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CONCURRENT AIRCRAFT ROUTING AND MAINTENANCE SCHEDULING

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ABSTRACT

The aircraft routing is the process of assigning each individual aircraft within each fleet to flight legs. The Federal Aviation Rules require the maintenance of all the aircrafts after specified hours of period as mandatory. The minimum total maintenance cost is provided as a result of the lost flight time which is brought to minimum. The common policies in this business sector follow the practices the maintenance of an aircraft once in 3-4 days periodically. This policy minimizes the risk of grounding of aircraft in the cost of the lost flight hours. In this study, we propose a concurrent, mathematical modeling approach for daily flight route and maintenance scheduling based on recorded flight hours. The model has been solved using CPLEX/GAMS MILP Software. The proposed approach was applied to the daily flight route-maintenance schedule problems of the domestic flights of two companies.

Keywords: *Aircraft Routing, Aircraft Maintenance Planning, Air Transportation, Integer Programming.*

BÜTÜNLEŞİK UÇAK ROTALAMA VE BAKIM ÇİZELGELEME

ÖZET

Uçak rotalama, her bir filo içerisindeki her uçağın uçuş bacaklarına atanma sürecidir. Ulusal Havacılık Kuralları, belli bir uçuş saatinden sonra bütün uçaklara zorunlu olarak bakım uygulanmasını gerektirir. En düşük toplam bakım maliyeti, kullanılamayan uçuş zamanı en küçüğe getirilmesiyle sağlanır. Havacılık sektöründe izlenen genel politika her 3-4 günde periyodik olarak uçaklara bakım uygulamaktır. Bu politika, kayıp uçuş saati maliyetinde uçakların yerde kalma riskini en küçüklemektedir. Bu çalışmada, uçuş saatleri temel alınarak günlük uçuş ve rota çizelgeleme için bütünleşik matematiksel modelleme yaklaşımı önerilmiştir. Model, CPLEX/GAMS MILP yazılımı kullanılarak çözülmüştür. Önerilen yaklaşım iç hat uçuş gerçekleştiren iki şirketin günlük uçuş rota bakım çizelgeleme problemlerine uygulanmıştır.

Anahtar Kelimeler: *Uçak Rotalama, Uçak Bakım Çizelgeleme, Hava Ulaştırma, Tamsayı Programlama.*

1. INTRODUCTION

Air travel has been one of the biggest developing sectors in the global industry since the first flight made by Orville and Wilbur Wright in 1903. Airlines carried approximately 2.25 billion people in 2007. They have made a global profit of $5.6 billion out of an income of $490 billion [1]. In the years between 2007 and 2026, it is expected that there will be an increase of 4.7% in the passenger traffic and an increase of 4.7% in the cargo traffic [2].

While the percentage of increase in the World Civil Aviation Sector was 5% in the last few years, it was 53.3% in Turkey [3]. In comparison to 2002, the yearly passenger numbers had increased by 350% in the domestic routes and by 63.2% in the international routes [3]. It has been estimated that the Turkish Civil Aviation Sector will increase by 4.5%-5% annually and will buy about 250 aircrafts worth $ 21 billion [4,5].

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Because of very high cost of aircraft purchase and management in the airline sector, the managements are trying to bring down the cost in the present competitive environment. As the aircraft purchase cost cannot be reduced, the managements mostly concentrate on its operation cost. The airline management cannot control the price of fuel and the rent of airport area directly. The only cost that can be controlled is the maintenance cost of the aircraft. The management that can plan the aircraft maintenances optimally can make millions of dollars worth of savings, and hence can be better placed over its rivals.

The airline managements prepare their maintenance programs by taking the documents of MPD (Maintenance Planning Documents), AMM (Aircraft Maintenance Manual), CMM (Component Maintenance Manual), SBs (Service Bulletins) and SLs (Service Letters) as reference [6]. The prepared programs are put into application if found sufficient by The Civil Aviation Authority of the country concerned. The aircraft maintenance period used, are applied according to A, B, C and D codes of the check periods [7, 8]. The parts and components on the aircraft are assigned to the letter coded control packages and the relevant maintenance is done like this. Moreover, along with this, today for the latest version aircrafts like B737-600/700/800/900, the alphabet coded maintenance applications are not now suggested by the firm in the maintenance planning documents as reference [9]. The producer companies give the maintenance periods, aircraft flight time, aircraft landing numbers, and year-life limit types of measurement to the users as reference. The airline management can get the parts and components which form the most of aircraft maintenance package done in a better period by taking into account the flight time. As a conclusion, the maintenance application can be done by taking into account the real flight times rather than taking the daily average flight period of the aircrafts. Thus, less aircraft maintenance can be achieved annually by applying maintenance according to the limit value or close to the value to ratio of aircraft usage. For example, if the aircraft, which maintenance interval is 400 flight hours, is done maintenance at around 400 flight hours instead of 360 flight hours, the eleventh maintenance cost can be avoided. On top of this maintenance cost savings, the aircraft utilization will be improved due to shorter grounding time.

