An Assesment on The Safety and Complexity of The Innovative Design of Istanbul's New TMA

Arife Aycan Mutlu, Ph.D.
Air Navigation Department
General Directorate of State Airports Authority (DHMI)
Ankara, Turkey
arifeaycan.kasap@dhmi.gov.tr

Murat Canpolat
Air Navigation Department
General Directorate of State Airports Authority (DHMI)
Ankara, Turkey
murat.canpolat@dhmi.gov.tr

***Abstract*—For an ANSP, to fulfill the responsibility with a high-quality service degree while maintaining safety in a difficult airspace, terminal manoeuvring areas (TMAs) should be designed carefully and equipped with the most efficient procedures. Point merge system, one of innovative SESAR (Single European Sky ATM Research) projects which is defined as a systemized method for sequencing arrival flows and developed by the Eurocontrol Experimental Centre in 2006, was launched in Istanbul's new TMA (LTFM TMA) being totally designed by DHMI to improve safety and efficiency. In this paper, the airspace complexity and safety indicators of re-organized LTFM TMA are presented to investigate the effects of the radical changes made, on the safety issue in comparison with the previous terminal maneuvering area, LTBA TMA. Results reflect that the LTFM TMA, one of the world's busiest terminal areas, presents notable decreases in terms of conflict number per aircraft, complexity metrics, adjusted density, the hour of interactions and flight hours, although the traffic numbers increase.**

Keywords- complexity; conflict; safety; point merge system; airspace design

I. INTRODUCTION

On 6 April 2019, Istanbul Airport (LTFM) has inherited the aviation code "IST" from Atatürk Airport (LTBA), which was opened in 1953 and ranked seventeenth worldwide in terms of passenger traffic in 2018 by Airports Council International and this big switch, which continued a total of 45 hours, was one of the most important air transport operations in the aviation history.

Istanbul Airport is expected to serve the highest number of passengers in the world after the construction to be completed totally as the airport structure with six runways, five independent parallel runways plus one additional east-west runway at the end of Phase 4 without any difference in safety performance.

Istanbul Airport and its deployment process are of great importance not only for Turkey, but also for the region and European ATM . We defined "LTFM Airspace Design", which was the heart of the matter in this process, as "*filling a blank page and defining a new airspace all over again by making radical changes*".

Initially, the aim of this study is to make a comparative analysis of the new and old Istanbul Terminal Manoeuvring Area (TMA) designs according to the evolution of traffic safety and complexity issues and to add a value to the literature by making this research over the region and period for the first time.

Therefore, the paper is organized as follows: the first section is about a review of theory and related works about point merge system (PMS) and complexity indicators. After these informative sections, it will present new "Istanbul TMA" deployment process by using the "tree diagram". It will then go through the methodology and method, which will clarify the tools used, data collection and selected indicators. Finally, it will present the analysis of results, followed by a conclusion.

II. THEORY & RELATED WORKS

A. POINT MERGE SYSTEM

Since the introduction of Area Navigation (RNAV), Eurocontrol is proposing new options for merging traffic in the TMA. In Document 4444 - Air Traffic Management by ICAO 2016, RNAV is defined as "a method of navigation which permits aircraft operation on any desired flight path within the coverage of the station-referenced navigation aids or within the limits of the capability of self-contained aids, or a combination of these" [1]. Although especially P-RNAV, which was introduced in 2006, is suitable for to be used in TMAs with an accuracy of ±1 NM for 95%, it has some disadvantages such as requiring too much heading instructions and difficulties in readability of charts. To overcome these difficulties, Point Merge System (PMS) has been introduced by Eurocontrol. This method was developed at EEC in 2006. The main benefits of PMS are predictability, "staffing" thanks to the standardization of working methods, and environmental effect due to making "Continuous Descent Approach (CDA)" possible, even under high traffic load [2].

The first and second aims of the PMS are to create and maintain spacing [3]. In LTFM STARs the PMS concept of operation is implemented taking into account the airspace requirements. One important contributing factor to the overall design is the "transition procedure" which is established to

combine the initial approach with the final. This procedure allows the aircraft to intercept the localizer courses of LTFM runways, complying with the simultaneous parallel runway operation requirements while ensuring the safety.

