Osmangazi Üniversitesi Müh. Mim. Fak. Dergisi C.XIII, S.1, 2000
Eng. & Arch. Fac. Osmangazi University, Vol. XIII, No. 1, 2000

A SCHEDULING ALGORITHM FOR AIR TRAFFIC FLOW MANAGEMENT

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ABSTRACT : *The aviation industry becomes increasingly successful and air travel grew faster than the capacity of air traffic control system. Consequently, air traffic congestion is the major problem of today's and near future's air traffic management. Air traffic congestion results in delays of flights prior to departure; in-flight holding; unsafe flights; use of uneconomic flight levels; re-routings and diversions; disruptions of flight schedules and fleet utilization; economic and fuel penalties for aircraft operators. Air traffic flow management units are established for demand and capacity balancing. A new scheduling algorithm for air traffic flow management to solve congestion problem is presented as a decision making aid in air traffic flow management.*

KEYWORDS : *Air Traffic Management, Air Traffic Flow Management (ATFM), Traffic Scheduling.*

HAVA TRAFİK AKIŞ YÖNETİMİ İÇİN BİR ÇİZELGELEME ALGORİTMASI

ÖZET : *Havacılık sanayisindeki hızla artan gelişmeler, hava taşımacılığının hava trafik kontrol sistemi kapasitesinden çok daha hızlı büyümesiyle sonuçlanmıştır. Bunun sonucunda hava trafik tıkanıklığı, günümüz ve yakın geleceğin hava trafik yönetiminin temel problemi olmuştur. Hava trafik tıkanıklığı kalkış gecikmeleri, uçuşta beklemeler, emniyetiz uçuşlar, ekonomik olmayan uçuş seviyelerinin kullanımı, yeni yollar ve yoldan sapmalar, uçuş tarifesi ve filo kullanımında bozulmalar ve uçak işleticisini zarara sokan yakıt ve maliyet artışlarıyla sonuçlanır. Hava trafik akış yönetimi birimleri sistem kapasitesi ve trafik talebi arasındaki dengenin sağlanması için kurulmuşlardır. Burada verilmiş olan çizelgeleme algoritması, hava trafik akış yönetimi birimlerinde trafik tıkanıklarını çözmek için geliştirilmiş yeni bir karar destek yardımcısıdır.*

ANAHTAR KELİMELER : *Hava Trafik Yönetimi, Hava Trafik Akış Yönetimi, Trafik Çizelgeleri.*

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NOMENCLATURE:

b	binary number,
c^k	service ceiling of the k-th flight,
d_{ij}	the distance between i and j nodes,
EML	cost due to new flight level,
$H = \{1,2,...,h)$	the index of flight levels,
h^k	flight level of the k-th flight,
GML	cost of delay,
$I = \{1,2,...,i,...,N)$	the set of nodes, entrance nodes,
$J = \{1,2,...,j,...,N)$	the set of nodes, after node i,
$K = \{1,2,...,k,...,N)$	the set of flights,
S	separation distance,
$T_j^{k,h}$	the arrival time of k-th flight to j-th node at flight level h,
$T^k{}_e$	the sector entrance time for k-th flight,
$T^k{}_{er}$	the sector entrance time requested by k-th flight,
$T^k{}_x$	the sector exit time for k-th flight,
$T^k{}_{xr}$	the sector exit time planned by k-th flight,
ΔT_t	the total delay,
$\Delta T^{kh}{}_j$	time difference between two aircraft crossing same j-th node.
V^k	airspeed of the k-th flight
X	the total number of flights

I. INTRODUCTION

Air traffic system consists of aircraft, airspace, navigation aids and manpower. All aircraft in flight or operating on the maneuvering area of an aerodrome form air traffic. Airspace, navigation aids and manpower are major elements of air traffic services units. Air Traffic Management (ATM) ensures the safe, orderly and economic flow of flights and it is responsible for overall air traffic system. Human controllers through use of some decision-making aids (radar and communication equipment) provide steady flow of flights in current air traffic system. To perform this task, controllers rely mostly on indirect information, which is:

- provided before the flight
- sensed by ground-based installations
- transponded from aircraft
- computed from collected data
- radioed by air crew
- telephoned by other controllers [1].

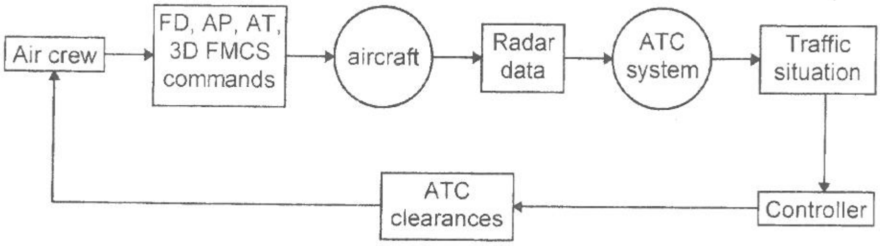


Figure 1. Basic air traffic control (ATC) loop [1].

Figure 1 presents a graphical description of the ATC decision-making loop. The aircrew provides Flight Director (FD), Auto Pilot (AP) and Auto Throttle (AT) inputs assisted by the Flight Management and Control System (FMCS). The aircraft positions are tracked by radar systems. In the ATC data processing system, the 3D positions of the aircraft are linked to available flight plan information and the compiled "present traffic situation" is presented to the controller. On the basis of this information, the controller builds in his mind a representative picture of the observed traffic. He than estimates the probable evolution of the traffic, identifies potential problems, elaborates tentative solutions, evaluates their likely consequences, decides on the implementation and communicates the instructions to the aircrew. The updated "present traffic situation" is periodically reconsidered and the loop is repeated [1].