Federal Aviation Administration in the United States requires the letter coded check packages. These checks vary their scope, duration, and frequency. A-type checks have to be performed every 65 flight hours. The other checks have longer durations. The type of B check is performed every 300 to 600 hours of flight. The C and D checks are performed every one to four years. The airlines in practice are performed A type checks at most 35 to 40 hours of flying. The time required to perform A checks is somewhere between 3 and 10 hours [10, 11].

Naturally, A-checks can be held accountable for most of the maintenance operations. In the literature, most of the studies assign aircrafts to the routes following an A-check. Since each aircraft practically spends around 12 hours per day, there remains three to four solid days before the next A-check. Therefore, an A-check is supposed to be issued every four or five days. Having considered the fact that legally allowed time between A-checks is 65 hours, this practical approach results in the loss of 17 to 30 hours of flight time accounting roughly for 25% to 45% of the duration. The operations management takes the advantage of this so-called cushion time to prevent any severe penalty for missing an A-check under the assumption of daily plans. If the plans could be performed and executed on hourly basis within a robust planning method, these steady loss percentages are expected to be reduced significantly without any missing of checks. These savings would be much more tangible in cases of route changes due to bad weather condition, illness of crew or technical reasons.

In this study, a concurrent daily aircraft maintenance and route planning approach has been proposed to minimize aircraft maintenance costs which form 18-23% of the airlines’ direct operating cost [12]. The proposed method incorporates the aircraft routing and maintenance scheduling problems into a mathematical model based on a flight-hour tracking approach. The model proposed has been solved using CPLEX/GAMS MILP Software. The approach has also been applied to the daily flight route-maintenance schedule problems of the domestic flights of two companies.

2. LITERATURE REVIEW

Daskin et al. has shown that by putting the aircraft routes in the single hub and spoke network structure, the management profit can be increased. The problem was modeled as MILP and was solved with Lagrangian relaxation [13]. Feo and Bard had presented a flight program development model which could be placed in the maintenance centers and which could solve the A type check requirement in a better way. The problem was formulated for American Airlines as a minimum cost, multi commodity flow network with integral constraints. For the linear programming relaxation solution and as it was quite big, a two-stage heuristic was used [14]. Kabbani and Patty the aircraft routing problem for American Airlines had been formulated in such a way that every column represented probable weekly aircraft routes and the rows represented the flights. In this study, the maintenance has been performed once in every three days [15]. Hane et al. had modeled the fleet assignment problems with side limitations as a large multi-commodity network flow with side constraints defined on a time-expanded network. The method used to solve problem was the interior-point algorithm and branching. Moreover, the authors had used some preprocessing method in order to diminish the dimension of problem [16]. Clarke et al. extended the study in Hane et al. [16] adding to the model maintenance and crew constraints. The solution that cannot provide the requirement of maintenance was accepted to be inappropriate. The requirement for maintenance had been classified as short term and long term according to the period it was performed. In the article, how maintenance constraint and crew assigned to the fleet had got integrated is not mentioned clearly [17]. Clarke et al. modeled the aircraft rotation problem as an Eulerian tour with side constraint that maximized the through value of connecting flights and satisfies maintenance constraints. The model was simplified with pre-process technique. It was solved with Lagrangian relaxation and subgradient optimization [10]. Desauliniers et al. had analyzed the maximum profit from daily heterogeneous aircraft routing and scheduling problem and the two models were presented. The linear relaxation of first model was solved by using column generation technique; the linear relaxation of the second model was solved by using Dantzig–Wolfe decomposition approach [18]. Gopalan and Talluri modeled maintenance routing problem and had used polynomial-time algorithm for the three-day maintenance and the balance-check visit requirements. In the model, swapping was done in the flights as well as fleet to obtain appropriate aircraft maintenance [11]. Barnhart et al. presented a string-based model and used a branch-and-price approach to solve combined fleet assignment and aircraft routing problem. The disadvantage of this model was having millions of series by flight programs having hundreds of flights [19]. Cordeau et al. modeled the aircraft routing and crew scheduling problems simultaneously, and used Bender decomposition approach for solution [20]. Sriram and Haghani analyzed the maintenance scheduling and aircraft reassignment. The authors took into consideration both A and B type checks in the formulation and used a heuristic method that was a hybrid of random search and depth first search [21]. Sarac et al. solved the aircraft maintenance routing problem by taking into consideration the maintenance slots and the man-hours which can be used at the maintenance station [22].

