Analysis of Time and Cost Benefits of Hybrid Dynamic Gate Assignment for Aircraft Taxi Movements and Gate allocation

Orhan Ertuğrul Güçlü and Cem Çetek, PhD
Faculty of Aeronautics and Astronautics
Anadolu University
Eskisehir, TURKEY
oeguclu@anadolu.edu.tr, ccetek@anadolu.edu.tr

The continuous growth in air traffic introduces increasing extra operational costs due to serious ground delays at major airports. Gate assignment plays an active role in reducing or even eliminating these ground holds and congestions. Gate assignment is conventionally done using slot allocation techniques which rely on static and long-term (strategic) planning. Such planning usually overlooks possible in-flight delays which lead to gate assignment problems (GAP) at destination airports. The Hybrid Gate Assignment is proposed as an alternative method to mitigate these problems. The Hybrid Dynamic Gate Assignment algorithm allocates available gates to arriving aircraft when they establish on the final approach course. Such a dynamic planning provides more robust gate assignment and delay management at the airports especially in the peak hours. This study analyzes time benefits and cost effects time of a Hybrid Dynamic Gate Assignment using a fast-time simulation model. In order to demonstrate the time and fuel cost benefits of tactical gate assignment, two scenarios (baseline and alternative), have been generated and tested in SIMMOD environment. These scenarios are run for 20 gates, 39 arrivals and 19 departures within two hours at Istanbul Ataturk Airport. This Hybrid Dynamic Gate Allocation has reduced costs beside delays significantly in this alternative limited scenario. Extension of this model to a full-scale airport model can provide important reductions in delays and extra direct operational costs for air navigation service providers and airlines.

I. Introduction

THE major problem of international airports is the lack of capacity to meet the growing traffic demands since most of them have no or limited facilities for physical development. Therefore the only way to overcome this problem is to manage the airport's traffic in the most efficient way. The efficient traffic management strongly depends on the performance of air traffic controllers, ground services and pilot reaction time. The uses of more effective computer based decision support systems are not only to increase their performance but also reduce delays and extra operational costs at airports.

Ground delays at taxiway intersections are one of the major contributors of delays and congestions at airports. They usually occur because of inefficient gate allocation for arriving aircraft. The capacity of airports can be increased by using the gates and parking positions efficiently. Numerous techniques have been developed and implemented to provide efficient use of gate and parking positions. This problem is first addressed by Tosic [1], who described the airport gate assignment as quadratic assignment problem. Though this approach is a well-known method, it is difficult to implement as number of aircraft increases. Later, Bihr [2], Haghani & Chen [3] and Mangoubi & Mahaisel [4] have done researches on solving the same problem using various operational research (OR) techniques. Although these works improve the results considerably, they are insufficient to model current traffic conditions. Xu & Bailey introduced a test case problem solving using the taboo search technique providing a faster result [5]. Although this method is more effective than others, it contains a number of shortcomings. Especially it could not present dynamic solution to the delay problems. Later, the researchers start focusing on information based problem solving to eliminate these shortcomings of solutions done by OR technique. Particularly Brazile & Swigger [6], Gosling [7] and Srihari & Muthukrishnan [8] have worked on this technique. Information based system provides solutions strongly depending on historical traffic data of airports. Therefore, it does not provide a robust solution for disturbances of dynamic airport environment.

The intelligent optimization techniques are proposed besides conventional techniques. Cheng et al. attempted to assess the performance of three meta-heuristics, namely, genetic algorithm (GA), taboo search (TS), simulated annealing (SA) and a hybrid approach based on SA and TS [9]. Yan et al. analyzed the effects of stochastic flight delays on static gate assignments and evaluate flexible buffer times and real-time gate assignment rules [10]. Yan & Huo used the weighting method, the column generation approach, the simplex method and the branch-and-bound technique to develop a solution algorithm to efficiently solve large-scale problems in practice [11]. Maharjan & Matis showed that a binary integer multi-commodity gate flow network model was presented with the objective of minimizing the fuel burn cost of aircraft taxi by type and expected passenger discomfort for ‘‘tight’’ connections as a function of inter-gate distance and connection time [12]. Yu Cheng had shown a knowledge-based airport gate assignment system integrated with mathematical programming techniques to provide a solution that satisfies both static and dynamic situations within a reasonable computing time [13]. H. Ding,

This paper has been supported by Anadolu University BAP 1307F297.

