Multi-Objective Modeling for Airlines Cooperation by Game Theory and Sustainable Development Approaches

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Abstract

In each time period, the passengers' demand for each route is finite and airlines compete for earning more profits. The complex competition among airlines causes some problems, such as complicating flight planning and increasing empty seats for some routes. These problems increase air pollution and fuel consumption. To solve these problems, this research studies the cooperation of the airlines with game theory and sustainable development app.roaches. To investigate the issue, the three steps are suggested as introducing the components of the multi-attribute game theory to the multi-objective model, modeling multi-objective formulation with a sustainable development app.roach, and solving the model by a multi-objective method. Pay-off functions are to maximize the profit of airlines, minimize the total difference among the No.s of flier passengers and their demand on all routes and all flight times, and minimize empty seats. All the above-mentioned objectives present economic, social, and environmental aspects of sustainable development. The results of the airline cooperation model are compared with the information about non-cooperation collected from airlines in the current form. The cooperation of airlines can improve the objective functions and the sustainable development app.roach. This research can be used to help airlines in identifying the role of cooperation in air transportation.

Keywords: Airline; multi-objective model; cooperation; game theory; sustainable development.

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1. Introduction

Air transportation should be reliable, effective, and safe. At the beginning of the air transportation market, airlines begin serving clients in different routes. An increase in transportation causes problems, such as traffic congestion, air pollution and transportation cost. Also, development of air transportation presents new challenges related to the aviation and airlines. Airlines play a crucial role in reducing costs and attracting passengers. Nowadays, airlines compete for providing better services to passengers and earning more profits.

There are a lot of definitions of sustainability; however, they are scattered in different sources of information. There are not fully defined in literature principles of sustainable development of public transport systems [Patlins, 2017]. The sustainable development app.roach seeks to strike a balance among economic, environmental, and social factors (namely, sustainability) in present and future. It also finds solutions to reduce complications from different sections. Furthermore, the cooperation of the airlines can affect economic, environmental, and social factors, so a sustainable development app.roach is studied in this research. The concept of sustainable development is a kind of effort to compound the growing concepts in the field of environmental issues along with social and economic issues.

In this research, “cooperation” means promoting economic and national market share agreement on joint exploitation of opp.ortunities for airlines and does not mean participation in stock ownership or mergers. This means that airlines coordinate with each other in flight scheduling for common interests and national interests of independent organizations. The goal of this research is to evaluate airlines’ cooperation and sustainable development app.roaches to solve the problems facing airlines and aviation. This research can be used to help airlines identify the role of cooperation in the interests in air transportation as a competitive strategy.

In each time period, the passengers’ demand for each route are finite and this makes it harder for airlines to compete. There are studies that focus on maximizing the profit or flight frequency for airlines; however, there was no attention to the new needs and sustainable development app.roach in the aviation industry.

Hansen introduced the air competition expanded in hub situations with the non-cooperation game to maximize the profit among airlines, in which a non-cooperation game developed airlines were able to choose their frequency [Hansen, 1990]. Takebayashi and Kanafani developed a model to simulate contemporary competition between the network and point-to-point (PP.) carriers in air transportation markets [Takebayashi and Kanafani, 2005]. They introduced the multi-level competition to optimize the No. of passengers under the network service quality.

The equilibrium in the air transportation industry seeks to evaluate the most profitable hub and spoke network for an airline to survive in a deregulated environment. Adler presented an integer linear programming model to generate the potential networks in the first stage of the game [Adler, 2001]. In the second stage, a non-linear programming model maximizes profits for each airline, based on the networks chosen by all participants. The variables of the model included the frequency and airplane size.

Adler and Smilowitz presented a solution for optimizing the maximum profit and network design by a game theoretic for analyzing cooperation of airlines [Adler and Smilowitz, 2007]. The result of the United States and European airline shows that some of the cooperation can be more successful than the others. Wei and Hansen used the game theory to analyze airlines based on the size of aircrafts and their service frequency in monopoly markets [Wei and Hansen, 2007].