B. COMPLEXITY INDICATORS

In the literature about ATC complexity, workload and traffic metrics, there are different definitions about concepts, selected indicators and data collection methods [4].

The research on complexity indicators has gone to Davis, Danaher and Fischl (1963) [5]. This first research was about evaluating the relationship between ATC complexity and controller workloads [4]. In this research, complexity was formulated as a proportion of arrival and departure traffic to overflight traffic. Stein (1985) conducted a simulation and in this simulation, for the first time, the definition of the density was based on the degree to which aircraft clustered within a small part of the airspace, not the overall airspace [6]. Meckiff et al (1998) made one of the first verbal definitions rather than a formula and defined complexity as a "measure of the difficulty that a particular traffic situation will present to an air traffic controller" [7].

Eurocontrol prepared an important report titled "Complexity Metrics for ANSP Benchmarking Analysis" for the Performance Review Commission by the ACE Working Group on Complexity and defined complexity indicators for application to enable ANSP benchmarking analyses. The two important indicators of this report for the definition of the complexity were selected as the adjusted density and structural index [8].

III. LTFM TMA DEPLOYMENT AND PROCESS

One of the "new seven management tools", a collection of tools put together by *quality professionals* following "the classical seven quality tool" compiled by Kaoru Ishikawa, is "tree diagram" [9]. The main purpose of this tool is to investigate ways to achieve a primary target, identify secondary means and find alternate ways to get these aims in a proper order.

Istanbul Airport was ranked fifth of the top 50-airport with average daily departure traffic of 634 in July of 2019. Atatürk Airport maintained the same rank in this list in 2018, too [10] [12].

According to the Network Operations Report, Atatürk Airport was ranked number five in the list of "*The Top 20-Locations for Airport Delays*" with *1402 min/day* on average and number four in the list of "*The Top 20 Airport/TMA ATFM Delay*" from January to July (year-to-date) with *1082 min/day* on average in July 2018 [10]. In this period, airport capacity was the main contributor (793 min/day), followed by weather (310 min/day) [11].

On the other hand, Istanbul Airport is not anymore in the list of "*The Top 20- Locations for Airport Delays*" in July 2019. As expected, the airport/TMA ATFM delay from January to July (year-to-date) for LTFM decreased to *640 min/day* on average in July 2019 [12].

In Figure 1, the tree diagram for LTFM TMA deployment process is presented. Initially, the *main target* is a successful deployment process for the TMA of LTFM, which is planned to become an incrementally evolving airport serving 150 million passengers with six runways in the final phase. It should be noted that the construction of LTFM airport is involving four major phases but the tree diagram in Figure 1 is limited to Phase 1a. Furthermore, the *secondary targets* are divided into four sections.

The first of *secondary targets* is a well-re-organized air space design without compromising the safety of air traffic management and aviation. This aim was reached with the support of the launch of Point-Merge System, totally designed by DHMI. The other tool for reaching this aim is the operability of LTFM with two independent parallel runways. Moreover, a new sectorization was another necessity to achieve the main goal. The number of ATC sectors was increased from the existing 7 to 13.

Another *secondary target* is related to human factors. Some vital and strategic decisions were taken about human factors such as selecting the coreteam, creating the innovative and collaborative environment enabling the learning organization in this team. As a result of the human resource planning process, the numbers of ATCOs in the Istanbul Approach and Tower were increased; more than 120 ATCOs have been recruited. In addition, the usage of atcTRsim for deciding all these radical changes related about air space design was another tool. Furthermore, choosing Eurocontrol Experimental Center (EEC) for replicating this new airspace design by real time simulations, which were bringing together about 161 controllers for more than 80 exercises, should be added to the tools related to this secondary aim.

