Int. J. Adv. Eng. Pure Sci. 2024, 36(1): <93-102>
DOI: 10.7240/jeps.1299907

RESEARCH ARTICLE / ARAŞTIRMA MAKALESİ

Optimization of a Mission-Based Flight Priority System

Emine YAYLALI [1], Feride Şüheda YILDIZ [2], Sena KOÇAK [3]

[1]*İstanbul Teknik Üniversitesi (İTÜ), İşletme Fakültesi, Endüstri Mühendisliği Bölümü, İstanbul, Türkiye*

[2]*Boğaziçi Üniversitesi, Mühendislik Fakültesi, Endüstri Mühendisliği Bölümü, İstanbul, Türkiye*

[3]*İstanbul Teknik Üniversitesi (İTÜ), Elektrik Elektronik Fakültesi, Kontrol ve Otomasyon Mühendisliği Bölümü, İstanbul, Türkiye*

Abstract

Purpose: The purpose of this study is to develop a mission-based flight priority system that decides which aircraft would match with which airborne operation, and determines a sequence of take-off for those airplane-operation peers. Both peers and take-off orders are specified by minimizing total operation cost which includes fuel cost, waiting cost and penalty cost for missed missions. The aim of this system is to create a cost effective, fast and efficient decision-making tool for allocating operation-aircraft assignments and determining the sequence of take-off, especially in emergency cases.

***Methodology*:** An integer programming model that minimizes the total cost are formulated. Four scenarios are designed to assess the performance of the system. The system, which includes five aircrafts and ten airborne operations, was revealed in the study. Integer programming is used while modeling the system and the Branch-and-Bound algorithm is used as the solution algorithm. The optimization algorithm was developed in MATLAB.

Findings: Both emergency scenarios and normal scenarios are maintained with the purpose of examining the behaviors and the result of the system under different conditions. It is believed that system have given the appropriate sequence and matchup for air vehicle-operation peers.

Originality: Since the integration of airplane-mission assignment and determining take-off sequence is rare in the literature, our study may be considered as a new approach. Therefore, in order to bring a new perspective, an optimization system related to the determination of flight priority and mission assignment was brought in this study.

Keywords*:* Optimization, Flight priority, Integer programming, Mission-based flight system

I. INTRODUCTION

Air traffic management has firstly emerged in the first decade of the 20th century. The term defines a service with an objective of preventing collisions which include longitudinal, vertical, and lateral separation minima of air vehicles from each other. At the beginning of each flight, the pilot is informed about wind direction and speed, condition of the runway, the existence of other air vehicles in the area by using flashing lights, flags, and radio communications. Due to the rapid increase in air traffic, pilots are needed to be informed about departing and landing processes as well. A sequence for departure and getting permission to take-off from the tower were established in order to make air traffic flow systematically [1] . Nowadays, air traffic control is managed by international rules and procedures.

Air traffic system is a complex system although it has some deterministic features such as having specific flight schedules and defined flight routes. The complexity of the system is coming from unpredictable demand in civil aviation, special flights, instantaneous change in weather conditions and air traffic, and unusual cases resulting from human nature or regulations, etc. In order to deal with the complexity of system, various methods are used in different sections of air traffic management. Taxiing process [2], use of runway [3], landing process [4], flight routes [5], departure trajectories [6], hangar management [7] are examples of improvable parts of air traffic management which are affected by demand uncertainty.

Corresponding Author: Emine Yaylalı, **Tel:** 0212 293 13 00-2073, **e-mail:** emineyaylali@itu.edu.tr

Submitted: 22.05.2023, **Revised:** 01.02.2024, **Accepted:** 27.02.2024

The aim of our study is to develop an optimization model which gives the optimal assignment for airborne operations and aircrafts, and determines the flight priority for air vehicles by minimizing cost and penalties. A mission-based system is used in order to construct a system for air vehicles with different missions and to assign airborne operations to proper aircrafts. Another goal of this study is to provide a take-off order for determined aircraft-airborne operation peers. Although there are some studies on mission prioritization and flight priority, our study is unique in terms of integrating these topics. For any company or hangar, the number of aircrafts, their characteristics and possible operations that each aircraft can handle are known a prior.

Therefore, we developed a deterministic model using integer programming (IP). It is possible to extend the model to a stochastic system to incorporate uncertainty in the type and timing of the operations. Although such system would be better representation of reality, it would be more complex, time-consuming and data required for such model is limited. As a result, the objective of the IP model is to create a useful, cost effective, fast and efficient decision-making tool for the determination of operation-aircraft assignment and sequence of take-off, especially in emergency cases.

In our study, a new approach that combines mission prioritization and flight priority is proposed. This study aims to construct an optimization system that decides both assignment of missions and air vehicles and a departure sequence for those mission-air vehicle sets by minimizing cost. Our tool could be used for air vehicles like unmanned aerial vehicles, airplanes, or helicopters. However, an aircraft is used as a reference case for scenario analysis. Literature review on the air traffic management is conducted and relevant studies with different and similar approaches have been summarized in Section 2. Problem formulation, methodology and specifications of the reference plane are presented in Section 3. Results and case studies are reported in Section 4 and finally, conclusions of our study are summarized in Section 4.