3. THE FORMULATION OF PROBLEM

The flight network is modeled as a connection network in which nodes represent flight legs and arcs represent feasible connections between the flight legs. In the connection network, the arc (*i, j*) exists if the flight legs *i* and *j* are being realized by the same aircraft. The destination city of node *j* and arrival city of *i* must be the same. It also requires that the arrival time of flight *i* plus the turn time is less than or equal to the departure time of flight leg *j*.

In the model, the following notation is used.

i and j indices for flight legs (nodes)
k index for aircraft
o dummy source node connected to every node $i \in N$
t dummy destination node connected to every node $i \in N$
c index for city (airport) $c \in C$
mt maintenance type
K set of aircraft
N set of station
C set of city (airport)
T_{di} departure time of flight leg *i*
T_{ij} duration of flight leg *i*
T_{si} required time for preparing the aircraft for next flight after flight leg *i*
M a considerable big number
Tdo_{ok} departure time for aircraft *k* at dummy source *o*
Tdt_{tk} departure time for aircraft *k* at dummy sink *t*
x_{ijk} 1, if aircraft *k* flies flight leg *i* and *j* consequently; 0, otherwise
Ca_{ic} 1, if arrival city of flight leg *i* is *c*; 0, otherwise
Cd_{jc} 1, if departure city of flight leg *j* is *c*; 0, otherwise
$Cmt_{mt,c}$ 1, if overnight airport *c* can serve for maintenance type *mt*; 0, otherwise
Amt_k 1, if aircraft *k* needs maintenance type *mt*; 0, otherwise.
r_k legal remaining flying hours for aircraft *k*.
DFFc(i) the flight *i* beginning in city *c*
OWNc(k) the aircraft *k* spent the night in city *c*
KM(k) set of aircrafts needs maintenance
KMw(k) set of aircrafts needs maintenance performed according to day period
KMc(i) the flight *i* performed to maintenance city
Nth_u the set of flight legs performed as a through flight

With this notation, the problem formulation becomes

$$Min \quad \sum_{k \in K}\left((r_k) - (\frac{1}{(r_k)}) \sum_{i \in N}\sum_{j \in N} T_{ij}x_{ijk} \right) \tag{1}$$

$$\sum_{k \in K}\sum_{j \in N} x_{ijk} = 1 \quad \forall i \in N / \{o,t\} \tag{2}$$

$$\sum_{j \in N} x_{ijk} = 1 \quad k \in K \quad ve \quad i = o \tag{3}$$

$$\sum_{i \in N} x_{ijk} = 1 \quad k \in K \quad ve \quad j = t \tag{4}$$

$$\sum_{j \in N} x_{ijk} - \sum_{j \in N} x_{jik} = 0 \quad \forall i \in N / \{o,t\} vek \in K \tag{5}$$

$$\sum_{k \in K}\sum_{j \in N} x_{ojk} - \sum_{k \in K}\sum_{i \in N} x_{itk} = 0 \tag{6}$$

$$Td_i + T_{ij} + Ts_i - Td_j \leq M(1 - x_{ijk}) \quad \forall k \in K \;\; ve \;\; \forall (i,j) \in N / \{o,t\} \tag{7}$$

$$Tdo_{ok} + T_{oi} - Td_i \leq M(1 - x_{oik}) \quad \forall k \in K \quad ve \quad \forall (i) \in N \tag{8}$$

$$Td_i + T_{it} + Ts_i - Tdt_{tk} \leq M(1 - x_{itk}) \quad \forall k \in K \quad ve \quad \forall (i) \in N \tag{9}$$