Although the processing capability of the human brain on the field of decision making is virtually unrivaled, the capacity of the communication channel to transfer information to and from the brain is very limited, i.e., a few bytes per second. It appeared that these facts are of paramount importance in the design of automated decision-making aids [1].

II. AIR TRAFFIC FLOW MANAGEMENT (ATFM)

Air traffic control objectives are:

(1) safety,

(2) orderly flow,

(3) economy

of flights. They are closely interrelated, but it is extremely difficult to satisfy all of them simultaneously. It's the old story of trying to please three masters at the same time. The difficult problem is to engineer a solution that will suitably address all three, or be acceptable to all three [2].

Solution of this kind of problems and applications are found only in planning and control functions of air traffic management. Planning is considered in short, medium and long term. Planning function involves:

(1) System planning (long term)

(2) Flight schedules planning (medium-short term).

System planning is associated with the planning of airspace structure, airways and ATC procedures. Flight schedules' planning is associated to the planning of flights within a time horizon of some months (generally 6 months) in connection with the traffic demand.

Strategic and tactical controls are control functions. In order to compare flight schedules with current system capacity, strategic control is a planning activity. ATFM units perform strategic control function. Tactical control is the real time control action. Strategic and tactical functions of an air traffic system and relation of these functions to ATFM are shown in Figure 2.

Strategic functions given in this figure contain:

a. Balancing capacity and demand: The purpose of this function is to foresee any potential unbalance between capacity and demand sufficiently early to be able to take any necessary corrective action without disturbing the normal flow of traffic.

b. Management of flight plan data: Subject to the need to balance capacity and demand, the flight plan data representing the traffic demand that has been accepted will be stored than transmitted to the control centers concerned with a reasonable amount of advance notice.

c. Traffic flow management: the permanent monitoring of the traffic flow; the permanent monitoring of airspace availability and the availability of ground services; coordination between several centers regarding the action to be taken in the event of difficulties concerning the traffic flow; transmission to control centers of any information relating to the traffic flow.

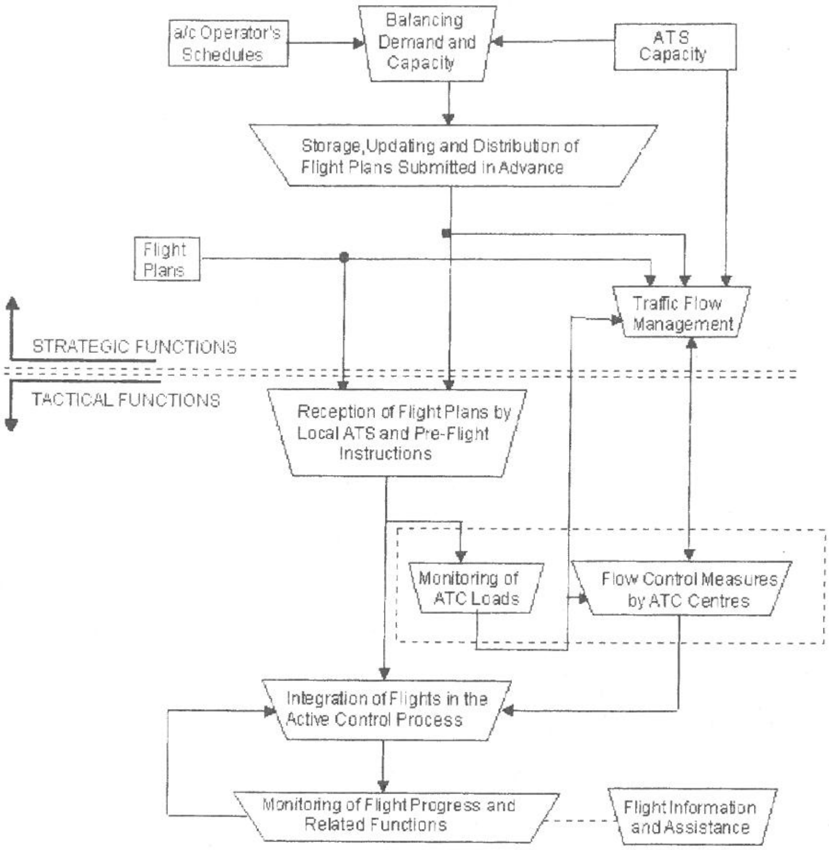


Figure 2. Strategic and tactical control functions [3].

International Civil Aviation Organization (ICAO) defines air traffic flow management as any activity concerned with the organization and handling of the flow of air traffic in such a way that, while ensuring the safe, orderly and expeditious flight of individual aircraft, the totality of the traffic handled at any given point or in any given area is compatible with the capacity of the ATC system [4].

III. ATC SYSTEM CAPACITY

Capacity is ability of the ATC system or any of its sub-systems or an operating position to provide service to aircraft during normal activities. It is expressed in numbers of aircraft entering a specified portion of the airspace in a given period of time. The maximum peak capacity, which may be achieved for short periods, may be appreciably higher than the sustainable value [4].

ATC system capacity constraints are:

(1) aircraft performance and equipment,

(2) airspace network structure,

(3) radar and radio navigation aids technology level,

(4) ATC procedures (separation),

(5) human (pilot and controller) capacity,

(6) meteorological factors,

(7) flight operations differences.