A. Lim, B. Rodrigues, Y. Zhu used a greedy algorithm to minimize un-gated flights [14]. In addition to these points we had paid attention to Askin cost factors [15]. In these factors we have seen that only fuel consumption factors should be considered while the aircraft taxing.

In this study, hybrid dynamic system is proposed to model time variant features of gate assignment problem effectively. Hybrid dynamic system is referred to as a knowledge based system which allows dynamic interactions between states of the system. The efficient use of parking positions requires managing the gate timing in the best way. The biggest problem is often encountered delays in the timing of the gate assignment during slot allocation. Especially planned gate at the slot allocation cannot be used efficiently due to the delays happened at departure, en-route and approach periods. Efficient planning of gates can also improve the taxi traffic efficiency. Because ground movements of aircraft depends on its assigned gate specified gate. Taxiway crossings would be minimized by imposing restrictions on taxiways to be used. As a result of these restrictions, the efficiencies would increase to the desired level at the taxiways and decrease the fuel consumption of the aircrafts.

Hybrid dynamic system can also eliminates the major drawback of slot allocation techniques. The crew that does the slot allocation makes their approximations by looking to the expected time of arrival. The gate allocation is done based on the expected time of arrival, aircraft type and airline. The planner, on the other hand, ignores the ground encounters at the taxiway intersections and leaves the separations at the taxiways to the ground controller. Thus, the work load of ground controller increases significantly and leads to ground delays and congestions at the airport.

These drawbacks can be avoided through the use of complete automation in the gate assignment process based on hybrid dynamic method. Gate allocation and taxi path planning decisions can be done with a system gathering the data of the aircraft on the final approach course from radar and the data of the aircraft's transponder after engine-start up permit (Figure 1). Therefore, a Computer Based Decision Method (CBDM) using this hybrid dynamic method would minimize the effects of cumulative delays and human factors.

Potential benefits of this system are analyzed through two scenarios created in SIMMOD environment. This paper is planned in the following order. First, the methodology of the work has been described. The validity and the performance of this method have been described in the next stage. At the end, the results of this work, which is done to implement this method, has been discussed. In the results we have calculated the typical idle fuel consumptions of the aircraft. The reason of choosing idle fuel consumption is while aircraft is taxing and waiting it consumes the fuel at the idle level. We have preferred B737 type of aircraft using CFM56-5B engine. Because flight operations in Istanbul Ataturk Airport mostly done with this type of aircraft using this engine.

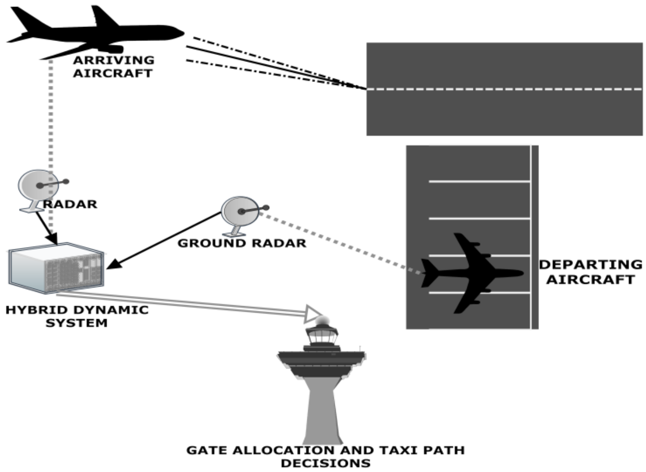

FIGURE 1.Hybrid Dynamic Gate Assignment System.