$$\sum_{k \in K} x_{ijk} \leq \sum_{c \in C} Ca_{ic} Cd_{jc} \quad \forall i \in N \quad ve \quad \forall j \in N \tag{10}$$

$$x_{ojk} \leq Cd_{jc} Ca_{oc} \quad \forall j \in N \quad ve \quad k \in K \tag{11}$$

$$\sum_{j \in DFFc(j)} x_{ijk} = 1 \quad \forall k \in OWNc(k) \;\; ve \;\; i = o \tag{12}$$

$$\sum_{i \in N} \sum_{m \in M} \sum_{c \in C} x_{itk} Ca_{ic} Cmt_{mt,c} A_{mt,k} = 1 \quad \forall k \in KM \tag{13}$$

$$\sum_{i \in N} \sum_{j \in N} T_{ij} x_{ijk} \leq r_k \quad \forall k \in K \tag{14}$$

$$\sum_{i \in KMc(i)} x_{ijk} = 1 \quad \forall k \in KMw \;\; ve \;\; j = t \tag{15}$$

$$\sum_{k \in K} \sum_{i \in \mathrm{Nth\_u}} \sum_{j \in \mathrm{Nth\_u}} x_{ijk} = 1 \tag{16}$$

$$t_{oj} = 0 \qquad \forall k \in K \tag{17}$$

$$Tdo_{ok} \geq 0 \;\; ve \;\; Tdt_{tk} \geq 0 \;\; \forall k \in K \tag{18}$$

$$x_{ijk} \in \{0,1\} \;\; \forall k \in K, \;\; i \in N \; ve \; j \in N \tag{19}$$

The objective function minimizes the total remaining legal flight time by giving higher priorities to the aircrafts with lower remaining flight times. The proposed objective function increases the utilization of aircrafts yielding savings over maintenance costs. The constraints for flight leg coverage (2) guarantee that an aircraft will be assigned to each flight leg. The aircraft coverage consists of two set of constraints. The first one (3) assigns every aircraft to the beginning of a flight leg, while the second one (4) ensures that every aircraft whose flight ends at a dummy sink will be assigned to a new flight for the day after. The flight conservation constraints set (5, 6) maintain the balance between the number of connection arcs coming and leaving node *i*. The flight conservation constraint (5) enforces each aircraft to make a circulation in the flight schedule. Thus, the aircraft continues flights until the flight reaching to a dummy point. The flight conservation constraint (6) is used for equaling the number of connection arcs leaving a dummy source node with the number of flight connections coming to a dummy sink. Doing so, the model provides the same number of aircraft at every airport for repeating flights. The sequence flight legs are provided by feasible time connections and feasible city-pair connections. The first one (7) ensures feasible connection with taking care of the time between flights. If the sum of the duration of flight time and the turn time at the end of a flight is less than the time of the beginning of the next flight, this constraint connects the flight *i* and *j* each other with flight connection arc. The departure time constraint in the same way is written for dummy source node (8) as well as for dummy sink (9). The constraint set (10) provides feasible connection by taking into consideration of airports for the flights taken place within the day. In this constraint, for aircraft *k* the x_{ijk} variable is 1 only when the departure city of flight leg *j* is the same with the arrival city of flight leg *i*. Otherwise, all the variables are equal to zero. The constraint set (11) is a constraint for dummy source node. It provides that every aircraft is assigned a starting flight leg. The constraint set (12) is the group which provides the assignment of first flights from the airports by taking into consideration the airport the aircrafts spend the night. The constraint set (13) provides that the aircrafts having value below certain limits are assigned to the airports for maintenance in their last flight after they completed appropriate routes. This set of restrictions ensures that the aircrafts are routed to the airports where the required maintenance can be performed. The parameter that represent the maintenance limits can be determined by the decision maker within the range of 9-12 flight hours according to average daily flight time. The aircrafts with flight hours exceeding the limiting range might overnight at the airport of the last flight. The constraint group (14) is used to make sure that the assigned routes remain within the legal flight time. The local Civil Aviation Authority issues severe fines including revoking flight licenses to airlines companies which neglect the maintenance within legally allowed flight period time in accordance with the relevant regulations. Although most of the aircraft maintenance procedures take the flight hours as basis, there may still be some day-based maintenance operations imposed by the manufacturers. The constraint (15) provides routes in such a way that at the end of n days the aircrafts are assigned to cities with appropriate maintenance centers. The constraints of (16) are formed to build through flights instead of connecting flights, since airlines providing this service to the passengers reported to have increased their profit, and have become preferred airlines [23]. The major advantage of a through flight over a connecting flight is to save passengers from the hassle of moving from one aircraft to another. *Nth_u* index set for these constraints represents the set of through flights. The duration of flight from dummy source to any airport is zero. The departure times of the dummy source and dummy sink for each aircraft *k* is different from zero.