III.1 Aircraft Performance Constraint

The pilot does his own navigation only when there is no nearby aircraft. If more than one aircraft are flying in the same airspace sector, an air traffic controller's intervention is required along with pilots' efforts for the safety of these flights. If two aircraft are flying along the same route on the same direction and the following aircraft is faster than the leading aircraft, the following aircraft must adjust its speed to the leading aircraft's slower speed. Therefore, the leading aircraft's speed is an aircraft performance constraint for the flights along this route.

Flight ceiling is another important aircraft performance constraint. Most aircraft suffer economic penalties of fuel and speed at lower operating altitudes.

III.2 Airspace Network Structure

The airspace under control is defined by a given set of standard routes and waypoints, corresponding to navigational aids and checkpoint locations. The airspace structure can be represented in a straightforward way as a directed network of arcs and nodes. The nodes are of following types:

(1) Source nodes, representing terminal control areas, generating departing traffic, or boundary points of airspace where traffic arriving from outer region is generated.

(2) Intermediate nodes, representing routes' intersections or given checkpoints.

(3) Sink nodes, representing points of arrival into terminal areas, or boundary points where traffic disappears to outer region.

The arcs represent the route segments connecting a couple of nodes. Furthermore, different arcs can be associated to different groups of flight levels along the same route [5].

III.3 Radar and Navigation Aids Technology

Radar is an important factor because efficient separation minimum can be achieved by a precise radar system.

The airway system generally allows aircraft to self navigate between terminal areas using the internationally accepted VOR/DME guidance along defined airways, which are invariable radials to or from the relevant aid [6]. The ICAO Future Air Navigation System (FANS) Committee completed a system concept for a satellite based Communication, Navigation, and Surveillance (CNS) system along with an evolutionary approach to ATM. The satellite and information technologies are the foundations of FANS and provide a cost-effective method to monitor and control air traffic, even in areas with limited radar and communication systems. CNS concept will automatically and continuously provide controllers highly accurate information on aircraft positions anywhere in the world [7].

III.4. ATC Procedures

The aircraft operating in the same general area shall be flown at such distances from each other that the risk of their colliding with each other is reduced. This safety distance is called "separation."

(1) Vertical Separation: Vertical separation is obtained by requiring aircraft using prescribed altimeter setting procedures to operate at different levels expressed in terms of flight level or altitudes. The vertical separation minimum shall be a nominal 300 meters (1000 feet) below an altitude of 8850 meters (29000 feet), and a nominal 600 meters (2000 feet) at or above this level [8].

(2) Horizontal Separations: The horizontal radar separation minimum shall be 9.3 km (5NM). The radar separation minimum may be reduced, but not below 5.6 km (3NM), if so prescribed by the appropriate ATS authority when radar equipment capabilities in association with rapid and reliable communication facilities and radar controller experience at a given location so permit [8]. There are two types of horizontal separation. These are lateral and longitudinal separation.

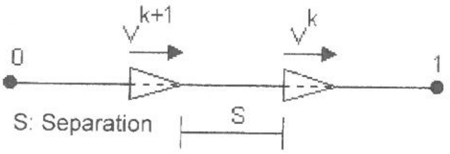


Figure 3. Aircraft separation criteria.

III.5. Human Capacity

The air traffic system is a very complex Man-Machine-System (MMS), and in an MMS, performance does not solely depend on the technical qualities of the system plus the operational environment [9].

Successful automated ATM systems will necessarily emulate the intuitive portions of the human management capability using various technologies drawn from the broad field of artificial intelligence. One of the unknown questions at this time is, "Will this technology decrease or increase the controller's workload?" With all the work going on around the world, this question is not being addressed. The answer could mark the end of automation [10].

III.6. Meteorological Conditions

Meteorological conditions affect all aircraft in flight. Information on the state of the system concerns radar data on flight evolution, short and medium term meteorological forecasts.

III.7. Flight Operations Differences

Flight operations differences:

- "airline", which means all regular, repetitive flights,
- "charter", which includes all non-scheduled, non regular carrier, business and other controlled flights,
- "military", flights of military aircraft [9].

IV. DEMAND-CAPACITY PROBLEM

Air traffic demand is the amount of flight operations in a given period of time and related to a given area, route, location or service [4]. The main causes of capacity problems are:

(1) accumulation of air traffic during specific periods of the year and also during certain times of the weeks, due to holiday patterns and travel habits of the traveling public;

(2) differences in the capacities of the various ATC systems or parts of these systems affected by traffic accumulations;

(3) insufficient advance notice of likely traffic demands and potential overloading of the system at certain points, in certain areas, and/or during specific time periods;

(4) lack of proven techniques and procedures to restore, in critical situations, a reasonable balance between traffic demand and available ATC capacity by

means acceptable to aircraft operators both from an operational and from economic point of view [11].

The ATFM service should be available to ensure the proper distribution of available capacity at any time, especially when an ATC overload may occur. The system associated can be outlined as in Figure 4 where both inputs and outputs are indicated. The inputs are flight plan data of the aircraft operators, the information relative to state of the system. The outputs are the amendments to the flight plans that represent control interventions on the flights and can be useful information for tactical control.

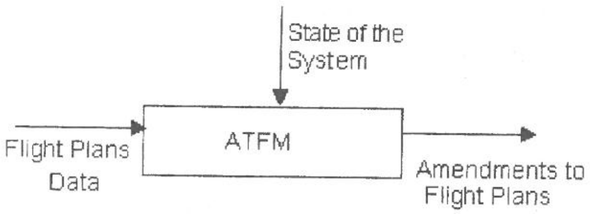


Figure 4. Representation of the ATFM function.