II. LITERATURE REVIEW

Air traffic control is an important and popular topic since it allows to minimize aircraft accidents and cost of air operations. Due to rapid growth in the cargo volume and passenger traffic, air traffic became a more complicated system. The complexity of the system leads to a rise in the number of studies that aims to solve problems in air traffic control [8]. A multi-level model was developed to examine optimization models and algorithms about air traffic in the terminal area. The authors concluded that optimization and control algorithms could be improved with real-life data [9].

Data based control, command techniques, and operator experience are also important components in air traffic management applications. Examples of these applications were explained and classified detail in [10]. Raj and Sheela preferred the neural network concept to construct a model in the air traffic control system [11]. In addition, intelligent prediction and planning algorithms were proposed to prevent airborne delays, provide more-automated air traffic management, and support real-time decisions by using the concept of neural network and machine learning [12].

Air traffic control systems have been studied for improving the traffic flow. Schultz and Reitmann developed an algorithm for forecasting aircraft boarding to ensure better boarding operations via a periodic neural network [13]. Neural networks have been employed in various problems in the air traffic control literature such as runway problem and landing scheduling. Efficient use of runway became more crucial due to the increase in demand. A study that was conducted at Tokyo International Airport focused on predicting landing runways based on actual runway assignment strategy by considering the capacity of airport and workload of controllers with the help of a neural network model [14]. Air traffic, and departure, a simulator via neutral network was designed to control air traffic and landing clearance. In a similar study, artificial neural networks have been applied to maintain the optimal distance between two airplanes during landing [15].

An alternative simulation model was constructed by Netjasov et. al to measure the accurate performance of safety and give essential information in terms of safety feedback. This model, which showed reliable results in different scenarios and air traffic levels, was developed as a network-based model [16]. An advanced smart hybrid model that employed machine learning was developed to deal with the problem of the short-term trajectory prediction which occurs in the terminal maneuvering area [17]. Accurately gathering data on air traffic and weather conditions is a crucial element in decision-making within air traffic management. A study identifying useable and correct information on weather and air traffic was conducted by Gorriparty et. al. In this study, a similarity measure was developed in order to provide reliable data in terms of weather conditions and air traffic by determining similar previous days for the management decisions taken on those days [18].

A fuzzy based approach could also be a good choice for managing the complex air traffic problem. In one of the earlier works, the fuzzy system determined the duration of the waiting time before entering an airport approach corridor [19]. Another study examined the control problem for the airplane speed by using the fuzzy approach with the purpose of improving safety and decreasing the stress level of the controller [20]. An intelligent fuzzy based model was designed to prevent airplane accidents and to develop advanced air traffic control by Idika and Baridam [21] . Furthermore, the fuzzy management of different air vehicles types was conducted by Jenab and Pineau [22].

Optimization techniques were adapted for problems in different areas of air traffic control. A mixed integer programming was developed for minimizing the time that a passenger spends while catching connection flights by Xu. Xu also used a tabu search algorithm for solving this MIP model [23]. Dell' Olmo & Lulli improved a new two-level hierarchical architecture for optimizing air traffic management problems via mixed integer programming and heuristic algorithm [24].

One of the major challenges in air traffic management is the struggle to keep up with increasing demand due to the rapid growth in air traffic. An integer optimization model was proposed to handle the situation of meeting the increasing demand in air traffic management by using Dantzig-Wolfe decomposition and a heuristic approach [25]. Another study suggested that developing a new combinatorial optimization model for air traffic management gives a more realistic view of parameters like air sector configuration and penalizations [26].

Our study is closely related to the mission and flight priority-based literature and cost-effective models. One study that is close to our work is about mission prioritization in unmanned aerial vehicles, where an optimization system was built in order to give UAVs flight permission according to their missions by considering weather risk analysis [27]. For the flight priority problem, a collaborative optimization model was improved and a genetic algorithm was used for finding a better taxi route for aircraft [28].

Flight priority problem can be extended to a hangar management system as suggested by Qin et al in 2018. In this system, a cost-based maintenance priority for aircrafts which are located in a constant capacity hangar was modeled. The model and parking stand allocation problem was solved by proposing a two-stage mixed integer programming model [29]. In terms of mission-based systems, Peng et al. proposed a model for determining optimal routing of missions while minimizing the cost of unvisited targets and experiencing shocks in unmanned aerial vehicles [30].

Numerous studies have explored into various aspects of air traffic management, including flight planning, flight and taxi route optimization, maintenance scheduling, parking allocation, and more, employing a variety of algorithms and modeling techniques. However, the existing body of literature predominantly focuses on optimizing civil aviation flights. In contrast, limited research has been conducted on the allocation of tasks to aircraft and the prioritization of takeoff procedures. Thus, our objective is to shed light on this research gap by developing a flight takeoff decision-making system that can be applied to a diverse range of aircraft types including unmanned aerial vehicles.

III. METHODOLOGY

The objective of the problem is to find the best aircraft-operation peers and to provide a proper take-off order for the peers by minimizing the total cost which includes fuel cost, a penalty cost for missed missions and idle cost (i.e., waiting cost for aircrafts in the hangar). The problem is formulated as an integer programming model.

Constraints, parameters, and the objective function of the system are summarized below. The related parameters are estimated from data for Cessna 172S which is selected as a representative aircraft in this study due to its common use in mission-related operations such as firefighting, training and emergency work [31]. Table 1 indicates the characteristics of Cessna 172S.