Zito, Salvoa, and Fron introduced a model was surveyed to maximize profit in a non-cooperation in two modes: monopoly and equilibrium markets for that how airlines make decisions in a competitive environment based on fare and frequency of services [Zito, Salvoa and Fron, 2011]. They developed a multi-objective mixed-integer linear programming (MILP) model for supp.ly chain planning by using the game theory on a cooperation mode. Zamarripaa et al. developed three attributes (total cost, delays and patronage costs for competitiveness issues) by different optimizations, in which the results of a case study were compared with both cooperation and non-cooperation scenarios [Zamarripaa et al. 2012].

Kimms and Demet determined the strategies to improve system performance by taking a sufficient profit for each partner in the game theory, in which fair allocation of income is important to long-term cooperation partners [Kimms and Demet, 2012]. They showed that income could be calculated even for large networks of cooperation effectively. Aggarwal, Chan, and Tiwari introduced an attitude to improve the aviation with the introduction of cost-effective and better services for airlines [Aggarwal, Chan, and Tiwari, 2013]. Service family selection was shared by using the game coalition. In this case, a group of services was planned for reaching mass customization.

Shiao and Hwang studied the competition of international air cargo carriers in two stages: 1) decision to or not to enter in the Asian general air cargo markets, and 2) profit optimization [Shiao and Hwang, 2013]. They concluded a profit equilibrium point with the waiting period, cargo Volume, and demand. The sharing revenues among airlines and airports should be checked. Saraswati and Hanaoka recognized the revenue sharing for the maximum benefit [Saraswati and Hanaoka, 2014]. They investigated several airlines and airports in the cooperative mode. The results showed that airports would prefer to share the profit to improve their revenue.

Evans and Schafer found the Nash equilibrium between competitor airlines by simulation, in which each airline has its own benefits and they tried to gain market share (split passengers) [Evans and Schafer, 2014]. The validity of this model for a group of 22 network airports in 14 states in the USA. The passenger demand, fares, flight delays, CO_2 and NOx gas system disposal were simulated and estimated in the Chicago O'Hare airport.

Ricardo et al. used the game theory in the allocation of profit between the players [Ricardo et al. 2015, Grauberger and Kimms, 2014]. These results show that the output of cooperative modes is higher than a non-cooperative mode. Dae Ko introduced competition between a low-cost carrier and full-service carrier airlines in fares, flight frequency, and a No. of flights on specific routes for maximizing the profit [Dae Ko, 2016].

In a supp.ly chain, scheduling plays a significant role in coordinating and cooperation. Beheshtinia and Ghasemi considered an integration of supp.lier and vehicle scheduling problems for transporting raw materials from the supp.liers to some manufacturing centers [Beheshtinia and Ghasemi, 2017]. The aim is to minimize the total tardiness of all assigned orders to the supp.liers and minimize the total travelled distance of the vehicles. A new meta-heuristic algorithm, namely multiple league championship algorithm (MLCA), is proposed to solve this problem and compared with two different algorithms. The results prove that the proposed algorithm has better performance.

Some studies have focused on environmental protection and economic interests in air transportation indirectly to maintain the sustainable development in the aviation industry [Lu, 2011. Hagmann et al. 2015 and Tasi et al. 2014]. Pagoni and Psaraki studied the carbon emissions, cost, and air fares in the aviation industry by a game theory app.roach to obtain the maximum profit [Pagoni and Psaraki, 2016]. Kilkis and Kilkis modeled nine airports based on their sustainable rating indicators and introduced the index and dimensions. Some aviation indicators are energy consumption per passenger, emissions dimensions, air pollution indicators, fossil fuels in aviation and sharing public transportation, and biological protection [Kilkis and Kilkis, 2015]. A sustainable development app.roach has been used for airline cooperation because many indicators of sustainable development related to the airline's operation. Sustainable development has been the objective of many fields, including the tourism and transportation sector. However, a major part of this airline industry deals with many negative impacts, such as air pollution, noise, CO_2 emission, and labor practice.

Saremi, Hosseini-Motlagh and Sadjadi app.lied an MILP model for considering container demands, and CO_2 emissions on Islamic Republic of Iran Shipp.ing Lines (IRISL), in which the results showed the inevitable influence of the fuel price and primary inventory level of the cost of the ships [Saremi, Hosseini-Motlagh and Sadjadi, 2016].

