:20 |
| 155 | | Tehran | Orumie | 22:50 | 01:00 |
| 156 | | Tehran | Ahvaz | 5:35 | 00:50 |
| 157 | | Tabriz | Tehran | 6:00 | 01:00 |
| 158 | | Tehran | Mashhad | 6:05 | 01:20 |
| 159 | | Orumie | Tehran | 6:25 | 01:00 |
| 160 | | Tehran | Tabriz | 6:55 | 01:00 |
| 161 | | Ahvaz | Tehran | 7:17 | 00:50 |
| 162 | | Tehran | Tabriz | 7:57 | 01:00 |
| 163 | | Mashhad | Tehran | 8:20 | 01:20 |
| 164 | | Tehran | Mashhad | 8:55 | 01:20 |
| 165 | 2022/04/15 | Mashhad | Tehran | 9:00 | 01:20 |
| 166 | | Tabriz | Tehran | 9:00 | 01:00 |
| 167 | | Tehran | Esfehan | 9:05 | 01:00 |
| 168 | | Tabriz | Mashhad | 10:00 | 02:00 |
| 169 | | Tehran | Shiraz | 10:40 | 01:20 |
| 170 | | Mashhad | Esfehan | 10:50 | 01:30 |
| 171 | | Tehran | Ahvaz | 11:00 | 00:50 |
| 172 | | Esfehan | Bandarabbas | 11:00 | 01:30 |
| 173 | | Tehran | Mashhad | 11:20 | 01:20 |
| 174 | | Tehran | Kish | 11:20 | 01:45 |
| 175 | | Shiraz | Tehran | 12:50 | 01:20 |
| 176 | | Mashhad | Tabriz | 13:00 | 02:00 |
| 177 | | Ahvaz | Tehran | 13:00 | 00:50 |
| 178 | | Esfehan | Mashhad | 13:10: | 01:30 |
| 179 | | Bandarabbas | Esfehan | 13:20 | 01:30 |
| 180 | | Mashhad | Tehran | 13:40 | 01:20 |
| 181 | | Kish | Tehran | 13:40 | 01:45 |
| 182 | | Tehran | Sabzevar | 15:00 | 01:00 |
| 183 | | Tehran | Kish | 15:00 | 01:45 |
| 184 | | Tehran | Mashhad | 15:00 | 01:20 |
| 185 | | Esfehan | Tehran | 15:40 | 01:00 |
| 186 | | Mashhad | Tehran | 15:40 | 01:20 |
| 187 | | Tabriz | Tehran | 16:00 | 01:00 |
| 188 | | Tehran | Kish | 16:15 | 01:45 |
| 189 | | Sabzevar | Tehran | 16:50 | 01:00 |
| 190 | | Mashhad | Tehran | 17:20 | 01:20 |
| 191 | | Tehran | Orumie | 17:30 | 01:00 |
| 192 | | Kish | Tehran | 17:30 | 01:45 |
| 193 | | Tehran | Qheshm | 17:40 | 01:50 |
| 194 | | Tehran | Tabriz | 18:00 | 01:00 |
| 195 | | Tehran | Shiraz | 18:10 | 01:20 |
| 196 | | Tehran | Bandarabbas | 18:40 | 01:45 |
| 197 | | Kish | Tehran | 18:40 | 01:45 |
| 198 | | Orumie | Tehran | 19:30 | 01:00 |
| 199 | | Tabriz | Tehran | 20:00 | 01:00 |
| 200 | | Shiraz | Tehran | 20:20 | 01:20 |
| 201 | | Tehran | Kish | 20:20 | 01:45 |
| 202 | | Qheshm | Tehran | 20:30 | 01:50 |
| 203 | | Bandarabbas | Tehran | 21:10 | 01:45 |
| 204 | | Tehran | Mashhad | 21:30 | 01:20 |
| 205 | | Tehran | Tabriz | 22:00 | 01:00 |
| 206 | | Kish | Tehran | 22:50 | 01:45 |
| 207 | | Tehran | Orumie | 22:50 | 01:00 |
| 208 | | Tehran | Ahvaz | 5:00 | 00:50 |
| 209 | | Tehran | Tabriz | 5:00 | 01:00 |
| 210 | | Mashhad | Tehran | 5:50 | 01:20 |
| 211 | | Tabriz | Tehran | 6:10 | 01:00 |
| 212 | 2022/04/16 | Orumie | Tehran | 6:28 | 01:00 |
| 213 | | Ahvaz | Tehran | 7:00 | 00:50 |
| 214 | | Tabriz | Tehran | 7:00 | 01:00 |
| 215 | | Tehran | Tabriz | 8:00 | 01:00 |
| 216 | | Tehran | Mashhad | 8:20 | 01:20 |