Table 1: Specifications of Cessna 172S Skyhawk

Feature	Value
Empty Weight	761.8 kg
Gross Weight	1162.7 kg
Usable fuel quantity	213 liters
Cruise Speed	229 km/h
Stall Speed	89 km/h
Never exceed speed	302 km/h
Maximum range	6.7 s
Range	1182 km
Service ceiling	4267.2 m
Rate of climb	3.86 m/s
Wing Loading	71.77 kg/m2
References: (Cessna, 1998)	

Missions are selected from real airborne operations of Cessna 172S Skyhawk [31]. The representative aircraft has 10 operations that can be performed. Furthermore, we classified all operations to have a mission number that represents priority level of the operation for the aircrafts. For instance, the most crucial mission is air ambulance service while the least essential one is aerial survey. Therefore, operation priority level (OPL) of air ambulance service is 10, while operation priority level of aerial survey is 1. The list of airborne operations and their importance level are displayed at Table 2.

Table 2. Airborne Operations and Importance Level

Airborne Operation	OPL
Aerial survey	1
Parachute operation	2
Float operation	3
Training	4
Surveillance and reconnaissance	5
Utility/Transport	6
Carrying ammunition	7
Search and rescue	8
Firefighting	9
Air ambulance service	10

3.1 Model Formulation

We formulated an integer programming model for a flight priority system with 5 air vehicles and 10 missions. Constraints, parameters and objective function of the model are presented in the below subsections.

3.1.1 Constraints

(a) There are i=5 aircrafts and j=10 operations in the system, and only 1 plane- mission peer is matched in each run.

(b) Only one air vehicle can take-off for each run.

(c) All air vehicles may not be able to perform all missions because of design and properties required for each mission. For instance, firefighting air vehicles require additional design features to store water and chemicals. Therefore, we determined a mission matrix that provides information on which operation(s) can be performed by which plane(s). However, due to unbalance between the number of missions and planes, we assumed that all planes can perform 4 missions.

(d) The fuel of the air vehicle should be equal to or greater than the required amount of fuel for the mission. Otherwise, the air vehicle is not allowed to take-off.

3.1.2 Parameters

i denotes the number of air vehicle, i = 1,2,3,4,5

j denotes the number of missions, j = 1,2,3,4,5,6,7,8,9,10

G_{ij} denotes the mission matrix where 1 represents that ith plane can perform jth mission and vice versa.

$$G_{ij} = \begin{bmatrix} 1 & 1 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 & 1 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 & 1 & 1 & 0 & 1 & 0 \\ 1 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

ALT_{ij} = Average altitude ith plane uses while performing jth mission

RPM_{ij} = Average revolution per minute ith plane uses while performing jth mission

OH_{ij} = Operation hour of ith plane for jth mission

UFQ_{ij}= Usable fuel quantity of ith plane (liter)

RFQ_{ij} = the required amount of fuel of ith plane in order to perform one hour of jth mission. This parameter is found by using the altitude-rpm-fuel amount equation. The equation is constructed by performing regression analysis on a given set of real-life data. The regression line is multiplied by a constant in order to transform galloon to liter and by operation hour to find the total required fuel quantity of the selected airborne operation. The equation for RFQ is

$$\boldsymbol{RFQ_{ij} = [-9.38043 - 0.00018 * ALT_{ij} + 0.00779 * RPM_{ij}] * OH_{ij} * 3.78541} \quad \textbf{(1)}$$

DSH_i = waiting time of ith plane in the hangar (hr.)

OPL_j = operation priority level of mission j, same with j index; if j is 1 it means OPL of that mission is also 1.

K = fuel price per gallon.

3.1.3 Costs

Costs included in the model are (a) mission penalty cost, (b) fuel cost of a mission, and (c) cost of spending time in the hangar (i.e., idle cost). Due to magnitude difference among these three types of costs, we normalized each cost.

3.1.3.1 Mission Penalty Cost

This cost represents the penalty of missing missions which could be missed due to impracticality of the mission or lack of airplanes to perform the mission. Unperformed mission means that an air vehicle has the ability to perform this mission but does not operate this mission. Since OPL can take at most 10, which is highest priority level, the penalty cost of that type of mission is formulized by dividing OPL by 10 for normalization. Impracticable mission means that an air vehicle does not have the ability to perform this mission. It is denoted by P_{ij} which is the cost of the plane i for not going to mission j.

The penalty cost is where mission prioritization is put into practice. By utilizing operation priority levels (OPL) and the formulated penalty cost for unperformed missions as described below, we ensure that missions with higher priority, characterized by a higher OPL, are seldom overlooked.