Sector capacity constraint causes ground delay or air delay or both. Additional ground handling costs, apron capacity problems and passenger dissatisfaction are major penalties of the ground delay. On the other hand, higher fuel consumption, higher maintenance cost and lower utilization rates are major consequences of the air delay. These consequences arise from non-optimum flight conditions.

ATFM units require a well-designed decision support aid to perform their demand-capacity balancing solutions. Such a decision support aid must provide an optimum time schedule and minimum operation costs for all the flights within the airspace that is under responsibility of the ATFM unit.

If aircraft in airspace are considered as clients in a waiting line of a service system, there should be a sequencing problem.

V. ECONOMIC FLOW MODEL

We consider arrival operations at a given airspace sector during a time interval [0,T] (normally a maximum of 60 minutes) for which we expect some congestion and during which certain flights are scheduled to arrive. The interval [0,T] is sub-divided into elementary periods, for example, 5 minutes.

It is assumed that meteorological conditions are uniform in the airspace sector within the selected time interval. So, all aircraft fly under same meteorological conditions. All flights are scheduled flights. Therefore, they are subject to strategic scheduling. It is also assumed that each flight has constant airspeed during its trip within the sector.

The economic flow model may now be formulated as follows:

$$\text{minimize } \Delta T_i = \sum_j \sum_k \sum_h \Delta T_j^{k,h} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

This is the minimum sum of delays for all the flights within the sector. New sector entrance times must be amended for some flights in order to achieve this goal. This objective function is subject to following conditions:

$$\text{For } \forall d_{ij}, \quad \frac{d_{ij}}{S} \geq x_{ij} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

This function represents the capacity of each arc within the given airspace sector. An arc is the airway between two intersection nodes. Since the aircraft have to maintain given in-trail separations due to safety reasons, the maximum rate of flow on each arc can never be exceed.

$$\text{For } \forall i, \quad x_i^l \leq 0 \vee 1 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

This equation represents the node capacity constraint. Only one aircraft or less may exist on a node at a given time. An aircraft cannot fly above its service ceiling. Equation (4) describes this constraint.

$$\text{For } \forall k, \quad c^k \geq h^k \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

The time difference between trailing aircraft is a function of the separation distance and airspeed of the leading aircraft.

$$\Delta T \geq \frac{S}{V^k} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

The total number of aircraft that plan to fly in the sector within the given time interval is another constraint.

$$X = \sum_{h=1}^{H} x^h \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

Solving such a large-scale problem can be a rather heavy task. In this case, simulation models appear to be a more convenient tool, especially for traffic analysis and management problems.

VI. SOLUTION ALGORITHM

Mathematical solution is not possible since too many aircraft types with different performances fly in an airspace sector, and model parameters are closely inter-related to each other. For that reason, a modified scheduling method is used for solution of this model. As ATC system is a service production system, solution methods of production planning and control shall be tailored to ATM problems.

Scheduling involves the timing of specific operations. In the decision-making hierarchy, scheduling decisions are the final step before actual output is achieved. The objective of scheduling is to achieve trade-off among conflict goals. Large-scale systems require approaches substantially different from those required by job shops, and project scheduling requires still different approach [12].

Scheduling methods require certain strategies for the flow of works. So, it is first required to define an entrance sequencing strategy for aircraft that intend to fly in the same airspace sector within the same period. Then, scheduling shall be provided.

VI.1. Sequencing Strategies for Improvement of Delays

Assume two aircraft that request entrance into an airspace sector of two intersecting routes (Figure 5). If these aircraft have different speeds and request entrance at the same time, one of them may be delayed in order to prevent a collision on intersection point. Therefore, a decision is required to select the aircraft that needs to be delayed. Aircraft speeds and route lengths are important decision parameters. Aircraft priority decision algorithm for this case is given in Figure 6.

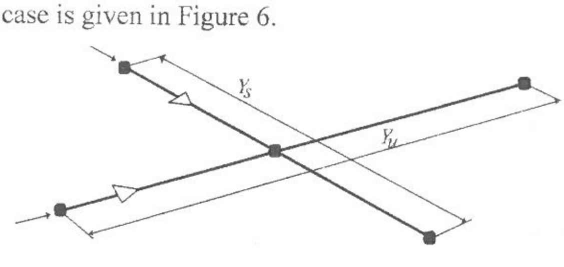


Figure 5. A sample route structure for aircraft priority.