II. METHODOLOGY

Istanbul Ataturk Airport is chosen for the analysis of this Hybrid Dynamic System. First, Istanbul Ataturk Airport is modeled in SIMMOD based on the most recent Aeronautical Information Publication (AIP) data. Later, runway features, gate features, the directions of the taxiways and the holding points have been set. Ataturk Airport has three runways (35R/17L, 35L/17R and 05/23), two of which were parallel, in the shape of an open V, shown in Figure 2. The most commonly used runway configuration (35R departure/05 arrival) is selected for simulation. This configuration is the most efficient runway orientation since the departures from runway 35R cannot be affected from the arrivals to runway 05. By choosing the best configuration, airborne delays are kept at minimum during the final approach. Using this configuration, therefore, the optimum benefit of the Hybrid Dynamic System is simulated for best case scenarios. Gate features are modeled according to aircraft type stated in the Istanbul Ataturk Airport Aircraft Parking/Docking Chart (Figure 3).

In the analysis, aircraft performance differences are ignored and a single aircraft and the most common type (B737-300) at Istanbul Ataturk Airport are chosen in order to generate the best case. Final approach separations of this type of aircraft have been decided as 5 miles. Landing and rolling probabilities on runway has been based on real values. Speeds and separations of aircraft on taxiways have been set from the real values of BADA [17]. After completion of this design, we have started to the preparation of the scenario.

Two scenarios are prepared for the analysis: the first (baseline) and second (alternative) scenarios. For each scenario, a group of 20 gates are chosen. These gates are the most intensively used ones and considered as they can increase the ground traffic on D taxiway. These gates are between 101 and 112, and between 201 and 208. For each scenario, one departure sequence and two arrival sequences have been determined for these 20 gates in two hour simulation time between 10:00-12:00 hours (Table 1).

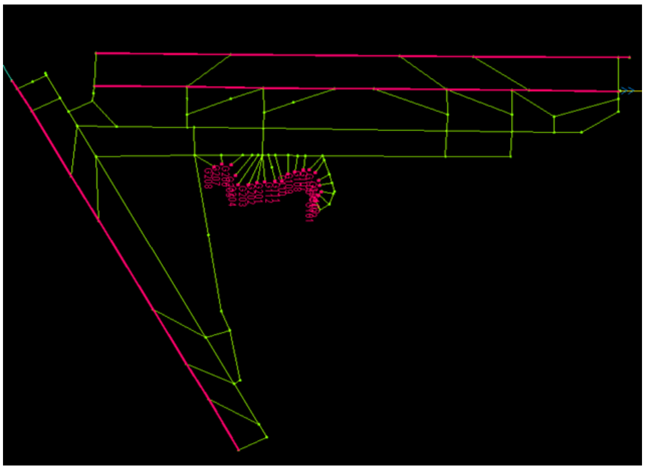

FIGURE 2. Design of Istanbul Airport on SIMMOD.

FIGURE 3. Gate locations of Istanbul Ataturk Airport on SIMMOD.

TABLE 1. Number of aircraft operations in the first (baseline) scenario

Time Interval	LTBA Arrivals	LTBA Departures	LTBA Operations
10:00-11:00	23	0	23
11:00-12:00	16	19	35
LTBA OPS. Total	39	19	58

A. The First (Baseline) Scenario

In the first arrival sequence, gate allocation has been done for 19 aircraft randomly (Figure 4). Their arrival and departure boarding times have been determined with a specific probability by SIMMOD. After completing departure boarding and pushing back, departure aircraft started taxiing to the holding (departure queue) point for runway 35R. At this time, while these 19 aircraft departing, 20 aircraft started to come to the gates as the second arrival sequence. While the second arrival sequence is taxiing to their gates, because of the aircrafts' lateness, there have been crossings on the taxiways between departure and arrival aircraft. Aircraft in the second arrival sequence may also wait for re-assignment of their stand number due to lateness of departure aircraft.