Penalty cost of impracticable missions:

$$P_{1j} = M \; for \; j \neq \{1, 2, 5, 8\} \quad (2)$$

$$P_{2j} = M \; for \; j \neq \{3, 4, 6, 8\} \quad (3)$$

$$P_{3j} = M \; for \; j \neq \{2, 6, 7, 10\} \quad (4)$$

$$P_{4j} = M \; for \; j \neq \{4, 6, 7, 9\} \quad (5)$$

$$P_{5j} = M \; for \; j \neq \{1, 4, 5, 10\} \quad (6)$$

where M is a very large number

Penalty cost of unperformed missions:

$$P_{1j} = OPL_j/10 \; for \; j = \{1, 2, 5, 8\} \quad (7)$$

$$P_{2j} = OPL_j/10 \; for \; j = \{3, 4, 6, 8\} \quad (8)$$

$$P_{3j} = OPL_j/10 \; for \; j = \{2, 6, 7, 10\} \quad (9)$$

$$P_{4j} = OPL_j/10 for \; j = \{4, 6, 7, 9\} \quad (10)$$

$$P_{5j} = OPL_j/10 for \; j = \{1, 4, 5, 10\} \quad (11)$$

3.1.3.2 Fuel Cost

Fuel cost is calculated by multiplying required fuel quantity by the amount of dollars per gallon (K). However, as mentioned earlier, that all costs are normalized. Therefore, to normalize it, fuel cost is divided by maximal usable fuel quantity of plane since the required amount of fuel cannot exceed the maximal usable fuel quantity. Since K is placed in both nominator and denominator of the equation it is eliminated. F_{ij} means fuel cost of i^{th} plane performing j^{th} mission.

$$F_{ij} = \frac{RFQ_{ij}}{UFQ_{max}} \quad (12)$$

3.1.3.3 Waiting Cost (Idle Cost)

An airplane that spends much more time in the hangar than the other planes have priority over mission assignments and possible take-off. To represent this intangible cost, we decreased total cost with time spent in the hangar. In other words, the total cost of an airplane is reduced if this plane is not assigned to a mission and stays idle in the hangar. We used a normalization constant of 15 to enable mission cost to have a higher weight in the total cost than the waiting cost. That means we prefer to perform the more important missions than allowing idle planes to be assigned to missions. W_i denotes the waiting cost of plane *i*.

$$W_i = \frac{DSH_{ij}}{15} \quad (13)$$

3.2 Integer Programming Model

x_{ij} is the decision variable where 1 denotes that plane i takes off for mission j.

Objective function of the model is to minimize the total cost as formulated below.

$$\min z = \sum_i \sum_j \left[(1 - x_{ij}) * P_{ij} + F_{ij} * x_{ij} - W_i * (1 - x_{ij}) \right] \quad (14)$$

Constraints of the IP model are presented below.

- Constraint (1) enables to assign every mission to only one airplane:

$$\sum_{i=1}^{5} \sum_{j=1}^{10} (x_{ij}) = 1 \quad (15)$$

- Constraint (2) enables to assign missions to planes according to the mission matrix, i.e., if a plane cannot conduct a type of mission, it will never be assigned that type of mission:

$$G_{ij} \geq x_{ij} \qquad \forall \, i, j \quad (16)$$

- Constraint (3) allows the model to assign planes to the mission if they have enough fuel for the mission:

$$RFQ_{ij} * x_{ij} \leq UFQ_i \qquad \forall \, i, j \quad (17)$$

- Binary constraint is defined as:

$$x_{ij} = \{0, 1\} \qquad \forall \, i, j \quad (18)$$

3.3 Altitude-RPM-fuel Equation and Regression Analysis

One of the constraints in the system defines the relationship between altitude-operation time-fuel consumption. This relationship is important in our model because air vehicle that is out of the range cannot get permission to take off. Therefore, we need to define an appropriate relationship between those three values. A relationship for altitude-operation time-fuel is shown in Figure 1. The table includes altitude values between 2000 and 12000 (units). Each altitude is matched with RPM values which are represented by multiples of 100 between the ranges of 2300 and 2500 (units). Figure 1 gives necessary fuel quantity that an air vehicle should have under the condition of an altitude, RPM, and temperature.

Sub-values for altitude (i.e., ALT = 2500 or 3000) and RPM (i.e., 2550) that are not in the table are interpolated. We utilized regression analysis to develop a relationship between altitude, RPM and fuel use. Using 105 data points that connect galloon per hour (GPH) values for each RPM-ALT peer, the following regression line was determined. This equation has been used in the equation (1) which is a part of the objective function.

$$\boldsymbol{G} = [-\mathbf{9.38043} - \mathbf{0.00018} * \mathbf{ALT} + \mathbf{0.00779} * \mathbf{RPM}] \quad \mathbf{(19)}$$

PRESS ALT FT	RPM	20°C BELOW STANDARD TEMP			STANDARD TEMPERATURE			20°C ABOVE STANDARD TEMP		
		% BHP	KTAS	GPH	% BHP	KTAS	GPH	% BHP	KTAS	GPH
2000	2550	83	117	11.1	77	118	10.5	72	117	9.9
	2500	78	115	10.6	73	115	9.9	68	115	9.4
	2400	69	111	9.6	64	110	9.0	60	109	8.5
	2300	61	105	8.6	57	104	8.1	53	102	7.7
	2200	53	99	7.7	50	97	7.3	47	95	6.9
	2100	47	92	6.9	44	90	6.6	42	89	6.3
4000	2600	83	120	11.1	77	120	10.4	72	119	9.8
	2550	79	118	10.6	73	117	9.9	68	117	9.4
	2500	74	115	10.1	69	115	9.5	64	114	8.9
	2400	65	110	9.1	61	109	8.5	57	107	8.1
	2300	58	104	8.2	54	102	7.7	51	101	7.3
	2200	51	98	7.4	48	96	7.0	45	94	6.7
	2100	45	91	6.6	42	89	6.4	40	87	6.1
6000	2650	83	122	11.1	77	122	10.4	72	121	9.8
	2600	78	120	10.6	73	119	9.9	68	118	9.4
	2500	70	115	9.6	65	114	9.0	60	112	8.5
	2400	62	109	8.6	57	108	8.2	54	106	7.7
	2300	54	103	7.8	51	101	7.4	48	99	7.0
	2200	48	96	7.1	45	94	6.7	43	92	6.4