Ghater Samani et al. proposed a two-echelon bi-objective model under the assumption of characteristics, including multi-commodity, simultaneous pickup and delivery and soft time windows [Ghater Samani et al. 2016]. The objective functions were to minimize the transportation/location costs and fuel costs, respectively. The proposed model used a robust app.roach for the uncertainty in customers' demands. The results imply to decreased costs.

Tsui, Yuen, and Fung survey a hub aviation and added to that knowledge to empirically investigate Hong Kong's eight major tourist source markets [Tsui, Yuen, and Fung, 2017]. The findings of this study suggested that the increased air transport capacity of foreign countries and Hong Kong to China, trade Volumes between China and its trading partners, air transport costs, and the global financial crisis are the key factors in affecting the No. of visitors to China by air passing through Hong Kong as their preferred stopover.

Majidi et al. proposed a mixed-integer nonlinear programming model to minimize the cost of fuel consumption and greenhouse gas (GHG) emissions of vehicles in vehicle routing problem with simultaneous pickup and delivery and time windows [Majidi et al. 2017]. The results indicated that the proposed solution method was the capability of finding high quality solutions in most instances.

Abdoli Aghaei et al. used a road map model, modified digital logic (MDL) and expert's viewpoints for developing the aircraft design and manufacturing industry [Abdoli Aghaei et al. 2015]. This roadmap was a foresight tool, and its goal and app.lication was to decrease the risk of an investment, aircraft design and manufacturing industry.

Danesh Asgari, Haeri and Jafari introduced a new app.roach to the selection of a right efficiency indicator in order to help managers and decision makers in the transportation industry to recognize right indices for performance improvement by the balanced scorecard and data envelopment analysis models [Danesh Asgari, Haeri and Jafari, 2017].

The research questions to address this issue are as follows. Does airline cooperation affect on their profits? Does airline cooperation affect on reduction of the total capacity flight? Does airline cooperation, respond to the passengers' demand at different times? Does airline cooperation affect on the sustainable development?

Airline's managers should strive to increase the efficiency in a management system and reduce costs as much as possible. Airlines should find solutions to flight scheduling, and for this purpose, they should consider some facilities and strategies. Thus, airlines face issues such as high costs, many No.s of flight frequency and omission of small airline companies. These companies have to prevent the problems and solve them with accurate and practical solutions. If the airlines do not cooperate, the capacity of the flights is going to be much more than the passenger demands and the empty seats will increase.

The contributions of research to address this issue are as follows: the cooperative game theory, a sustainable app.roach used to solve above-mentioned problems and a balance between supp.ly and demand. In this research, three steps are introduced to address these issues: (1) introducing the components of a multi-attribute game to the multi-objective model, (2) multi-objective modeling by a sustainable development app.roach, (3) solving a multi-objective model by a developed method. Suggestion process can be used for airlines in other similar cases. This problem is modeled by a multi-attribute game theory and solved by using Lingo software. To validate this model, the results were compared with the non-cooperation mode.

Table 1. Comparing this research with the existing literature

Author	Game theory	CO_2 emission	Sustainable	Aviation	Further details
Hansen	*			*	Non-cooperation, choosing their frequency, maximizing the profit, airline
Takebayashi	*				Optimizing the No. of passengers in transportation
Adler	*			*	Frequency and airplane size, airline
Adler	*			*	Maximum profit, cooperation of airlines
Wei	*			*	Analyzing airlines based on the size of aircraft and their service frequency
Zito	*			*	Maximizing the profit in a non-cooperation
Zamarripaa	*			*	Total cost, delays, and patronage costs for cooperation and non-cooperation
Kimms	*			*	Profit, fair allocation, cooperation game and the revenue sharing by the core
Aggarwal	*			*	Cost-effective, services for airlines, coalition
Shiao	*			*	Profit optimization
Saraswati	*			*	Revenue sharing for the maximum benefit. Several airlines use cooperative airports
Evans	*			*	The payoff is Benefits and airlines trying to gain the market share
Ricardo	*				Allocation of profits between the players. non-cooperative
Grauberger	*				Allocation of profits between the players. non-cooperative
Dae Ko	*			*	Low-cost and full-service airlines, fares, flight frequency, No. of flights on specific routes for maximizing the profits
Beheshtinia	*				Supp.ly chain, scheduling cooperation
Pagoni	*	*		*	Carbon emissions, cost, and airfares
Lu			*	*	
Hagmann			*	*	
Tasi			*	*	
San Kilkis		*	*	*	Air pollution indicators
Saremi		*			Minimizing the transportation costs and location costs. Minimizing the fuel costs
Ghater Samani					
Tsui			*	*	
Majidi					Minimizing the cost of fuel consumption and GHG emissions of vehicles
Abdoli Aghaei				*	Developing aircraft design and manufacturing industry
Danesh Asgari					Efficiency indicator in the transportation industry
This paper	*	*	*	*	Three steps are introduced to address the issues: (1) introducing the components of a multi-attribute game to the multi-objective model, (2) multi-objective modeling by a sustainable development app.roach, (3) solving a multi-objective model by a developed method.