| | | | | | |
|---|---|---|---|---|---|
| 217 | | Tehran | Ahvaz | 8:50 | 00:50 |
| 218 | | Tehran | Kermanshah | 9:00 | 01:00 |
| 219 | | Tehran | Orumie | 9:05 | 01:00 |
| 220 | | Tehran | Bandarabbas | 9:20 | 01:45 |
| 221 | | Tabriz | Tehran | 10:00 | 01:00 |
| 222 | | Mashhad | Sari | 10:30 | 01:10 |
| 223 | | Ahvaz | Tehran | 10:50 | 00:50 |
| 224 | | Orumie | Mashhad | 11:00 | 02:00 |
| 225 | | Orumie | Tehran | 11:00 | 01:00 |
| 226 | | Kermanshah | Tehran | 11:00 | 01:00 |
| 227 | | Bandarabbas | Mashhad | 12:00 | 02:00 |
| 228 | | Sari | Mashhad | 12:20 | 01:10 |
| 229 | | Tehran | Tabriz | 13:00 | 01:00 |
| 230 | | Tehran | Mashhad | 14:00 | 01:20 |
| 231 | | Mashhad | Orumie | 14:00 | 02:00 |
| 232 | | Tehran | Esfehan | 14:05 | 01:00 |
| 233 | | Mashhad | Esfehan | 14:10 | 01:30 |
| 234 | | Mashhad | Bandarabbas | 14:40 | 02:00 |
| 235 | | Tabriz | Tehran | 16:00 | 01:00 |
| 236 | | Esfehan | Tehran | 16:00 | 01:00 |
| 237 | | Esfehan | Kish | 16:00 | 01:15 |
| 238 | | Tabriz | Istanbul | 16:00 | 01:15 |
| 239 | | Esfehan | Mashhad | 16:20 | 01:30 |
| 240 | | Mashhad | Kish | 16:20 | 02:00 |
| 241 | | Bandarabbas | Tehran | 17:30 | 01:45 |
| 242 | | Tehran | Tabriz | 17:55 | 01:00 |
| 243 | | Kish | Esfehan | 18:00 | 01:15 |
| 244 | | Mashhad | Ahvaz | 18:40 | 00:50 |
| 245 | | Tehran | Kish | 19:05 | 01:45 |
| 246 | | Kish | Mashhad | 19:20 | 02:00 |
| 247 | | Istanbul | Tabriz | 19:30 | 01:15 |
| 248 | | Tabriz | Tehran | 20:00 | 01:00 |
| 249 | | Tehran | Shiraz | 20:10 | 01:20 |
| 250 | | Ahvaz | Mashhad | 21:20 | 01:30 |
| 251 | | Kish | Tehran | 21:30 | 01:45 |
| 252 | | Tehran | Orumie | 21:50 | 01:00 |
| 253 | | Tehran | Tabriz | 22:00 | 01:00 |
| 254 | | Mashhad | Tehran | 22:20 | 01:20 |
| 255 | | Shiraz | Tehran | 22:20 | 01:20 |
| 256 | 2022/04/17 | Tabriz | Tehran | 5:50 | 01:00 |
| 257 | | Tehran | Tabriz | 6:00 | 01:00 |
| 258 | | Mashhad | Qheshm | 6:20 | 02:00 |
| 259 | | Orumie | Tehran | 6:52 | 01:00 |
| 260 | | Tabriz | Mashhad | 7:50 | 02:00 |
| 261 | | Tehran | Tabriz | 7:57 | 01:00 |
| 262 | | Tehran | Ahvaz | 8:30 | 00:50 |
| 263 | | Tehran | Kermanshah | 8:50 | 01:00 |
| 264 | | Qheshm | Mashhad | 9:00 | 02:00 |
| 265 | | Tabriz | Tehran | 9:50 | 01:00 |
| 266 | | Tehran | Qheshm | 9:53 | 01:50 |
| 267 | | Ahvaz | Tehran | 10:08 | 00:50 |
| 268 | | Mashhad | Tabriz | 10:50 | 02:00 |
| 269 | | Kermanshah | Tehran | 10:58 | 01:00 |
| 270 | | Tehran | Tabriz | 11:48 | 01:00 |
| 271 | | Mashhad | Tehran | 11:50 | 01:20 |
| 272 | | Tehran | Mashhad | 12:05 | 01:20 |
| 273 | | Qheshm | Tehran | 12:38 | 01:50 |
| 274 | | Tehran | Esfehan | 13:50 | 01:00 |
| 275 | | Tabriz | Tehran | 14:00 | 01:00 |
| 276 | | Tehran | Ahvaz | 14:10 | 00:50 |
| 277 | | Mashhad | Tehran | 14:20 | 01:20 |
| 278 | | Esfehan | Ahvaz | 15:40 | 00:50 |
| 279 | | Tehran | Kish | 15:50 | 01:45 |
| 280 | | Tabriz | Tehran | 16:00 | 01:00 |
| 281 | | Ahvaz | Tehran | 16:00 | 00:50 |
| 282 | | Tehran | Orumie | 16:00 | 01:00 |
| 283 | | Tehran | Shiraz | 16:40 | 01:20 |
| 284 | | Ahvaz | Esfehan | 17:30 | 00:50 |
| 285 | | Tehran | Mashhad | 17:55 | 01:20 |
| 286 | | Orumie | Tehran | 18:00 | 01:00 |
| 287 | | Tehran | Tabriz | 18:05 | 01:00 |
| 288 | | Kish | Esfehan | 18:20 | 01:15 |
| 289 | | Shiraz | Tehran | 19:00 | 01:20 |
| 290 | | Shiraz | Kish | 19:00 | 01:00 |
| 291 | | Esfehan | Tehran | 19:20 | 01:00 |
| 292 | | Tehran | Abadan | 19:55 | 01:00 |
| 293 | | Tabriz | Tehran | 20:00 | 01:00 |
| 294 | | Mashhad | Ahvaz | 20:10 | 01:30 |
| 295 | | Esfehan | Kish | 20:20 | 01:15 |
| 296 | | Kish | Shiraz | 20:40 | 01:00 |
| 297 | | Tehran | Tabriz | 22:00 | 01:00 |
| 298 | | Kish | Tehran | 22:10 | 01:45 |
| 299 | | Abadan | Tehran | 22:10 | 01:00 |
| 300 | | Ahvaz | Mashhad | 22:50 | 01:30 |