The third secondary target for reaching the main goal is about new systems and infrastructure. Launching 7 new sectors in Istanbul TMA, implementing AMAN (Arrival Manager), A-SMGCS (Advanced-Surface Movement Guidance and Control System) and D-ATIS (Data link-automatic terminal information service) by the integration of the system the current system for providing the interoperability were the milestones in technical part of the project. In addition, launching CAT-I/II/III approaches provided the implementation of simultaneous independent parallel runways operations. Developing the first national air traffic control simulator, atcTRsim, and getting important contributions from this tool was a strategic step towards future for one of major actors in European ATM to sustain the safety of the airspace.

The last secondary target is a well-organized and inclusive coordination with all stakeholders. To achieve this successful coordination, giving information about the stages of the process by publicity and briefing meetings was not enough, but also a close coordination with all neighboring states and Eurocontrol was a requirement to optimize the airspace design and management and to increase safety and quality. While launching the new air space, DHMI implemented all changes by taking into consideration of all these important tools about coordination. Lastly, the review and signature of the Letters of Agreement were conducted to facilitate the traffic flow for Istanbul Airport.

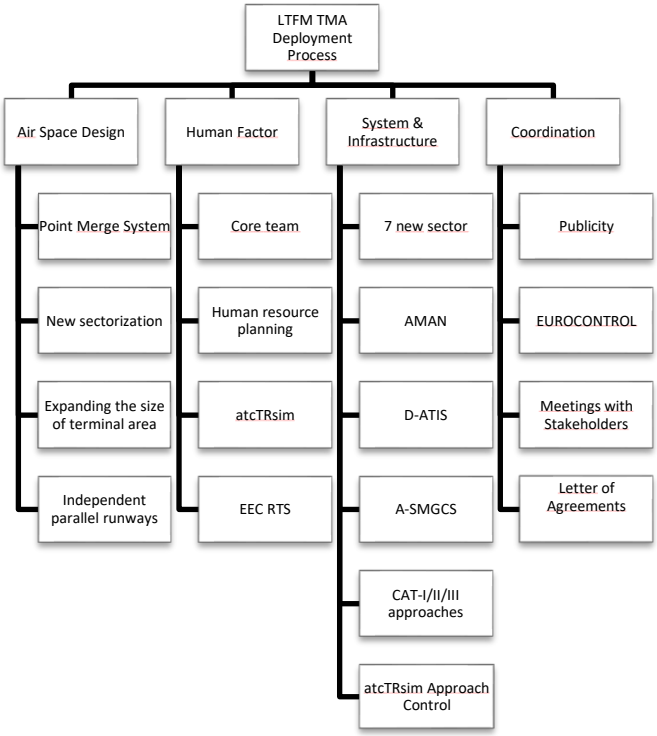

Figure 1. The Tree Diagram of Istanbul TMA Deployment Process

IV. METHODOLGY & METHOD

The following hypotheses are tested; by reorganizing the Istanbul's new TMA all over again,

- The adjusted density of the TMA has been decreased.
- The PRU complexity of the TMA has been decreased.
- The conflict number per aircraft has been decreased.

By testing these, it is aimed to be assessed that PMS, one of the major changes in Istanbul's new TMA, and new airspace design does not risk safety in terms of any increase in the complexity or density of the air space or number of conflict per aircraft.

A. TOOLS

For the analysis of the differences between two Istanbul TMAs, LTBA TMA and LTFM TMA, from the perspective of complexity scores and conflict number, we select and extract the actual and initial traffic from Demand Data Repository (DDR2) from Eurocontrol and we obtain indicators on safety and complexity using the Network Strategy Tool [13].

Initial trajectory is known as "the FTFM (Filed Tactical Flight Model) or M1 trajectory" and defined as "the last filed flight plan from the airline." The actual trajectory is "the CTFM (Current Tactical Flight Model) or M3 trajectory" and it is the closest estimate of the actually flight trajectories in DDR database, which is different from the filed flight plan due to the available radar vector and daily operations.

B. DATA COLLECTION

Istanbul Airport has become fully operational since 06 April 2019, 21:00 UTC. Any day for April or May is not being selected because these months may not reflect the traffic flow accurately for LTFM and can cause errors and bias while assessing the evolution of TMA. Three days from June and July are selected to compare 2018 and 2019. These days are arbitrary normal operation days and they correspond to the days from Monday to Saturday. The dates and their details selected are shown in TABLE I.