Figure 1. Cessna 172S Performance Table (Kaynak: [32]**)**

3.4 Solution Algorithm

The IP model was created in MATLAB primarily using “intlinprog” function and Branch-and-Bound technique. Two main input parameters of the IP are plane and mission. Planes are identical and have a constant number of 5, while there are 10 possible missions in the system. Since there are only 5 planes in the system, the maximum number of missions that can be completed in short-time intervals could be at most 5 missions. In this study, four case scenarios are determined and missions in each scenario were input to the IP model. Scenarios and the selection of the related missions are explained in Section 4 in detail.

Parameters such as ALT, RPM, OH and UFQ could take any values within given intervals. These intervals vary according to the type of air vehicle. Therefore, we determined intervals for these parameters according to the specification of the sample plane. Then, the model utilizes uniform random distribution for selected intervals of RPM, OH and UFQ. For ALT values, we categorized four sub-intervals as high-altitude (HA), medium-altitude (MA), low-altitude (LA) and no limit (NL) with respect to the operation type. The reason behind this categorization is that different operations require different flight altitudes. For instance, a float operation requires low-altitude while carrying ammunition operation requires high-altitude. Operations and corresponding ALT values are given in Table 3. While we used uniformly distributed parameters in our model for simplicity, other probability distributions could also be utilized.

Table 3. Operations and Corresponding ALT Values

Operations and ALT intervals	Operation Type	Max ALT	Min ALT
HA	Aerial survey	9000	12000
HA	Parachute operation	9000	12000
LA	Float operation	2000	5000
NL	Training	2000	12000
MA	Surveillance and reconnaissance	5000	9000
MA	Utility/ Transport	5000	9000
HA	Carrying ammunition	9000	12000
LA	Search and rescue	2000	5000
MA	Firefighting	5000	9000
MA	Air ambulance service	5000	9000

The ranges of DSH are assumed to be 0 to 5 (units). The initial DSH values for all planes are uniformly distributed. DSH is updated every 30 minutes for every plane. The algorithm increases the DSH of the plane that does not take-off by 0.5 hours. DSH has a negative effect on the cost. It means that if the plane has been in the hangar more than other planes, then it has more priority than others.

The algorithm works iteratively, i.e., if the system has n missions, then the algorithm runs n times. In each run, the algorithm results one mission-plane peer which has the lowest cost. If remaining missions and planes cannot be paired-off due to infeasibility, the algorithm results with no solution.

IV. FINDINGS

The application section is constructed by conducting various scenarios. Scenarios, which are made according to different circumstances, are conducted to analyze and interpret relationships between parameters and results of the model. Tables are built in order to represent the value of parameters clearly, however, all parameters are not given in the table to prevent the complexity and to increase the clarity of scenarios. ALT, RFQ, UFQ, DSH, and missions are indicated in the tables. While determining scenarios, it is considered whether they can be observed and applied in real life. Scenarios may be listed as; dispatching soldiers, fire outbreak, combination of different scenarios, and earthquake disaster.

4.1 Scenario 1: Dispatching Soldiers

In dispatching soldiers scenario, the operations that will be required are determined as parachute operation, carrying ammunition and surveillance & reconnaissance. Parachute operation is needed to land the soldiers into the area, carrying ammunition provides transportation of required ammunition and utility, and thanks to surveillance & reconnaissance operation area control and security are ensured. Mission numbers, which are 2, 7, and 5 respectively, are entered into the system. Table 4 gives the required parameters and their values. The system gives the result one by one as:

- Plane 4 takes-off to perform mission 7.
- Plane 1 takes-off to perform mission 5.
- Plane 3 takes-off to perform mission 2.

Table 4. Information for Scenario 1

	RFQ			UFQ	DSH
	Mission				
Air Vehicle	2	5	7		
1	128.04	134.74	1000	179	4.11
2	1000	1000	1000	103	3.92
3	65.15	1000	172.63	131	3.83
4	1000	1000	96.43	105	1.10
5	1000	156.02	1000	110	1.62

When Table 4 is analyzed, it is seen that $RFQ_{3,2}$ is less than first and second aircraft-operation peers and DSH_3 is relatively high, so plane 3-mission 2 peer has the cost decreasing features. Nevertheless, it gets permission to take-off lastly since in such a match operation priority level, which is 2, is extremely small to take-off firstly. Therefore, despite the presence of cost-decreasing factors, the cost of the last peers is still higher than that of the first and second peers. The 4th aircraft takes off firstly with operation 7, since $RFQ_{4,7}$ is less and operation number is greater than other peers, so that match has the least cost. In addition, when a real dispatching soldiers scenario appears, surveillance & reconnaissance operation would probably be performed before parachute operation to provide safety of the area. Accordingly, the relationship between operation priority level and other parameters, and impact of OPL, in a different meaning mission cost, on the result is clearly seen. Also, the system gives logical results in terms of take-off order.