2. Materials and Methods

2.1 Game Theory

Game theory is "the study of mathematical models of conflict and cooperation between intelligent rational decision-makers". Game theory is mainly used in economics, political science, psychology, logic, computer sciences, and biology [Myerson, 1991]. It analyzes situations inVolved in the parties of conflicting interests. It has two forms, namely sequential or dynamic and classical or normal. Dynamic game theory covers two (or more) players that play sequentially with some knowledge, such as chess. In normal game theory, players play simultaneously.

On the other hand, game theory has another classification, namely cooperation and non-cooperation. In the non-cooperation game, all players try to maximize their own interests independently; however, in cooperation games, players may be motivated to achieve their interests with an agreed strategy. If there is no any cooperation between all the players, it is called an alliance. The game has three parts: players, player strategies that can be discrete or continuous, and pay-off or utility function.

First, we establish a set of utility functions defined on a decision space for a group of individuals. Yu introduced the concept of a utopia point in the group decision problems [Yu, 1973]. Let X be a decision vector with x, and use $\bar{X}$ to denote the set of all feasible x. The compact set $\bar{X}$ has a maximum value u, where u_j is the utility function for airline j; thus, u_j^* is the maximum utility. The n players can obtain thus $u^* = (u_1^*, u_2^*, \dots, u_n^*)$ is the point, in the utility space, in which everyone is happ.y. Yu called it the utopia point, where D indicates the distance between the utopia point u^* and utilities resulting from the decision x. That distance will be minimized.

$$\text{Min } D = \left\{\sum_{j=1}^{n} \left|u_j^* - u_j\right|^p\right\}^{\frac{1}{p}} \quad 1 \le p \le \infty \qquad (1)$$

In the above method, there is only one payoff function for each player; however, in this study, three types of pay-off functions were used for each player [Yu, 1973].

2.2 Suggested Process for Solving the Issue

Considering the issue of competing airlines with the cooperative app.roach in game theory and sustainable development, the following three steps are suggested for any limited No. of routes and airlines that can be used in other similar cases:

Step 1: Introducing the components of a multi-attribute game to the multi-objective model.

Step 2: Multi-objective modeling by a sustainable development app.roach.

Step 3: Solving a multi-objective model by the developed method.

2.3 Step 1: Introducing the components of multi-attribute game to the multi-objective model

In each time period, the passenger's demand for each route is finite, and airlines compete for their market shares. In this research, airlines are the players and they want to maximize their profit, decrease the empty seats, and minimize the total difference among the No.s of flier passengers and their demand on all routes and flight times. These are the attribute or pay-off functions of the game. Airline strategies are discrete and the share of demands on each route and flight scheduling of the game, which display by x_{ijk} and y_{ijk} in the multi-objective model.

In this research, the game type is normal and cooperative with multi-attribute functions and discrete strategies. The game gets played one time at the beginning of the programming and the cooperative results are used for scheduled flights for a specified time period. During the game, the No. of the players and strategies must be identified. Therefore, the game is complete information.