4. APPLICATIONS

Three sets of flight programs for experiments have been prepared based on the data of two commercial airlines. The sets include 22, 64, and 136 flights consecutively. The problems have been solved by using CPLEX/GAMS mixed integer linear program solving software. The results of the experiments obtained have been presented and interpreted.

In the problem set of 22 flights, the number of aircrafts is set to four; and the number of through flights is set to 1. The results of concurrent aircraft route and maintenance planning model, are shown in Figure 1 for each aircraft. The figure indicates that the aircrafts with longer legal remaining flying hours are utilized less while the ones with shorter remaining flying hours are utilized up to 100%. For instance, the aircraft having number 1 on the tail has the highest remaining flying hours (850 minutes) with the lowest utilization percentage (42%). The aircraft having number 3 on the tail having 450 flight minutes were utilized 100%. As seen in Figure 1, the model assigned the aircrafts with minimum remaining legal flight hours to routes. However, this does not mean that an ascending sortation of remaining flight hours can be used to solve as a prioritization scheme in assigning aircrafts to routes. It depends on the place where the aircraft is, the flight time, other connecting and through flights, and the airport it has landed in the last flight. The sample data sheet for 22 flights is given in Table 1, and the routes map is shown in Figure 2.

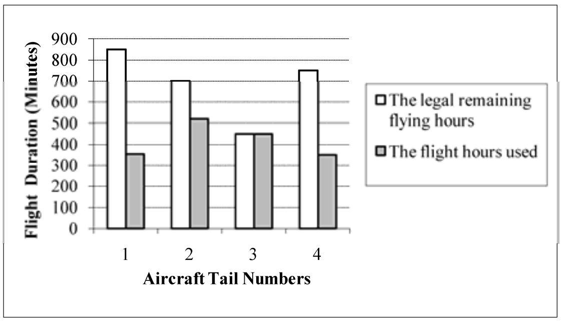

Figure 1. For 22 Flights – Concurrent Aircraft Routing and Maintenance Scheduling Solutions.

Table 1. Sample Data Sheet for 22 Flights-Test Problems.

Flight Numbers	From	To	Departure Time	Arrival Time	Flight Numbers	From	To	Departure Time	Arrival Time
F101	ADA	IST	05:25	07:00	F112	IST	ADB	13:00	14:00
F102	ESB	IST	07:00	08:00	F113	IST	AYT	08:25	09:40
F103	ESB	IST	19:00	20:00	F114	IST	AYT	11:25	12:40
F104	AYT	IST	10:30	11:45	F115	IST	ADA	23:35	01:10
F105	AYT	IST	13:30	14:45	F116	IST	TZX	07:00	08:45
F106	DNZ	IST	20:05	21:15	F117	IST	TZX	17:25	19:10
F107	IST	ESB	17:00	18:00	F118	ADB	IST	10:00	11:00
F108	IST	ESB	22:00	23:00	F119	ADB	IST	15:00	16:00
F109	IST	DNZ	18:10	19:20	F120	KYA	IST	22:20	23:30
F110	IST	KYA	20:25	21:35	F121	TZX	IST	10:00	11:45
F111	IST	ADB	08:00	09:00	F122	TZX	IST	20:05	21:55

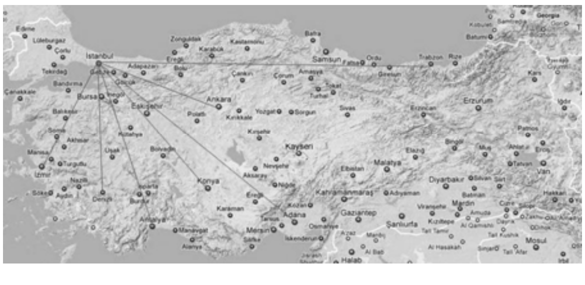

Figure 2. For 22 Flights – Routes Map.