4.2 Scenario 2: Fire Outbreak

In a fire outbreak case, the need for firefighting operation is obvious. Air ambulance may also be required in the case of injury or death. Lastly, utility/transport airborne operation could be used in order to carry medical stuff and humanitarian needs. Mission numbers 9, 10, and 6, respectively, were entered into the system. The values of the parameters are demonstrated in Table 5 and the result was received as:

- Plane 5 takes-off to perform mission 10.
- Plane 4 takes-off to perform mission 9.
- Plane 3 takes-off to perform mission 6.

Table 5. Information for Scenario 2

	RFQ			UFQ	DSH
	Mission				
Air Vehicle	6	9	10		
1	1000	1000	1000	139	2.06
2	76.78	1000	1000	193	2.65
3	21.79	1000	142.81	166	0.60
4	224.82	36.19	1000	162	1.73
5	1000	1000	74.31	203	4.05

In this system, RFQ has a crucial impact due to directly affecting fuel cost. Thereby, the system tends to give priority aircraft-operation peers that have least RFQ values. Nevertheless, since there are other parameters influencing the cost, impact of RFQ could be decreasing in some cases. $RFQ_{3,6}$ is the least one among other peers, however aircraft 3-mission 6 peer takes-off lastly. The result of that is DSH of the third plane is extremely small and OPL of the sixth mission is the least. When first and second mission-plane peers are examined, it is seen that although the importance of missions is close and RFQ for the first peer is greater than the second peer, plane 5 takes-off first with mission 10. The reason behind this is DSH of the first peer is much greater than the second peer. Therefore, the effect of DSH on RFQ and OPL are shown in that scenario.

4.3 Scenario 3: Combination of Different Cases

This scenario is different from the others in terms of not requiring more than one plane for one case. One circumstance, like fire outbreak, includes more than one operation, like firefighting, transportation, and air ambulance, and thereby requires more than one aircraft in the previous two scenarios. Nevertheless, in this scenario, it is assumed that only one plane can be operated and there is no need for multiple planes simultaneously on the air for any scenarios. Those circumstances are training, fishery survey, that is performed by aerial survey operation, and agriculture irrigation being fulfilled by firefighting plane. As a result, 4, 1, and 9 operation numbers were given to the system. While parameters are indicated in Table 6, the result is determined as:

- Plane 2 takes-off to perform mission 4.

- Plane 4 takes-off to perform mission 9.
- Plane 1 takes-off to perform mission 1.

Table 6. Information for Scenario 3

Air Vehicle	RFQ Mission 1	4	9	UFQ	DSH
1	128.04	1000	1000	139	0.87
2	1000	24.84	1000	193	3.83
3	1000	1000	1000	166	1.30
4	1000	124.94	103.08	162	0.71
5	114.92	156.31	1000	203	3.23

There is a noticeable difference between operation importance level in this scenario. Hence, it is expected that agriculture irrigation operation, which has operation number 9, gets permission to take-off firstly according to mission prioritization. Nevertheless, operation 9 can be performed by only aircraft 4, and there is extremely high difference of RFQ values among peers (for example, $RFQ_{4,9}$ is 103.0787 while $RFQ_{2,4}$ is 24.84). Since the system was also constructed based on minimizing cost, the least fuel cost and highest waiting time have caused the cost to decrease in the case of mission 4-aircraft 2 peer. Furthermore, plane 2 has permission to the first departure for mission 4, then plane 4 with mission 9, and lastly the combination of plane 1 and mission 1. Finally, according to this scenario the importance and the impact of RFQ on operation priority level is revealed.

4.4 Scenario 4: Earthquake

An earthquake requires air ambulance in order to arrive quickly in the area in case of injury and death, search and rescue operation in case of missing and being trapped in the wreckage, and utility/transport for receiving humanitarian aids and medical stuff. Operation numbers for those missions are 10, 8, and 6, respectively. After mission numbers are entered into the system, the solution appeared as

- Plane 1 takes-off to perform mission 8.
- Plane 5 takes-off to perform mission 10.
- Plane 4 takes-off to perform mission 6.

Table 7. Information for Scenario 4

Air Vehicle	RFQ Mission 6	8	10	UFQ	DSH
1	1000	138.21	1000	184	4.54
2	76.81	161.82	1000	125	1.90
3	187.19	1000	199.82	107	2.24
4	99.43	1000	1000	186	3.59
5	1000	1000	162.45	175	2.64

The required value for parameters is indicated in Table 7. The effect of duration spent in the hangar on the operation priority level can be seen in this scenario. While mission 10 exhibits a higher OPL than mission 8 and their RFQs are in closer proximity due to the significantly reduced waiting time for operation 10 - Plane 5 compared to operation 8 - Plane 1, resulting in the former receiving takeoff permission sooner. Search and rescue plane take-off firstly, then air ambulance goes after it, and lastly utility/transportation operation makes departure. The flight order determined by the system closely mirrors real-world logic. In the event of an earthquake, both air ambulance and search and rescue planes may need to take off first. However, our system carefully analyzes all available data to determine the initial departure sequence.