2.4 Step 2: Multi-objective Modeling By A Sustainable Development App.Roach

2.4.1 Notations

Decision variables:

y_{ijk}: 1 if the airline *j* at the flight time *i* was used for air route *k*; 0, otherwise
x_{ijk}: No. of passengers that fly at the flight time *i* by airline *j* on the air route *k*
Parameters:
m_{jk}: Maximum No. of flights for airline *j* on air route *k* in a specific time period
m: No. of competitor airlines (*j* index)
n: No. of flight time (*i* index)
L: No. of air routes (*k* index)
H: No. of objective functions (*h* index)
f_{ijk}: Fixed cost of airline *j* at flight time *i*, on air route *k*
v_{ijk}: Variable cost of airline *j* at flight time *i* and on air route *k*
D_{ik}: Passenger demand for the air route *k* at flight time *i*
t_{ijk}: Airline's share from the sale of tickets at flight time *i* for airline *j* on air route *k*
s_{ijk}: Capacity of airline *j* at flight time *i* and for the air route *k*
M: Very large No.
u_{jh}: Utility function for airline *j* and objective function *h*
F_{ik} : For air route *k* at the flight time *i*, the total difference among the No.s of flier passengers and their demand

2.4.2 Assumptions:

- The parameters of the model are well-known for all players (i.e., airlines).
- The results of the cooperative model for a specified time period used for flight scheduling.
- The game is done one time at the beginning of the specific period.
- Airlines compete for a limited No. of routes.
- Demand forecast for each route is determined by airport information, and all demands can be answered by competitor airlines.
- The game type is normal, cooperative and multi-attribute. Strategies are discrete and pure.
- The game is done simultaneously and didn't exist dominate power in this problem that we survey.
- According to the game's attribute (three objective or payoff functions) in the model, there is no dominant force among airlines and only airlines decide on model variables (game strategies).

2.4.3. The multi-objective model:

$$Max \sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{k=1}^{L}(t_{ijk}x_{ijk} - v_{ijk}x_{ijk}) - \sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{k=1}^{L} y_{ijk}\, f_{ijk} \tag{2}$$

$$Min \sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{k=1}^{L} y_{ijk}\ \ s_{ijk} - \sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{k=1}^{L} x_{ijk} \tag{3}$$

$$Min \sum_{i=1}^{n}\sum_{k=1}^{L} {}^{1}\!/_{2}\ F_{ik} \tag{4}$$

s.t.

$$x_{ijk} \le y_{ijk}\ s_{ijk}\ \forall i,j,k \tag{5}$$

$$x_{ijk} - My_{ijk} \le 0\ \forall i,j,k \tag{6}$$

$$1 \le \sum_{i=1}^{n} y_{ijk}\ \ \forall j,k \tag{7}$$

$$\sum_{i=1}^{n} y_{ijk} \le m_{jk}\ \ \forall j,k \tag{8}$$

$$\sum_{i=1}^{n}\sum_{j=1}^{m} x_{ijk} = \sum_{i=1}^{n} D_{ik}\ \ \forall k \tag{9}$$

$$\left|\sum_{j=1}^{m} x_{ijk} - D_{ik}\right| = F_{ik}\ \ \forall i,k \tag{10}$$

$$y_{ijk} = 0,1\ \forall i,j,k \tag{11}$$

$$0 \le x_{ijk}\ \forall i,j,k \tag{12}$$

Objective function (2) maximizes the airlines profit by calculating the difference between the revenue of airlines from the sale of tickets and costs. This objective introduces the economic dimension of sustainable development.

Objective function (3) minimizes the total flight empty capacity. The use of seat coefficient is a measure for prioritizing airlines. This objective can eliminate extra flights and costs, and reduce fuel consumption and air pollution. This objective introduces the economic, environmental, and social factors of sustainable development. The reduced capacity can cause increased dissatisfaction among passengers from flight time, reducing the passengers and profit for an airline because some of the passengers are reallocated to the other airlines or other flight times. This concerns the conflict between the first and third objectives.

Objective function (4) minimizes the total difference among the No. of flier passengers and their demand on all routes and all flight times. The passenger's demand of on a route for each time is different. Maybe, the demand is more than the capacity of flights at a time for a route. In this mode, the remaining passengers have to travel at other times, that dissatisfies passengers from flight time. Therefore, objective function (4) tries to balance the between supp.ly and passengers' demand for all routes and all times, and decreases passenger dissatisfaction from flight time which is the social and economic dimension of sustainable development. This objective can cause increases in flights, empty seats, and cost. Because of the absolute function in (10), the total No. of F_{ik} should be divided by two in this objective.