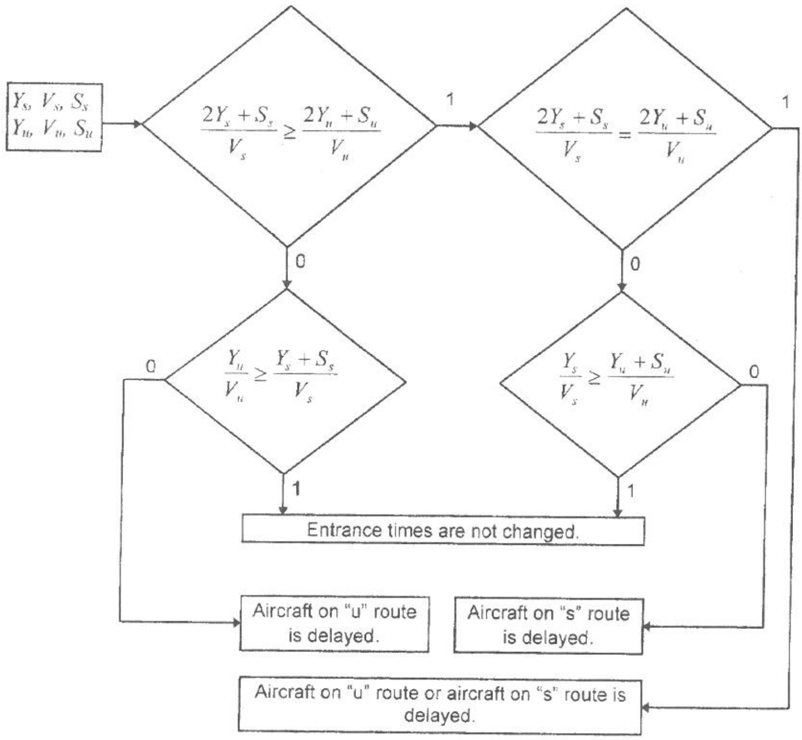


Figure 6. Decision tree for aircraft priority

VI.2. Scheduling Algorithm

Figure 7 represents algorithm structure. Index of "h" represents ATC flight level. For example, flight level of 37000 feet, 33000 feet and 29000 feet is "h" index of 1, 2 and 3. Index h is not used in the algorithm in order to avoid index complexity.

An example-scheduling table used to simplify scheduling applications is shown in Table 1. In the scheduling table, "q_n" is the normal fuel consumption without delay. "GML" is the fuel consumption due to delay. "EML" is the fuel consumption due to re-routing.

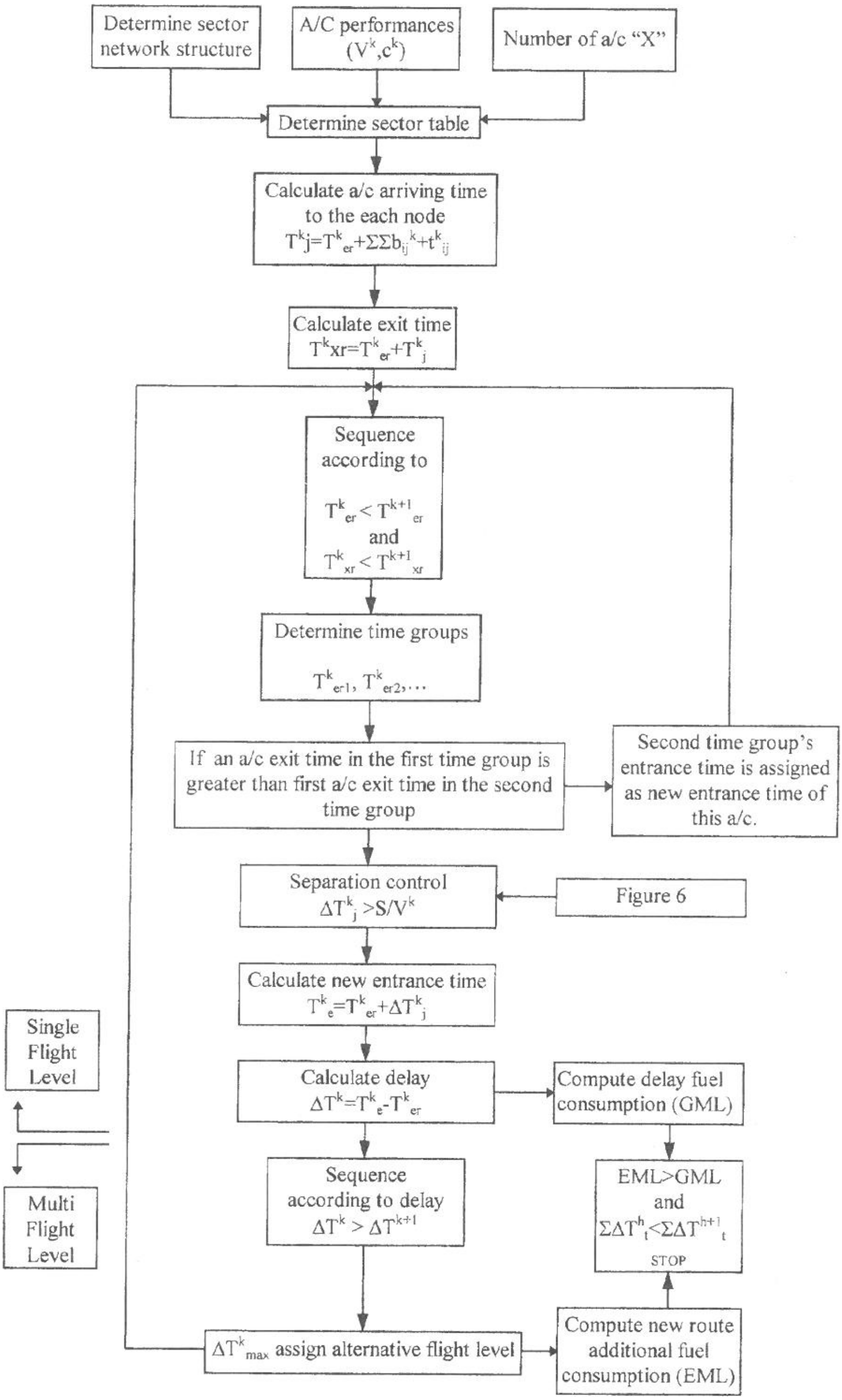


Figure 7. Algorithm structure [13].