V. CONCLUSION AND DISCUSSION

Air traffic management is a complex system which consists of various fields such as ground control, air control, landing and departure process, mission assignments, aircraft maintenance arrangement, determining flight schedule, etc. While our study reviewed numerous existing studies, it's worth noting that flight priority and mission assignment, in comparison to other areas, have received relatively limited attention.Therefore, our study brings a new approach to air traffic management in terms of integrating mission assignment and flight priority.

A decision-making tool is developed in order to assign the airborne operation to an aircraft and to determine an appropriate take-off order for assigned aircraft-operation peers. The objective of the optimization system while performing processes is minimizing cost. Different kinds of costs and parameters were selected in the modeling phase of the system. Cessna 172S Skyhawk was selected as sample aircraft in order to clearly specify the parameters and to provide real airborne operations. Five planes and ten operations were selected for the construction of the optimization system. The decision variable of the system is composed of binary variables, thereby pure integer programming was selected as the modeling technique of the system. We utilized MATLAB to construct the solution algorithm, employing the "intlinprog" function with a Branch-and-Bound solution algorithm during this phase.

We generated scenarios to analyze, evaluate, and provide recommendations on the system's ability to meet expectations. These scenarios involve actual airborne operations and could potentially manifest in real-life situations. Dispatching soldiers, fire outbreak, the combination of different cases that are fishery survey, agriculture irrigation and training, and earthquake disaster are the constituted scenarios. The value of the parameters and results have been indicated by tables in the application phase. Scenarios have shown the relationship between parameters, and how those parameters and costs affect the decision of the system. It is thought that applications have given the logical results, and have met the expectations. Therefore, we expect that our model can be used as a decision-making tool in emergency cases.

While the model has been demonstrated for one type of aircraft, it is possible to use this model for other aircrafts and unmanned aerial vehicles. The usage of unmanned aerial vehicles is dramatically increased in recent years and swarm drone concepts are commonly used for defense and surveillance operations. There is a potential for drone-related applications of our model and the benefit of our model would be providing a fast, reliable and quantitative decision-making system for the flight takeoff problem. Limitations of our model includes the lack of a time dimension, deterministic nature of mission information (requiring prior knowledge of all missions and their OPLs) and, the absence of support for simultaneous takeoffs.

Since this study is a new approach in its field there also exist some improvements in the study. The number of aircraft might be increased to provide more balance between the number of operations and aircrafts. Furthermore, weather conditions, damaged, and maintenance of aircrafts can be considered to apply this study in real life. Nevertheless, we believe that the objective being identified at the beginning of the study has been accomplished.

Acknowledgements

This study is supported by Turkish Aerospace Industries LIFT UP ’20 programme. We would like to thank Turkish Aerospace Industries (TAI) for their support and contribution to our study.

REFERENCES

[1] “History of Air Traffic Control | USCA.” https://www.usca.es/en/profession/history-of-air-traffic-control/ (accessed Jul. 02, 2020).

[2] Y. Zhang and Q. Wang, “Methods for determining unimpeded aircraft taxiing time and evaluating airport taxiing performance,” *Chinese J. Aeronaut.*, 2017, doi: 10.1016/j.cja.2017.01.002.

[3] H. Feuser Fernandes and C. Müller, “Optimization of the waiting time and makespan in aircraft departures: A real time non-iterative sequencing model,” *J. Air Transp. Manag.*, 2019, doi: 10.1016/j.jairtraman.2019.101686.

[4] A. Salehipour, “An algorithm for single- and multiple-runway aircraft landing problem,” *Math. Comput. Simul.*, 2020, doi: 10.1016/j.matcom.2019.10.006.

[5] V. Ho-Huu, S. Hartjes, H. G. Visser, and R. Curran, “An optimization framework for route design and allocation of aircraft to multiple departure routes,” *Transp. Res. Part D Transp. Environ.*, 2019, doi: 10.1016/j.trd.2019.10.003.

[6] M. Zhang, A. Filippone, and N. Bojdo, “Multi-objective optimisation of aircraft departure trajectories,” *Aerosp. Sci. Technol.*, 2018, doi: 10.1016/j.ast.2018.05.032.

[7] V. Karpov, A. Panin, and A. Semenov, “Calculation of Reliability of Hangars for Parking and Maintenance of Vehicles,” 2017, doi: 10.1016/j.trpro.2017.01.014.

[8] L. Bianco and M. Bielli, “Air traffic management: Optimization models and algorithms,” *J. Adv. Transp.*, vol. 26, no. 2, pp. 131–167, 1992, doi: 10.1002/ATR.5670260205.

[9] H. Balakrishnan, “Control and optimization algorithms for air transportation systems,” *Annu. Rev. Control*, 2016, doi: 10.1016/j.arcontrol.2016.04.019.

[10] H. Idris, “Human-Centered Automation of Air Traffic Control Operations in the Terminal Area,” MIT, 1994.

[11] N. Raj and G. Sheela K, “Intelligent Air Traffic Control using Neural Networks,” *IJSTE - International J. Sci. Technol. Eng.*, 2016.

[12] J. Nogami, S. Nakasuka, and T. Tanabe, “Real-Tıme Decısıon Support For Aır Traffıc Management, Utılızıng Machıne Learnıng,” *Control Eng. Pract.*, vol. 4, no. 8, pp. 1129–1141, 1996.