In the set of 64 flight-problems, the number of aircrafts is set to 11. The flight program was formed in terms of hub-and-spoke network with a single hub. This means that there was less connection possibility among these flights. The total time period of 64 flight periods-11 aircrafts assigned to maintenance and route planning and their legal remaining flying hours comparison have been shown in Figure 3. The sample data sheet for 64 flights is given in Table 2, and the routes map is shown in Figure 4.

Table 2. Sample Data Sheet for 64 Flights-Test Problems.

Flight Numbers	From	To	Departure Time	Arrival Time	Flight Numbers	From	To	Departure Time	Arrival Time
F101	IST	ADA	06:30	08:00	F133	ADB	IST	16:30	17:30
F102	IST	ADA	15:15	16:45	F134	ADB	IST	22:30	23:30
F103	IST	ADA	20:00	21:30	F135	IST	ASR	06:30	07:50
F104	ADA	IST	08:55	10:25	F136	IST	ASR	19:40	21:00
F105	ADA	IST	17:40	19:10	F137	ASR	IST	08:50	10:10
F106	ADA	IST	22:30	23:55	F138	ASR	IST	21:50	23:10
F107	IST	AYT	06:30	07:30	F139	IST	KYA	11:30	12:40
F108	IST	AYT	10:45	11:45	F140	KYA	IST	13:20	14:25
F109	IST	AYT	16:45	17:45	F141	IST	MLX	11:50	13:20
F110	IST	AYT	20:45	21:45	F142	MLX	IST	14:15	15:45
F111	AYT	IST	08:30	09:30	F143	IST	MQM	13:25	15:10
F112	AYT	IST	12:35	13:35	F144	MQM	IST	16:10	17:55
F113	AYT	IST	18:45	19:45	F145	IST	SZF	11:55	13:10
F114	AYT	IST	22:50	23:50	F146	SZF	IST	14:10	15:25
F115	IST	DLM	15:35	16:45	F147	IST	TZX	06:40	08:15
F116	DLM	IST	17:45	18:55	F148	IST	TZX	18:55	20:30
F117	IST	DIY	06:40	08:25	F149	TZX	IST	09:15	10:50
F118	IST	DIY	18:55	20:40	F150	TZX	IST	21:35	23:10
F119	DIY	IST	09:25	11:00	F151	ESB	AYT	18:15	19:15
F120	DIY	IST	21:40	23:25	F152	ESB	AYT	16:15	17:15
F121	IST	ERZ	12:10	14:00	F153	AYT	ESB	20:15	21:15
F122	ERZ	IST	14:55	16:45	F154	AYT	ESB	18:15	19:15
F123	IST	GZT	06:30	08:15	F155	ESB	DIY	09:15	10:30
F124	IST	GZT	19:50	21:35	F156	ESB	DIY	10:30	11:45
F125	GZT	IST	09:10	10:55	F157	DIY	ESB	11:30	12:45
F126	GZT	IST	22:35	00:20	F158	DIY	ESB	12:45	14:00
F127	IST	ADB	06:30	07:30	F159	ESB	ADB	22:15	23:30
F128	IST	ADB	10:30	11:30	F160	ESB	ADB	20:15	21:30
F129	IST	ADB	14:25	15:25	F161	ESB	ADB	13:45	15:00
F130	IST	ADB	20:30	21:30	F162	ADB	ESB	07:00	08:15
F131	ADB	IST	08:30	09:30	F163	ADB	ESB	07:45	09:00
F132	ADB	IST	12:30	13:30	F164	ADB	ESB	16:00	17:15

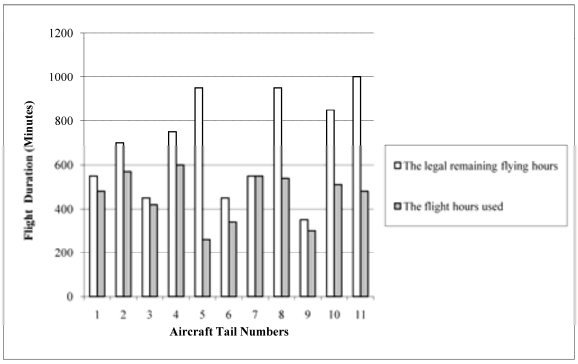

Figure 3. For 64 Flights – Concurrent Aircraft Routing and Maintenance Scheduling Solutions.