Table 1. Scheduling table for target sector

Flight No or Call sign	Aircraft Type	Airway	Requested Flight Level	Assigned Flight Level	T_{er}	T_f	T_{xr}	T_e	T_x	T_1	...	T_i	ΔT_t	q_n	GML	EML
	B747															
	DC10															
	B727															
	EA31															
	B737															
	F28															
	C500															
	...															

VII. EXAMPLE SOLUTIONS

The example target sector's network structure contains nine nodes in single flight level, 18 nodes in two flight levels and so on. There are four airways in single flight level, eight airways in two flight levels and so on (Figure 8). Aircraft types are:

Airbus 310

Boeing 727/200

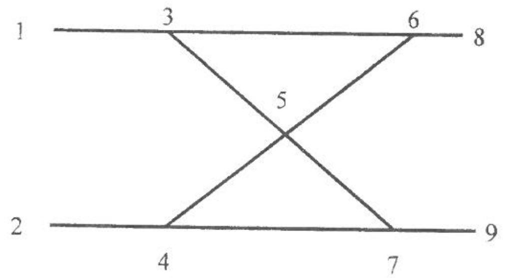
Boeing 737/300

Boeing 747/200

Cessna 500

Fokker F28

McDonnell Douglas DC10



Airway 1, FL 370: 1-3-6-8
Airway 2, FL370: 2-4-7-9
Airway 3, FL370: 1-3-5-7-9
Airway 4, FL370: 2-4-5-6-8
Airway 5, FL330: 1-3-6-8
Airway 6, FL 330:2-4-7-9
Airway 7, FL 330: 1-3-5-7-9
Airway 8, FL 330: 2-4-5-6-8

Figure 8. An example target sector for simulation.

Fifteen aircraft intend to enter example sector within 15 minutes. 5 aircraft requested to enter at zero hour, another 5 aircraft requested to enter 00:00:05 hour, the third group of 5 aircraft requested to enter 00:00:10 hour. The types flight routes, call signs, requested flight levels and requested entrance times of these aircraft are given in scheduling table of Table 2. This table is the preliminary table that shows flight duration and exit times in accordance with requested entrance times. If this table is studied deeply several conflicts are going to be seen on different intersection nodes of the example sector. For example, FN 13 and FN 14 conflict at 5th node, FN 12 and FN 14 conflict at 4th node, if these flights are conducted according to requested entrance times.

Table 2. Scheduling table of preliminary flight schedule

Flight No or Call sign	Aircraft Type	Airway	Requested Fight Level	Assigned Fight Level	T_{er}	T_f	T_{xr}	T_e	T_x	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	ΔT_t	q_n	GML	EML
FN001	B747	1	FL370		0,0	19,2	19,2			0,0		3,8			12,5		19,2			2.000		
FN002	DC10	2	FL370		0,0	19,2	19,2				0,0		3,8			12,5		19,2		1.822		
FN003	B727	3	FL370		0,0	24,3	24,3			0.0		4,1		10,5		16,9		24,3		1.305		
FN004	EA31	4	FL370		0,0	24,3	24,3				0,0		4,1	10,5	16,9		24,3			1.906		
FN005	F28	1	FL370		0,0	28,0	28,0			0,0		5,5			18,2		28,0			872		
FN006	B737	1	FL370		5,0	21,2	26,2			5,0		9,1			18,8		26,2			871		
FN007	F28	2	FL370		5,0	28,0	33,0				5,0		10,5			23,2		33,0		872		
FN008	C500	3	FL370		5,0	36,4	41,4			5,0		11,2		20,8		30,3		41,4		203		
FN009	B747	4	FL370		5,0	22,0	27,0				5,0		8,8	14,5	20,3		27,0			2.288		
FN010	C500	1	FL370		5,0	31,8	36,8			5,0		11,2			25,7		36,8			178		
FN011	DC10	1	FL370		10,0	19,2	29,2			10,0		13,8			22,5		29,2			1.822		
FN012	B727	2	FL370		10,0	21,2	31,2				10,0		14,1			23,8		31,2		1.140		
FN013	EA31	3	FL370		10,0	24,3	34,3			10,0		14,1		20,5		26,9		34,3		1.906		
FN014	B737	4	FL370		10,0	24,3	34,3				10,0		14,1	20,5	26,9		34,3			996		
FN015	B747	1	FL370		10,0	19,2	29,2			10,0		13,8			22,5		29,2			2.000		
																				20.181		

Scheduling table of Table 3 shows solution obtained by application of scheduling algorithm. In this solution, flights are delayed 0 to 15 minutes. As it is seen from the table, sequence of the flights was changed also. Extra fuel burn due to delay is around 2325 lbs. while total delay is 64 minutes.