[13] M. Schultz and S. Reitmann, “Machine learning approach to predict aircraft boarding,” *Transp. Res. Part C Emerg. Technol.*, 2019, doi: 10.1016/j.trc.2018.09.007.

[14] Y. Nakamura, R. Mori, H. Aoyama, and H. Jung, “Modeling of Runway Assignment Strategy by Human Controllers using Machine Learning,” 2017, doi: 10.1109/DASC.2017.8102099.

[15] V. B. Kulkarni, “Intelligent air traffic controller simulation using artificial neural networks,” *2015 Int. Conf. Ind. Instrum. Control. ICIC 2015*, pp. 1027–1031, Jul. 2015, doi: 10.1109/IIC.2015.7150897.

[16] F. Netjasov, D. Crnogorac, and G. Pavlović, “Potential safety occurrences as indicators of air traffic management safety performance: A network based simulation model,” *Transp. Res. Part C Emerg. Technol.*, vol. 102, no. March, pp. 490–508, 2019, doi: 10.1016/j.trc.2019.03.026.

[17] Z. Wang, M. Liang, and D. Delahaye, “A hybrid machine learning model for short-term estimated time of arrival prediction in terminal manoeuvring area," *Transp. Res. Part C Emerg. Technol.*, 2018, doi: 10.1016/j.trc.2018.07.019.

[18] S. Gorripaty, Y. Liu, M. Hansen, and A. Pozdnukhov, "Identifying similar days for air traffic management," *J. Air Transp. Manag.*, vol. 65, pp. 144–155, 2017, doi: 10.1016/j.jairtraman.2017.06.005.

[19] J. R. Clymer, "Induction of fuzzy rules for air traffic control," *Proc. IEEE Int. Conf. Syst. Man Cybern.*, vol. 2, pp. 1495–1502, 1995, doi: 10.1109/icsmc.1995.537984.

[20] A. V Lovato, J. D. S. Silva, and E. Araujo, "Airplane Speed Control: A Fuzzy Logic Approach," 2004, Accessed: Jun. 22, 2020. [Online]. Available: https://www.researchgate.net/publication/249783005_Airplane_Speed_Control_A_Fuzzy_Logic_Approach.

[21] N. Idika and B. B. Baridam, "(PDF) An Intelligent Air Traffic Control System using Fuzzy Logic Model.," *Int. J. Appl. Inf. Syst.*, vol. 12, no. 11, 2018, Accessed: Aug. 21, 2021. [Online]. Available: https://www.researchgate.net/publication/340166411_An_Intelligent_Air_Traffic_Control_System_using_Fuzzy_Logic_Model.

[22] K. Jenab and J. Pineau, "Automation of Air Traffic Management Using Fuzzy Logic Algorithm to Integrate Unmanned Aerial Systems into the National Airspace," *Int. J. Electr. Comput. Eng.*, vol. 8, no. 5, p. 3169, 2018, doi: 10.11591/ijece.v8i5.pp3169-3178.

[23] J. Xu and G. Bailey, "The Airport Gate Assignment Problem: Mathematical model and a tabu search algorithm," *Proc. Hawaii Int. Conf. Syst. Sci.*, 2001, doi: 10.1109/HICSS.2001.926327.

[24] P. Dell'Olmo and G. Lulli, "A new hierarchical architecture for air traffic management: Optimisation of airway capacity in a free flight scenario," *Eur. J. Oper. Res.*, 2003, doi: 10.1016/S0377-2217(01)00394-0.

[25] X. Diao and C. H. Chen, "A sequence model for air traffic flow management rerouting problem," *Transp. Res. Part E Logist. Transp. Rev.*, 2018, doi: 10.1016/j.tre.2017.12.002.

[26] D. García-Heredia, A. Alonso-Ayuso, and E. Molina, "A Combinatorial model to optimize air traffic flow management problems," *Comput. Oper. Res.*, vol. 112, 2019, doi: 10.1016/j.cor.2019.104768.

[27] D. M. (Grand F. Salentiny and N. Mewes, John S. (Mayville, "Mission Prioritization and Work Order Arrangement for Unmanned Aerial Vehicles and Remotely-Piloted Vehicles," 2016.

[28] Y. Jiang, Z. Liao, and H. Zhang, "A collaborative optimization model for ground taxi based on aircraft priority," *Math. Probl. Eng.*, vol. 2013, pp. 1–9, 2013, doi: 10.1155/2013/854364.

[29] Y. Qin, F. T. S. Chan, S. H. Chung, T. Qu, and B. Niu, "Aircraft parking stand allocation problem with safety consideration for independent hangar maintenance service providers," *Comput. Oper. Res.*, vol. 91, pp. 225–236, 2018, doi: 10.1016/j.cor.2017.10.001.

[30] R. Peng, "Joint routing and aborting optimization of cooperative unmanned aerial vehicles," *Reliab. Eng. Syst. Saf.*, 2018, doi: 10.1016/j.ress.2018.05.004.

[31] P. A. Bedell, "Cessna Skyhawk SP," 1998. AOPA. https://www.aopa.org/news-and-media/all-news/1998/september/pilot/cessna-skyhawk-sp

[32] "Cessna 172 S (PH-HBW) Difference Training document compared to C172R (OOCVE) model," [Online]. Available: http://www.ebzr.be/wp-content/uploads/2018/07/APCK_differences_Cessna_172_S_and_R_document.pdf.