Constraint (5) shows that the No. of allocated passengers that are flying by airline *j* at flight time *i* and for air route *k* should not be more than the airline capacity. Constraint (6) shows when *y* is equal to zero, *x* is zero and when *y* is equal to one, *x* is greater or equal to zero and calculates the No. of passengers. Constraints (7) and (8) show that, for each route and each airline at a specific period, the total No. of flights at all times should be at least one and maximized m_{jk}. Constraint (9) shows that, for each route, the total No. of passengers on all flights should be equal to the total passenger demand. Demand forecast for each route is determined by airport information and all demands can be answered by competitor airlines. Constraint (10) calculates F_{ik} by the difference among the total No. of passengers that will fly by airlines from passenger demand at each time and on each route. Constraints (11) and (12) show that type of variables.

2.5. Step 3: Solving the model by a multi-objective method

This study is based on the cooperative game and group decision making. Also, utopia values for airlines are available used by the similarity of Yu's method to solve the multi-objective model. This method is selected because it is used for multi-attribute game models. In the Yu's method, for each player, there was only one pay-off function. However, in this study, three types of a pay-off function are used for each player. The alternative methods can be another multi-objective methods and multi-attribute game theory methods, such as Nash methods.

The solutions are determined for multi-attribute game model introduced by (u_{jh}) utility function for airline *j* and attribute *h* or objective *h*, and u_{jh}^* is utility optimization.

$$Min\ D = \left\{ \sum_{h=1}^{H} \sum_{j=1}^{m} \left| u_{jh}^* - u_{jh} \right|^p \right\}^{\frac{1}{p}} \quad \forall j, h \tag{13}$$

For the cooperation of the airlines, the objective functions 1, 2, and 3 by *h* = 1, 2, and 3 optimized with constraints separately and u_{jh}^* calculated. The placement u_{jh}^* in objective (13) with the unit off, then the mathematical model with objective function (13) and constraints (4) to (11) for *p*=1 is solved, and the Nash equilibrium point in a cooperative mode can be obtained. *P* can be taken each No. according to the Yu's method. In the Yu's method, a small amount of *P* is used to emphasize the utility of all players [Asgharpour, 2014]. Since in the cooperation game, players try to achieve more benefits simultaneously, so the results of the mathematical model suggest the best values of the variables (strategies) for any airline in the game and airlines agreed with decision variables.

3. Results

Airlines should balance the passengers' supp.ly (capacity of flights) and demand. In other words, airlines should select the strategies that able to improve their operations. Integrated control and monitoring should be app.lied with a common online management system.

This problem is solved by the mathematical model for four airlines and three air routes in a specified period. For validation, the results of the airline's cooperation model prepared by using Lingo software with the non-cooperation are compared with Tables 2 to 4. Information about the non-cooperative results are collected from airlines in the current form.

Tehran-Mashhad, Tehran-Shiraz and Tehran-Kish routes are investigated for four airlines in the specified period. Information about the parameters of the model such average costs and capacity of airlines is well-known and are obtained by interviewing airline managers and their website. The average of the forecasted demand on each route for the specific period by the information about the Mehrabad airport is collected. Table 2 shows the profit of airlines and No. of passengers in cooperative and non-cooperative modes. Table 3 and Figure 1 show the empty seats and the No. of flights decreased in a cooperative mode.

Comparing the No. of flights for airlines on air routes in Table 4 and comparing the total objectives with Table 6 are shown in cooperative and non-cooperative games. The results show that, in the cooperation situation, the total profit for airlines will be increased. The analysis of this issue shows that some airlines (i.e., first and second airlines) in a cooperative game, see a slight reduction in profits, removing extra flights and decreasing empty seats. This demonstrates the concept of a non-dominant solution by using a multi-objective decision-making method. By removing extra flights, airlines can develop the flights on other routes effectively and earn more profit; however, other airlines lose profit.

The No. of empty seats is an important measure for evaluating the airlines. Based on multi-objective mathematical model, by reducing the No. of flights, the No. of empty seats can be reduced. The results show that the total No. of empty seats will be decreased from 1737 seats to just 87 seats. It shows a suitable use of resources and help the airline ranking. The total No. of flights will be decreased from 30 flights to 23. This leads to a reduction in environmental pollution, fuel usage, CO_2 emissions, and costs. It also contributes to the health and welfare of society and provides the economic, environmental, and social dimensions of sustainable development.