Table 3. Conflict solution with scheduling algorithm and results

Flight No	Aircraft Type	Airway	Requested Flight Level	Assigned Flight Level	T_{er}	T_f	T_{xr}	T_e	T_x	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	ΔT_t	q_n	GML	EML
FN001	B747	1	FL 370	FL 370	0,0	19,2	19,2	0,0	19,2	0,0		3,8			12,5		19,2		0,0	2000,1	0,0	0,0
FN002	DC10	2	FL 370	FL 370	0,0	19,2	19,2	0,0	19,2		0,0		3,8			12,5		19,2	0,0	1821,9	0,0	0,0
FN003	B727	3	FL 370	FL 370	0,0	24,3	24,3	1,0	25,3	1,0		5,1		11,5		17,9		25,3	1,0	1304,8	53,7	0,0
FN004	EA31	4	FL 370	FL 370	0,0	24,3	24,3	2,0	26,3		2,0		6,1	12,5	18,9		26,3		2,0	1905,7	156,9	0,0
FN006	B737	1	FL 370	FL 370	5,0	21,2	26,2	7,0	28,2	7,0		11,1			20,8		28,2		2,0	870,8	82,0	0,0
FN009	B747	4	FL 370	FL 370	5,0	22,0	27,0	9,0	31,0		9,0		12,8	18,5	24,3		31,0		4,0	2288,0	415,8	0,0
FN011	DC10	1	FL 370	FL 370	10,0	19,2	29,2	13,0	32,2	13,0		16,8			25,5		32,2		3,0	1821,9	284,1	0,0
FN015	B747	1	FL 370	FL 370	10,0	19,2	29,2	14,0	33,2	14,0		17,8			26,5		33,2		4,0	2000,1	415,8	0,0
FN012	B727	2	FL 370	FL 370	10,0	21,2	31,2	10,0	31,2		10,0		14,1			23,8		31,2	0,0	1140,4	0,0	0,0
FN013	EA31	3	FL 370	FL 370	10,0	24,3	34,3	10,0	34,3	10,0		14,1		20,5		26,9		34,3	0,0	1905,7	0,0	0,0
FN014	B737	4	FL 370	FL 370	10,0	24,3	34,3	11,0	35,3		11,0		15,1	21,5	27,9		35,3		1,0	996,3	41,0	0,0
FN005	F28	1	FL 370	FL 370	0,0	28,0	28,0	15,0	43,0	15,0		20,5			33,2		43,0		15,0	872,0	467,5	0,0
FN007	F28	2	FL 370	FL 370	5,0	28,0	33,0	14,0	42,0		14,0		19,5			32,2		42,0	9,0	872,0	280,5	0,0
FN010	C500	1	FL 370	FL 370	5,0	31,8	36,8	16,0	47,8	16,0		22,2			36,7		47,8		11,0	177,7	61,4	0,0
FN008	C500	3	FL 370	FL 370	5,0	36,4	41,4	17,0	53,4	17,0		23,2		32,8		42,3		53,4	12,0	203,4	67,0	0,0
																			64,0	20180,9	2325,8	0,0

Table 4 shows multi flight level solution results. By this solution maximum delay is 7 minutes, extra fuel burn due to delays and flight level changes is 1430 lbs. while total delay is 29 minutes.

Table 4. Multi flight level solution results

Flight No	Aircraft Type	Airway	Requested Flight Level	Assigned Flight Level	T_{ar}	T_f	T_{xr}	T_e	T_x	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	ΔT_t	q_n	GML	EML
FN001	B747	1	FL 370	FL 370	0,0	19,2	19,2	0,0	19,2	0,0		3,8			12,5		19,2		0,0	1999,8	0,0	0,0
FN002	DC10	2	FL 370	FL 370	0,0	19,2	19,2	0,0	19,2		0,0		3,8			12,5		19,2	0,0	1821,7	0,0	0,0
FN003	B727	3	FL 370	FL 370	0,0	24,3	24,3	1,0	25,3	1,0		5,1		11,5		17,9		25,3	1,0	1304,8	53,7	0,0
FN004	EA31	4	FL 370	FL 370	0,0	24,3	24,3	2,0	26,3		2,0		6,1	12,5	18,9		26,3		2,0	1905,6	156,9	0,0
FN006	B737	1	FL 370	FL 370	5,0	21,2	26,2	7,0	28,2	7,0		11,1			20,8		28,2		2,0	870,7	82,0	0,0
FN009	B747	4	FL 370	FL 370	5,0	22,0	27,0	8,0	30,0		8,0		11,8	17,5	23,3		30,0		3,0	2288,3	311,9	0,0
FN011	DC10	1	FL 370	FL 370	10,0	19,2	29,2	12,0	31,2	12,0		15,8			24,5		31,2		2,0	1821,7	189,4	0,0
FN012	B727	2	FL 370	FL 370	10,0	21,2	31,2	10,0	31,2		10,0		14,1			23,8		31,2	0,0	1140,3	0,0	0,0
FN014	B737	4	FL 370	FL 370	10,0	24,3	34,3	11,0	35,3		11,0		15,1	21,5	27,9		35,3		1,0	996,3	41,0	0,0
FN013	EA31	3	FL 370	FL 370	10,0	24,3	34,3	10,0	34,3	10,0		14,1		20,5		26,9		34,3	0,0	1905,6	0,0	0,0
FN005	F28	1	FL 370	FL 330	0,0	28,0	28,0	0,0	28,0	0,0		5,7			19,0		29,3		0,0	969,6	0,0	97,5
FN015	B747	1	FL 370	FL 330	10,0	19,2	29,2	10,0	29,2	10,0		13,9			23,0		30,1		0,0	2131,4	0,0	131,6
FN007	F28	2	FL 370	FL 330	5,0	28,0	33,0	10,0	38,0		10,0		15,7			29,0		39,3	5,0	969,6	173,3	97,5
FN010	C500	1	FL 370	FL 330	5,0	31,8	36,8	11,0	42,8	11,0		17,4			32,4		44,0		6,0	186,3	35,1	8,6
FN008	C500	3	FL 370	FL 330	5,0	36,4	41,4	12,0	48,4	12,0		18,4		28,3		38,2		49,7	7,0	213,2	41,0	9,9
																			29,0	20525,1	1084,3	345,2

VIII. CONCLUSION

There is a close relation among total delay, total fuel consumption and the number of aircraft that are required to change flight level. Total delay depends on the number of aircraft that are required to change flight level. However, total delay starts to increase again after that minimum point, because desolate flight level becomes crowded by assignment of new flights to that level. Delay fuel decreases up to a number of aircraft that are required to change flight level. However, re-routing fuel increases due to changing flight level or using except to optimum route. Consequently, total fuel increases. For the optimum solution of this situation, it is required to change flight levels of five aircraft. Minimum sector fuel loss is obtained by this way.