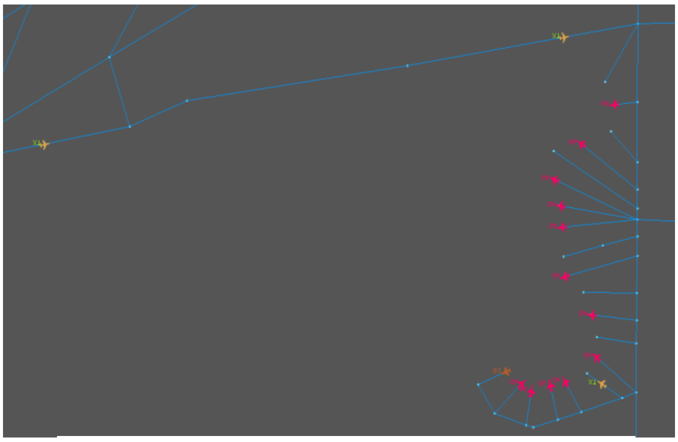

FIGURE 4. A scene of first arrival sequence from the taxiways and gates.

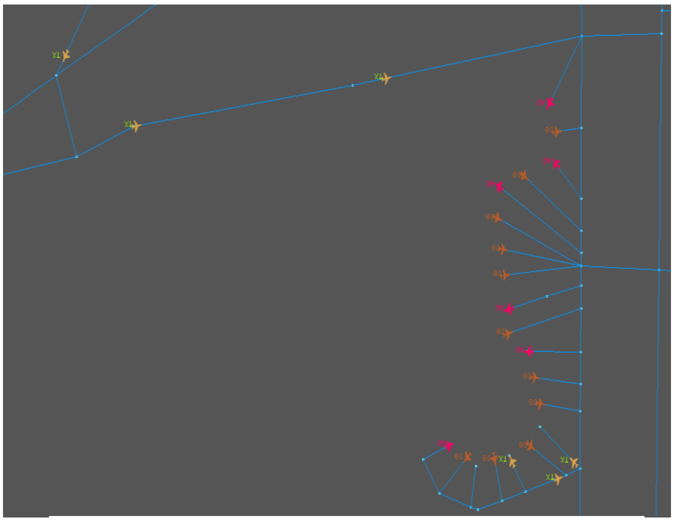

FIGURE 5. A scene of waits for departing and arriving aircraft crossings

Re-assigning the stand number has caused a chain problem in gate allocations shown in Figure 5. So that after re-assigning an aircraft's stand number, the other aircraft affected from this revision should have their gates to be changed to a new suitable gate. All of these factors increased delay time at the taxiways and this type of arrival and departure timing happened.

B. The Second (Alternative) Scenario

After completing the baseline scenario, an alternative scenario is prepared based on hybrid dynamic gate assigning algorithm shown in Figure 7. In the improved scenario, no change has been done on the first arrival sequence of 19 aircraft but their taxi paths are re-assigned if it is required to avoid ground holds at the intersections. Arrival times of the second sequence aircraft have not been changed as well. But new taxi paths and new stand are re-assigned when it is required.

After considering all delays, we have assigned the new gate numbers to the aircraft at the 11NM of final approach course. The assigned gates are chosen among the ones at which the departing aircraft have their engine start-up permits. This selection process requires a dynamic assignment according to the engine start-up times using Hybrid Dynamic System. In addition, while allocating the gates to the aircraft, we have considered the occupancy times of the taxiways. With these parameters we have determined the departure and arrival aircraft's taxi paths. By the help of this, we could decrease the number of crosses at the taxiways.

III. Results

When we look at the delay times in Table 2, it is 589.2 minutes for arriving aircraft. It represents that each of 20 arriving aircraft have been delayed about 10 minutes in 2 hours of flight. The departure flights have the delays because of crosses with the arrival flights shown in Table 3. So that total delay at both arrival and departure flights became 607.5 minutes.