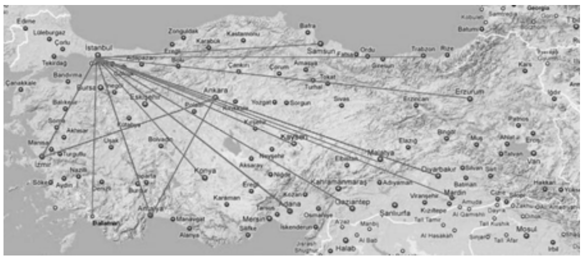

Figure 4. For 64 Flights – Routes Map.

In the third problem consisting of 136 flights we focused on the computation times over different aircraft numbers based on the proposed approach. This problem is a hub-and-spoke network with two hubs. The model has been solved for varying number aircrafts from 30 to 38. Since increasing number of aircrafts generates more alternatives, the increments in the computation time are not steep resembling a linear trend. For 136 flights, daily concurrent aircraft maintenance and routing model, solution and time relationship with different numbers of aircraft have been shown in Figure 5. The sample data sheet for 136 flights is given in Table 3, and the routes map is shown in Figure 6.

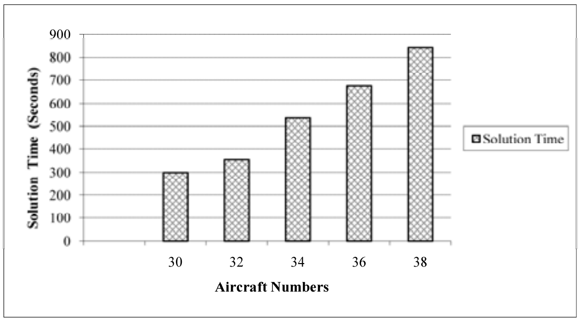

Figure 5. For 136 Flights – The Solution Times for Concurrent Aircraft Routing and Maintenance Scheduling Model According To Aircraft Numbers.

Table 3. Sample Data Sheet for 136 Flights-Test Problems.

Flight Numbers	From	To	Departure Time	Arrival Time	Flight Numbers	From	To	Departure Time	Arrival Time
F101	ADA	IST	05:25	07:00	F169	IST	ESB	22:00	23:00
F102	ADA	IST	09:35	11:10	F170	IST	ESB	23:45	00:45
F103	ADA	IST	11:10	12:45	F171	IST	DLM	07:05	08:20
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
F166	IST	ESB	18:00	19:00	F234	TZX	IST	07:20	09:05
F167	IST	ESB	19:00	20:00	F235	TZX	IST	10:00	11:45
F168	IST	ESB	20:00	21:00	F236	TZX	IST	20:05	21:55

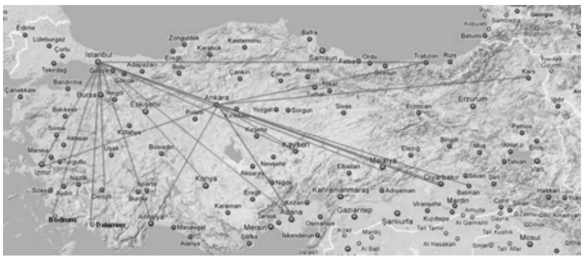

Figure 6. For 136 Flights – Routes Map.

5.CONCLUSIONS

With the developing economy and the lifting of limitation in the aerospace sector, the Turkish Civil Aviation Sector is expected to develop by 4.9% in the coming years. In airlines industry where competition is very stiff, a successful management must have a solution plan to reduce maintenance costs accounting for 18-23% of the total operation costs.

In this study, a mathematical-model driven approach is proposed to maximize the flight times between maintenances. The model assign aircrafts to flights to build a route by taking the remaining flight times into consideration as well as the location information of the airports that can serve the aircrafts for that specific maintenance. The model is formulated to address the issue of hour-based flight time instead of the day-based flight times of the common practice.

Maximizing the flight times and assigning the aircraft to the airports with the appropriate maintenance centers as the final destination before maintenance period ends enable the proposed approach to minimize early and tardy maintenances. Minimizing early and tardy maintenances promises significant savings for airlines.

Another advantage of the approach is to provide smooth maintenance requirements by giving higher priority to the aircrafts with less remaining flight times. This prioritization scheme reduces the peaks and, therefore the tension over the maintenance centers due to capacity stretches. Instantaneous capacity increases required from maintenance centers usually causes an additional cost. This cost does not only include direct maintenance costs due to extra shifts but also indirect costs of lower utilized aircrafts due to inevitable grounding for maintenance activities. The experiments have been performed for A-checks. However, once this approach has been adopted as a concurrent routing-maintenance planning tool, the savings will prevail to the other types of checks, B, C and D in the same way. Consecutively, the airline operators will have advantage over their competitors without any violation of the rules laid down by the civil aviation authority.