| | | | | | |
|---|---|---|---|---|---|
| 301 | | Tehran | Orumie | 22:50 | 01:00 |
| 302 | | Tehran | Yazd | 4:41 | 01:00 |
| 303 | | Tehran | Tabriz | 4:43 | 01:00 |
| 304 | | Tabriz | Tehran | 5:54 | 01:00 |
| 305 | | Orumie | Tehran | 6:20 | 01:00 |
| 306 | | Yazd | Tehran | 6:40 | 01:00 |
| 307 | | Tabriz | Tehran | 6:45 | 01:00 |
| 308 | | Tehran | Zahedan | 7:20 | 01:50 |
| 309 | | Tehran | Tabriz | 7:54 | 01:00 |
| 310 | | Tehran | Ahvaz | 8:25 | 00:50 |
| 311 | | Tehran | Ardebil | 8:53 | 01:00 |
| 312 | | Tehran | Kermanshah | 9:10 | 01:00 |
| 313 | | Tabriz | Tehran | 10:00 | 01:00 |
| 314 | | Zahedan | Tehran | 10:00 | 01:50 |
| 315 | 2022/04/18 | Ahvaz | Tehran | 10:30 | 00:50 |
| 316 | | Ardebil | Tehran | 11:00 | 01:00 |
| 317 | | Mashhad | Tehran | 11:00 | 01:20 |
| 318 | | Esfehan | Bandarabbas | 11:00 | 01:15 |
| 319 | | Kermanshah | Tehran | 11:00 | 01:00 |
| 320 | | Tehran | Tabriz | 12:00 | 01:00 |
| 321 | | Tehran | Mashhad | 12:30 | 01:20 |
| 322 | | Tehran | Bandarabbas | 13:00 | 01:45 |
| 323 | | Bandarabbas | Esfehan | 13:20 | 01:15 |
| 324 | | Tehran | Esfehan | 13:40 | 01:00 |
| 325 | | Tehran | Kish | 14:05 | 01:45 |
| 326 | | Tehran | Mashhad | 14:10 | 01:20 |
| 327 | | Mashhad | Ahvaz | 15:00 | 01:30 |
| 328 | | Esfehan | Tehran | 15:40 | 01:00 |
| 329 | | Bandarabbas | Tehran | 15:40 | 01:45 |
| 330 | | Tabriz | Tehran | 16:00 | 01:00 |
| 331 | | Mashhad | Tehran | 16:20 | 01:20 |
| 332 | | Kish | Esfehan | 16:40 | 01:15 |
| 333 | | Tehran | Orumie | 17:30 | 01:00 |
| 334 | | Tehran | Tabriz | 18:00 | 01:00 |
| 335 | | Ahvaz | Tehran | 18:00 | 00:50 |
| 336 | | Tehran | Qheshm | 18:40 | 01:50 |
| 337 | | Esfehan | Kish | 18:50 | 01:15 |
| 338 | | Tehran | Shiraz | 19:30 | 01:20 |
| 339 | | Orumie | Tehran | 19:30 | 01:00 |
| 340 | | Tabriz | Tehran | 20:00 | 01:00 |
| 341 | | Tehran | Ahvaz | 20:00 | 00:50 |
| 342 | | Kish | Tehran | 21:00 | 01:45 |
| 343 | | Qheshm | Tehran | 21:30 | 01:50 |
| 344 | | Shiraz | Tehran | 21:50 | 01:20 |
| 345 | | Tehran | Tabriz | 22:00 | 01:00 |
| 346 | | Ahvaz | Mashhad | 22:00 | 01:30 |
| 347 | | Tehran | Orumie | 22:50 | 01:00 |