TABLE 2. Total, standard deviation and average of travel and delay times of arriving aircraft in the first (baseline) scenario

Time Interval	LTBA-All Arrival Flow	Overall Arrival Times (min.)					
		Travel			Delay		
		TOT	SDV	AVE	TOT	SDV	AVE
10:00-11:00	23	240.4	0.61	10.45	335.2	11.33	14.57
11:00-12:00	16	166.8	0.58	10.42	254.1	6.83	15.88
LTBA ARR. Total	39	407.2	0.6	10.44	589.2	9.76	15.11

TABLE 3. Total, standard deviation and average of travel and delay times of **departure** aircraft in the first (baseline) scenario

Time Interval	LTBA-All Dep. Flow	Overall Departure Times (min.)					
		Travel			Delay		
		TOT	SDV	AVE	TOT	SDV	AVE
11:00-12:00	19	108.4	0.61	5.71	18.3	1.02	0.96
LTBA Dep. Total	19	108.4	0.61	5.71	18.3	1.02	0.96

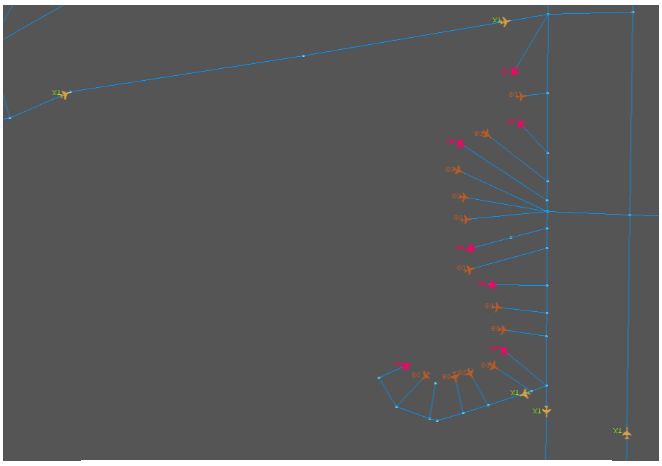

FIGURE 6. A scene from the second(alternative) scenario.

At the end of the second scenario, departing and arriving durations of the aircraft have shown in table 4 and 5.

TABLE 4. Total, standard deviation and average of travel and delay times of arrival aircraft for *revised* (alternative) scenario

Time Interval	LTBA-All Arrival Flow	Overall Arrival Times (min.)					
		Travel			Delay		
		TOT	SDV	AVE	TOT	SDV	AVE
10:00-11:00	23	240.4	0.61	10.45	339	11.17	14.74
11:00-12:00	16	164.1	0.63	10.26	153.4	5.68	9.59
LTBA ARR. Total	39	404.5	0.63	10.37	492.4	9.66	12.63

TABLE 5. Total, standard deviation and average of travel and delay times of departure aircraft for *revised* (alternative) scenario

Time Interval	LTBA-All Dep. Flow	Overall Departure Times (min.)					
		Travel			Delay		
		TOT	SDV	AVE	TOT	SDV	AVE
11:00-12:00	19	114.6	1.22	6.03	28.6	1.12	1.5
LTBA DEP. Total	19	114.6	1.22	6.03	28.6	1.12	1.5

When we analyze these values we see that total delay at both arrival and departure flights has been reduced to 521 minutes. And total arrival delay became 492.4 minutes. The total difference of second term arrival aircrafts is about 96.8 minutes between first and second scenario. If we think each aircraft separately, we see that almost 5 minutes delay gain is provided to them. Also when we look at the departure its delay has been increased to 28.6 minutes. And total departure travel has increased about 6 minutes. If we consider both arrival and departure delay times, it is totally 86.5 minutes less than the first scenario. This 86.5 minutes gain has become in 2 hours flight of these 39 aircraft. This gain has done mostly on arrival aircraft. When we consider this 5 minutes delay gain in depth, we see that its earnings are much more than 5 minutes because of cost factors of aircrafts.