6. REFERENCES

[1] IATA, “IATA 2008 Annual Report”, International Air Transport Association, 2008.

[2] Airbus, “Airbus Global Market Forecast 2009-2028”: Airbus, 2009.

[3] http://www.unece.org/trans/doc/transsitdocs/2008turkey.pdf

[4] http://www.radikal.com.tr/haber.php?haberno=215701&

[5] http://www.defencetalk.com/boeing-supports-and-celebrates-growth-in-the-turkish-aviation-market-15522

[6] Kinnison, H. A., “Aviation Maintenance Management”, McGraw-Hill, New-York, 2004.

[7] Orhan, I., Kapanoglu, M., Karakoc, T.H. 2007, “Flight-Hour Based Optimization for Aircraft Scheduling”, INFORMS, 369, WD43, A.B.D.

[8] Orhan, I., Kapanoglu, M., Karakoc, T.H., 2010, "Planning And Scheduling Of Airline Operations", Pamukkale University Journal of Engineering Sciences, 16(2), 181-191, 2010.

[9] Boeing, "Section 1-System Maintenance Program, 737-600/700/800/900 Maintenance Planning Document" . s.1.0-5, 2005.

[10] Clarke, L.W., Johnson, E.L., Nemhauser, G.L., Zhu Z., "The Aircraft Rotation Problem", Annals of Operations Research, 69, 33-46, 1997.

[11] Gopalan, R., K. Talluri, "The Aircraft Maintenance Routing Problem", Operations Research, 46, 260–271, 1998.

[12] Radnoti, G., "Profit Strategies for Air Transportation", McGraw-Hill, New York, 2002.

[13] Daskin, M.S. and Panayotopoulos N.C., "A Lagrangian Relaxation Approach to Assigning Aircraft to routes in Hub and Spoke Networks", Transportation Science, 23(2), 91-99, 1989.

[14] Feo, T.A., Bard J. F., "Flight Scheduling and Maintenance Base Planning", Management Science, 35, 1415-1432, 1989.

[15] Kabbani, N.M. and Patty B.W., "Aircraft Routing at American Airlines", Proceedings of the Thirty-Second Annual Symposium of the Airline Group of the International Federation of Operational Research Societies, Budapest, Hungary, 1992.

[16] Hane, C.A., Barnhart, C., Johnson E.L., Marsten R.E., Nemhauser G.L., Sigismindi G., "The Fleet Assignment Problem: Solving A Large Scale Integer Program", Mathematical Programming, 70, 211-232, 1995.

[17] Clarke, L.W., Hane, C.A., Johnson, E.L., Nemhauser, G.L., "Maintenance and Crew Considerations in Fleet Assignment", Transportation Science, 30, 249–261, 1996.,

[18] Desauliniers, G., Desrosiers, J., Dumas, Y., "Daily Aircraft Routing and Scheduling", Management Science, 43, 841-855, 1997.

[19] Barnhart, C., Boland, N.L., Clarke L.W., Johnson E.L., Nemhauser, G.L., "Flight String Models for Aircraft Fleeting and Routing", Transportation Science, 32(3), 208-220, 1998.

[20] Cordeau, J.F., Stojkovi´c, G., Soumis F., Desrosiers, J., "Benders Decomposition for Simultaneous Aircraft Routing and Crew Scheduling", Transportation Science, 35, 375–388, 2001.

[21] Sriram, C. and Haghani, A., "An Optimization Model for Aircraft Maintenance Scheduling and Re-Assignment", Transportation Science, 37, 29-48, 2003.

[22] Sarac, A., Batta, R., Rump, C.M., A Branch-and-Price Approach For Operational Aircraft Maintenance Routing", European Journal of Operational Research, 175, 1850-1869, 2006.

[23] Ahuja, R.K., Goodstein, J., Mukherjee, A., Orlin, J.B., Sharma, D., "A Very Large-Scale Neighborhood Search Algorithm for the Combined Through and Fleet Assignment Model", Working paper.4388-01, MIT Sloan School of Management, 2001.

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