Table 2. Profits and No. of passengers

Airline No.	Profit		No. of Passengers	
	Cooperative	Non-cooperative	Cooperative	Non-cooperative
1	74,985	76,400	1103	1200
2	44,810	54,555	610	935
3	136,335	112,810	1565	1410
4	129,730	96,714	1580	1313
Total	385,860	340,479	4858	4858

Table 3. Empty seats and No. of flights

Airline No.	Empty Seats		No. of Flights	
	Cooperative	Non-cooperative	Cooperative	Non-cooperative
1	77	570	6	8
2	10	235	4	7
3	0	465	6	7
4	0	467	7	8
Total	87	1737	23	30

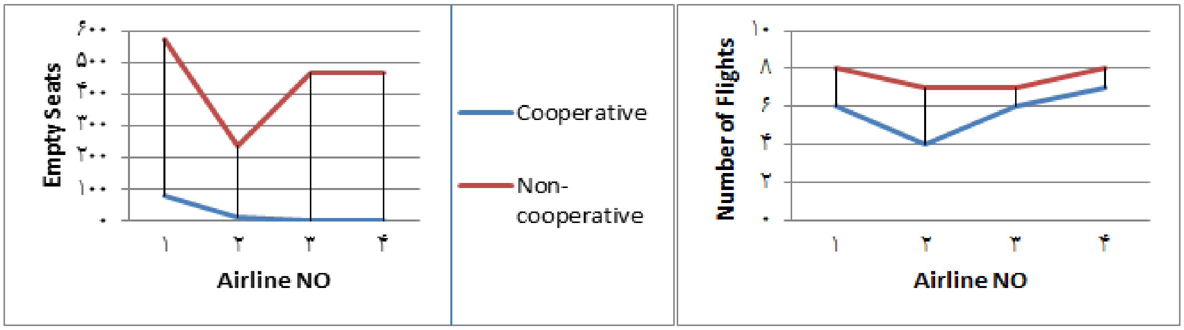

Figure 1. Empty seats and No. of flights

Table 4. No. of flights for each airline on each air route

Airline No.	No. of Flights on First Route		No. of Flights on Second Route		No. of Flights on Third Route	
	Cooperative	Non-cooperative	Cooperative	Non-cooperative	Cooperative	Non-cooperative
1	1	2	2	3	3	3
2	2	3	1	2	1	2
3	1	2	2	2	3	3
4	3	3	1	2	3	3
Total	7	10	6	9	10	11

Table 5. CO_2 emission for routes in cooperative mode

Routes	Distance (Km)	Average fuel consumption	Average of co_2 emission (Tone)	Reduced flights for all airlines	Reduced average fuel consumption	Total CO_2 does not emit (tone)
Tehran-Mashhad	741	3705 (Kg)	11.48	3	11115 (Kg)	34.45
Tehran-Shiraz	682	3410 (Kg)	10.57	3	10230 (Kg)	31.71
Tehran-Kish	1043	5215 (Kg)	16.16	1	5215 (Kg)	16.16
Total for all routes				7	26560 (Kg)	82.32

Table 6. Comparing total objectives in cooperative game and non-cooperative mode

Objectives of Sustainable Development	Cooperative	Non-Cooperative
Total profit for airlines (economical goal)	385,860	340,479
Total No. of empty seat (social, environmental, and economic goals)	87	1737
Total No. of flights (social, environmental, and economic goals)	23	30
The total difference among the No. of passengers that will fly by airlines from passenger demand (social and economic goals)	295	210

The passenger's demand on a route for each time is different. It may be demand is more than the capacity of flights at a specific time on a route. In this mode, the remaining passengers will have to travel at other times, whose results are dissatisfied with a flight time. Therefore, minimizing the total difference among the No.s of flier passengers and their demand on all routes and all flight times is used. Also, when the demand is low at a time, this objective function decreases the No. of flights.

By reducing the No. of flights from 30 to 23, the empty seats are substantially reduced and the total difference among the No. of passengers that will fly by airlines from passenger demand on all routes and all flight times increases from 210 to 295. If this objective function is not used, the difference is very high, and the No. of flights increases inefficiently.