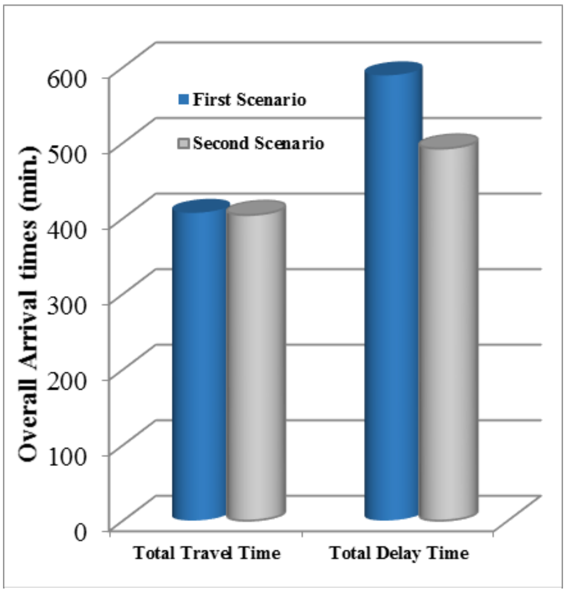

Figure 7. Travel and delay times of first and second scenario.

When we look at the travel time graph there is no significant difference between two scenarios shown in Figure 7. This means taxi travelling times are not increased due to route changes. However, undesired ground holds are eliminated in the alternative scenario. As a matter of fact, we have aimed first arrival sequence not to be changed. When we take a look at to the total delay time, there is a significant reduction of 16.6% in the second scenario.

Fuel Consumption Rates

Fuel consumption is an essential point for ground maneuvering for airlines. Less engine working time is a valuable thing for them. Undesired ground holds causes extra fuel consumption. As we have used B737 type of aircraft using CFM56-5B engine, fuel consumption at the ground movements is selected idle. In the idle mode, B737 type of aircraft using CFM56-5B engine consumes approximately 0,101 kg/s as mentioned in the ICAO Emission Databank [18].

TABLE 6. Total fuel consumption of 39 arriving aircraft during first and second scenarios for total ground travel and ground holds separately.

	First Scenario (Baseline)	Second Scenario (Alternative)
Consumption caused by ground holds for arriving aircraft	3571 kg	2984 kg
Total consumption during ground travel for arriving aircraft	6038 kg	5435 kg

From Table-6, we can see that there is a huge amount of difference during 2 hours of scenario for 39 arrival aircraft. The difference of total consumption during ground travel for arrival aircraft is 603 kg. The difference of consumption caused by ground holds is 587 kg in 2 hours of simulation for 39 arriving aircraft. In the alternative scenario we could decrease the total travel consumption besides ground holds consumption.

TABLE 7. Total fuel consumption of 19 departing aircraft during first and second scenarios for total ground travel and ground holds separately.

	First Scenario (Baseline)	Second Scenario (Alternative)
Consumption caused by ground holds for departing aircraft	111 kg	173 kg
Total consumption during ground travel for departing aircraft	657 kg	695 kg

TABLE 8. Total fuel consumption of both 19 departing and 39 arriving aircraft during first and second scenarios for total ground travel and ground holds separately.

	First Scenario (Baseline)	Second Scenario (Alternative)
Total fuel consumption of arriving and departing aircraft (ground holds included).	6695 kg	6130 kg

From Table-7, total consumption of departing aircraft has increased. But when we look at the gain of the arriving aircraft, it is more than the loss in the departing aircraft. In table 6, the difference of whole scenario is approximately 565 kg for totally 58 aircraft. It is about 10 kg of fuel gain for each aircraft.