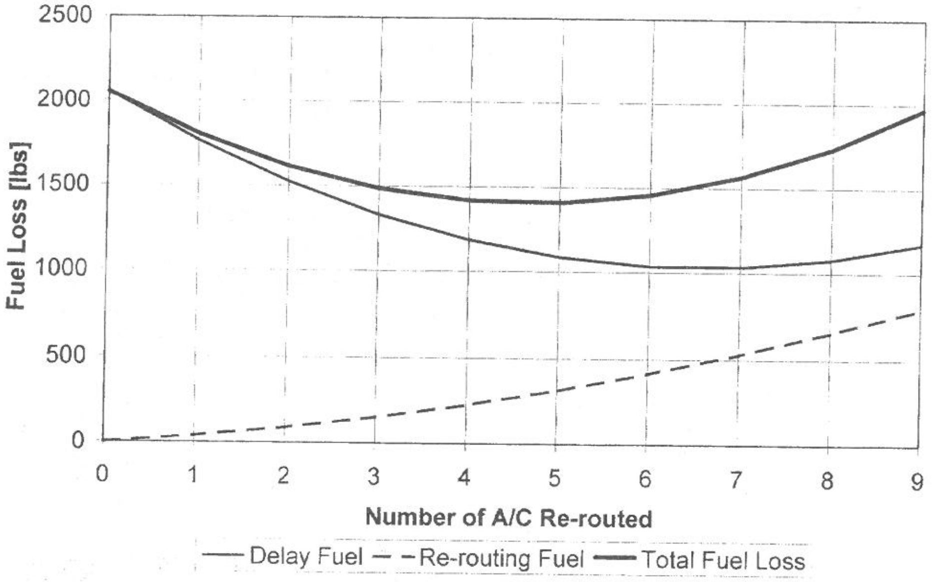


Figure 9. The number of aircraft changing flight level and fuel consumption and delay relations.

Application of algorithms that are similar to the one introduced here by ATFM units may reduce tactical control workload of the controllers. These algorithms decrease the number of controller interventions that require decision-making efforts. For that reason, such algorithms are fundamentals of decision support systems. Under today's heavy traffic load conditions, decision support systems are now absolutely required in order to achieve air traffic management objectives. Decision support systems are one aspect of the development, which can reach fruitful implementation before turn of the century.

REFERENCES

[1] A. Benoit And J.-M. Pomeret And S. Swerstra, "Decision making aids (DMA) in on-line ATC systems", Machine-Intelligence in ATM, Guidance and Control Symposium, Berlin, Germany; *AGARD Conference Proceedings* no.538, pp14/1-14/11, 1993.

[2] J.E Dow, "Keynote address", Plans and Developments for Air Traffic Systems, 20th Symposium of the Guidance and Control Panel, Cambridge, USA; *AGARD Conference Proceedings* no.188 , 1975.

[3] EUROCONTROL, "*Developments in Automated ATC Systems*", Eurocontrol Institute Press, Luxembourg , 1989.

[4] ICAO, "*Air Navigation Plan, European Region*", ICAO, Montreal ,1997.

[5] L. Bianco And M. Bielli, "Air traffic management: Optimization models and algorithms", *Journal of Advanced Transportation* vol.2, pp131- 167, 1992.

[6] K. Watling And R.C. Rawlings, "Studies of automatic navigation systems to improve utilization of controlled airspace", 20th Symposium of the Guidance and Control Panel Cambridge, USA; *AGARD Conference Prsoceedings* no.188, pp.1/1-1/15, 1975.

[7] R.N. PITTS, "An evolutionary approach", *ATM Yearbook 94/95*, Camrus Publishers, pp.28-31 ,1995.

[8] ICAO, "Procedures for Air Navigation Services, Rules of the Air Traffic Services, Document 4444", ICAO, Montreal ,1985.

[9] R. Seifert, "System, airspace, and capacity requirements for future ATC-systems", ATM Civil/Military Systems and Technologies, Guidance and Control Panel Symposium, Copenhagen, Denmark; *AGARD Conference Proceedings* no.273, pp.7/1-7/15, 1979.

[10] A.D. Hlibowicki And D. Bowen, "Intelligent systems for airspace control and management", Machine-Intelligence in ATM, Guidance and Control Symposium, Berlin, Germany; *AGARD Conference Proceedings* no.538, pp.3/1-3/11 ,1993.

[11] ICAO, "*Air Traffic Services Planning Manual*", ICAO, Montreal ,1984.

[12] W.J. Stevenson, "*Production/Operations Management*", Irwin Inc., Boston, 1990.

[13] A. Cavcar, "Hava Trafik Akış Yönetimi ve Hava Sahası Kapasitesi Analizi", Doktora Tezi, Osmangazi Üniversitesi, Fen Bilimleri Enstitüsü ,1997.