Table 4 shows the No.s of flights for each airline on each air route in a cooperative game model and a non-cooperative mode (i.e., the existing mode). Aircraft engine emissions are directly related to fuel burn 1 kg of jet fuel burned generates 3.16 kg of CO_2 [Cokorilo, 2016]. So, the key for airlines to minimize their environmental impact is to use fuel efficiently. Table 5, for each route, shows the average of fuel consumption, average of CO_2 emission, reduced flights for all airlines in a cooperative mode, reduced average fuel consumption and total of CO_2 does not emit. The average of the CO_2 emission column in Table 5 is calculated based on 1 kg of jet fuel burned generating 3.16 kg of CO_2. Due to the reduced flights for all routes, the total CO_2 is about 82.32 tones and reduced average fuel consumption is 26560 Kg. This calculation is based on the route distance and average fuel consumption is achieved. The results are shown in Table 6. Actually, through airlines' cooperation, an agreement is established and airlines achieve their interests on the agreed strategy through the model decision variables and they will reach a Nash point along with a sustainable development app.roach.

Airlines use the other's information for decreasing unnecessary flights and cost, improving flight scheduling based on passenger demand, expanding flight networks, balancing flight frequency, improving the management and seat usage coefficient, decreasing costs of additional flights, reducing air pollution, and fuel consumption.

4. Discussion and Conclusions

Significant developments are in the field of air transportation. A large No. of countries made remarkable strategies in international air transport. Also, in airline management, there are some complex problems. This research evaluated the airlines' cooperation with game theory and sustainable development app.roaches.

This research can be used to help airlines by identifying the role of cooperation in air transportation as a competitive strategy. The following three steps are suggested for solving the issue: (1) introducing the components of multi-attribute game to the multi-objective model, (2) multi-objective modeling with a sustainable development app.roach, and (3) solving the model by a multi-objective method. The three-step suggestion process for airline cooperation for optimal flight scheduling and better utilization of the fleet that can be used in other similar cases.

The multi-attribute game theory was modeled on cooperative mode and sustainable development app.roach. The pay-off functions are to maximize the profit of airlines, minimize empty seats or maximize the seat usage coefficient, and minimize the total difference among the No.s of flier passengers and their demand on all routes and all flight times. All above objectives will show all economic, environmental, and social aspects of sustainable development. In the cooperation game, the results of the mathematical model suggest the best values of the variables or strategies for each airline in the game; therefore, airlines agree with the decision variables.

This problem is solved in four airlines, three busy air routes, and three flight times at a specific period. The results are shown in the previous section, in which the total No. of empty seats can be decreased from 1737 seats to just 87 seats. It shows a suitable use of resources and helps the airline ranking. The total No. of flights can be decreased from 30 flights to 23. Cooperation between airlines makes it possible to increase their profit and use of seat coefficient while decreasing passenger dissatisfaction from a flight time. Also, airlines’ cooperation can result in cancelling the non-required flights and developing flights on other needed routes. Therefore, this action increases the profit, reduces the air traffic rate and interrelated costs, and also decreases the fuel consumption and environmental pollution. These benefits lead to sustainable development.

Airlines play a crucial role in sustainable development and the cooperation of the airlines can have an effect on economic, environmental, and social factors. Air transportation should be reliable, effective, and safe. The passengers’ demand for each route is finite. Airlines’ cooperation can be very interesting for more market in competition. Business cooperation allows airlines to access a large air network and provision of necessary services.

According to Table 5, the airline cooperation reduces the No. of flights. Consequently, it can reduce Co_2 emission or air pollution and fuel consumption. Total Co_2 emission for all routes is about 82.32 tones and reduced average fuel consumption is about 26560 Kg. Also, airlines are able to provide passengers with the varied flight schedules and a wider choice of take-off and landing times.

Despite all the features and benefits from cooperation with the air transport industry, which should be encouraged airlines; there are some issues that need to be addressed. Therefore, further research is necessary to develop the other advantages effects of cooperation. The cooperation model has a complexity in terms of cooperation frameworks and has yet to undertake studies in this regard. Future research should concern new policies that need to be developed for airline cooperation and their impact on airlines, as well as the development and use of other solving methods of multi-attribute game theory.

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