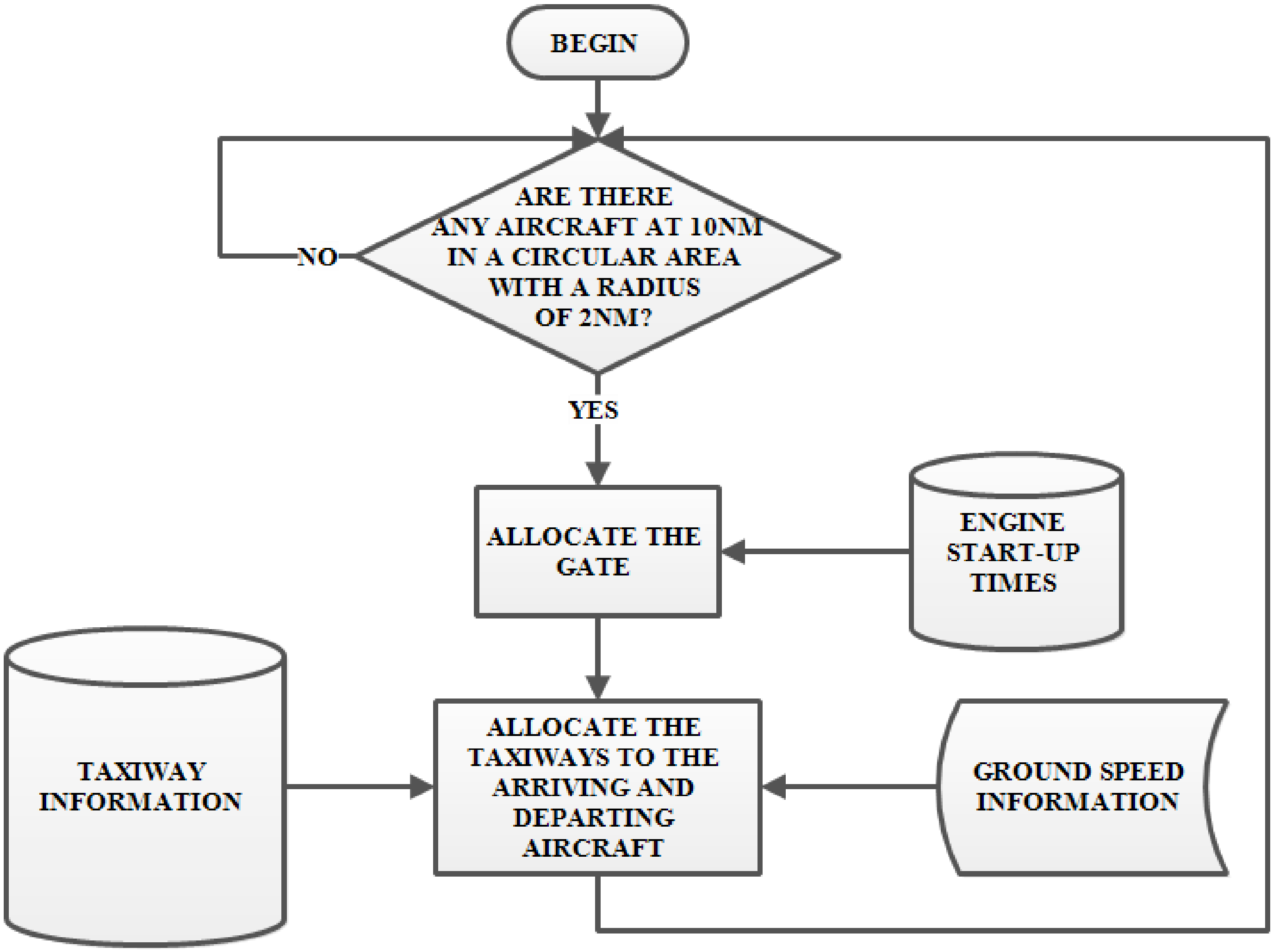

FIGURE 8. Flow chart of Hybrid Dynamic Gate Assignment

IV. CONCLUSION

A hybrid dynamic system is more suitable than the other methods because it can minimize the effects of delays considerably even in the best traffic cases. It is also observed that this delay reduction does not cause any travelling time penalty for aircraft. On the contrary, it provides less fuel consumption during air traffic control operations. From the fuel consumption results, we can see that it provides less fuel consumption although in a small traffic operation simulation. Mostly, delays happen at the departure, en-route and approach periods. But the effects of these delays are seen at the ground of arrival airport. So that ground traffic starts to increase and due to this, delays cause airports not to be used at their desired capacities. Many International Airports do not have the capability of enlarging their areas and do not have the suitability for building extra aprons or runways. So that, enhancement in capacity can be done only by increasing the efficiency of ground traffic and gate allocation. In case of using a hybrid dynamic algorithm described in Figure 8, gate allocation and taxi delay reduction can be done more efficiently. Therefore, the capacity of airports can be improved without any further physical extensions. Decision support systems using this algorithm can be developed and installed to airport tower control units with much smaller costs.