**APPENDIX 2:** Ata airline air fleets

| Row | Type of air fleet | Number of fleets | Passenger capacity |
|---|---|---|---|
| 1 | Boeing MD-83 | 8 | 170 |
| 2 | Airbus A320 | 3 | 168 |
| 3 | Boeing 737 | 2 | 136 |
| 4 | EMB-145 | 3 | 50 |

## Persian Abstract


**چکیده**

یکی از موضوعاتی که تحقیقات زیادی را در زمینه بهینه‌سازی صنعت هوایی به خود اختصاص داده است به برنامه‌ریزی پروازها، ناوگان هوایی و نحوه ارتباط این دو با یکدیگر مرتبط می‌شود که به اختصار برنامه‌ریزی خطوط هوایی نامیده می‌شود. با وجود اهمیت بسیار بالای این موضوع در سودآوری شرکت‌های هوایی و استفاده مناسب از منابع آن‌ها، پیچیدگی محاسباتی بالای این مدل‌ها سبب تفکیک این مساله به زیرمسائل مجزا و در نتیجه کاهش دقت پاسخ نهایی شده است. تاکنون مقالات زیادی در زمینه‌های مختلف این موضوع منتشر شده است که در بعضی از موارد تلاش برای ایجاد یکپارچگی در فرآیند دیده می‌شود ولی در اکثر آن‌ها نگاه عملیاتی به موضوع وجود نداشته و بعضی از الزامات کلیدی به دلیل ساده‌سازی مدل‌ها مغفول مانده است. در این مقاله مدلی یکپارچه از دو مرحله اصلی برنامه‌ریزی خطوط هوایی شامل تخصیص ناوگان و مسیریابی تعمیرات محور هواپیما ارائه شده و عملکرد این مدل با استفاده از داده‌های واقعی یکی از خطوط هوایی ایران مورد بررسی قرار گرفته است. در ادامه مقایسه عملکرد این مدل با روش عملیاتی شامل حل مرحله به مرحله زیرمسائل و یکی از مقالات جدید و مشابه در این حوزه مورد بررسی قرار گرفته و بهبود نتایج نشان داده شده است. همچنین تحلیل حساسیت مدل نسبت به بعضی از پارامترها انجام شده و صحت عملکرد آن را تایید نموده‌اند.