In the future studies, the simulation experiments will be expanded to wider range of scenarios including different aircraft types and traffic scenarios. Meanwhile the aircraft cost factors will be added into analyses.

Brief biographıes of the authors

Orhan Ertugrul Guclu, B.Sc. has graduated in 2012 from Hacettepe University Department of Electrical and Electronics Engineering. He has been working as Research Assistant at Anadolu University, Faculty of Aeronautics and Astronautics.

Cem Cetek,PhD has completed his doctoral study in 2006 at Anadolu University Graduate School of Science. He has been working as Assistant Professor at Anadolu University, Faculty of Aeronautics and Astronautics.

REFERENCES

[1] Tosic, V. (1992). A review of airport passenger terminal operations, analysis and modeling. Transportation Research-A 26 (1), 3-26.

[2] J Bihr, R. (1990). A conceptual solution to the aircraft gate assignment problem using 0,1 linear programming. Computers & Industrial Engineering 19 (1-4), 280-284.

[3] Haghani, A. and Chen, M.C. (1998). Optimizing gate assignments at airport terminals. Transportation ResearchA 32 (6), 437-454.

[4] Mangoubi, R.S. and Mathaisel, D.F.X. (1985). Optimizing gate assignment at airport terminals. Transportation Science 19 (2), 173-188.

[5] Xu, J.F. and Bailey, G. (2001). “The airport gate assignment problem: Mathematical model and a tabu search algorithm,” Proceedings of the 34th Hawaii International Conference on System Sciences, IEEE, 10p.

[6] Brazile, R.P. and Swigger, K.M. (1988). GATES: An airline gate assignment and tracking expert system. IEEE Expert, 33-39.

[7] Gosling, G.D. (1990). Design of an expert system for aircraft gate assignment. Transportation Research-A 24 (1), 59-69.

[8] Srihari, K. and Muthukrishnan, R. (1991). An expert system methodology for an aircraft -gate assignment. Computers & Industrial Engineering 21(1-4), 101-105.

[9] Chun-Hung Cheng, Sin C. Ho and Cheuk-Lam Kwan (2012). The use of meta-heuristics for airport gate assignment. Expert Systems with Applications 39 (2012) 12430–12437.

[10] Shangyao Yan, Chi-Yuan Shieh, Miawjane Chen (2002). A simulation framework for evaluating airport gate assignments. Transportation Research Part A 36 (2002) 885–898.

[11] Shangyao Yan Cheun-Ming Huo (2001). Optimization of multiple objective gate assignments. Transportation Research Part A 35 (2001) 413-432.

[12] Binod Maharjan, Timothy I. Matis (2012). Multi-commodity flow network model of the flight gate assignment problem. Computers & Industrial Engineering 63 (2012) 1135–1144.

[13] Yu Cheng (1997). A Knowledge-based airport gate assignment system integrated with mathematical programming. Computers ind. Enging Vol. 32 No. 4. (1997) 837-852. American Institute of Aeronautics and Astronautics

[14] H. Ding, A. Lim, B. Rodrigues, Y. Zhu (2005). The over-constrained airport gate assignment problem. Computers & Operations Research 32 (2005) 1867–1880.

[15] Askin T. Isikveren (2002). Identifying Economically Optimal Flight Techniques of Transport Aircraft. Journal of Aircraft Vol. 39, No. 4, July–August 2002.

[16] Guclu O.E., Cetek C. (2013). Optimization of Aircraft Taxi Movements and Gate Allocation using Hybrid Dynamic Gate Assignment. MAC-TLIT 2013 Conference, Prag. May 2013.

[17] BADA Version 3.5, 23.05.2005.

[18] ICAO, 10.02.2014: www.easa.europa.eu/environment /edb/datasheets/individual-engine-datasheet.php?sheet=cfm-international