TABLE I. THE SELECTED DATES AND DETAILS

Airport	Date	Day	Airport	Dates	Day
LTBA	14.06.2018	Thursday	LTFM	13.06.2019	Thursday
	15.06.2018	Friday		14.06.2019	Friday
	16.06.2018	Saturday		15.06.2019	Saturday
	09.07.2018	Monday		08.07.2019	Monday
	10.07.2018	Tuesday		09.07.2019	Tuesday
	11.07.2018	Wednesday		10.07.2019	Wednesday

C. INDICATORS

However, there is no universally agreed definition of complexity to ATM as told in Section 2, we use PRU complexity definition of Eurocontrol. It defines complexity as "the external factors that impact the controller workload and/or the level of difficulty of the ATC task, without considering the internal, ATC procedures-related factors" [8]. The other related indicator about our hypothesis in NEST is conflict numbers.

1) COMPLEXITY INDICATORS

The complexity score is based on two indicators; adjusted density and structural index.

2) ADJUSTED DENSITY

The adjusted density is used to measure traffic density by calculating the amount of traffic that exists within a given unit of volume over a given unit of time. We use FL85 as lower limit and FL245 for upper limit.

The adjusted density is defined as the ratio of "hours of interaction" to "flight hours".

$$Adjusted\ Density = Hours\ of\ interactions/Flight\ Hours$$

The hours of interactions are the sum of all durations of all the interactions including vertical, horizontal and speed, in all cells between FL85 and FL245.

A horizontal interaction is calculated by the headings of two aircrafts with a difference of greater than 20° while entering the cell simultaneously. This type of interaction is an indicator for the flow structure of traffic.

$$HDIF = Hours\ of\ horizontal\ interactions/Flight\ Hours$$

A possible vertical interaction occurs when two aircrafts present in the same cell and have different altitudes; climbing, cruising or descending. $VDIF$ is a measure of the complexity arising from the interactions between flights in different flight phases and shows traffic in evolution.

$$VDIF = Hours\ of\ vertical\ interactions/Flight\ Hours$$

Lastly, a speed interaction presents between two aircrafts simultaneously in the same cell have different speeds greater than 35 kts. $SDIF$ stands for the indicator of traffic mix (climbing, descending or cruise traffic).

$$SDIF = Hours\ of\ speed\ interactions/Flight\ Hours$$

The sum of the flight durations controlled in all cells in a defined area over a period is called flight hours. The 3D dimensions of cells are 20 NM x 20 NM x 3000 FT and flight time in these cells averaged during discrete 60-minute periods represents "flight hour", as recommended in reference document titled "Complexity Metrics for ANSP Benchmarking Analysis" by ACE [8].

3) STRUCRURAL INDEX

Since vertical, horizontal and speed interactions are all being subsets of adjusted density and so they are highly correlated with adjusted density, F , $VDIF$ and $SDIF$ are transformed to relative indicators by dividing to adjusted density. The relative indicators, showing the percentage of type of interactions, are denoted by RVDIF, RHDIF and RSDIF.

Structural index indicator represents the structure of the traffic flow and it depends on vertical, horizontal and speed interactions.

$$Structural\ Index = RVDIF + RHDIF + RSDIF$$

Structural index shows the total complexity of the set of traffic in a defined area over the period. If every interaction meets all requirements of criteria, then the structural index should be three. The important thing about structural index is that it provides the comprehension from year to year for one airspace or ANSP.

4) COMPLEXITY SCORE

Complexity score enables the general overview that combines all the aspects related to the traffic density, traffic mix, traffic evolution and flow structure.

$$Complexity\ Score = Adjusted\ Density\ x\ Structural\ Index$$

The indicators used are listed in Table II.

TABLE II. THE INDICATORS OF COMPLEXITY DIMENSION

Complexity Dimension	Indicator	Notation
Traffic in evolution	Potential vertical interactions	VDIF
Traffic mix	Potential speed interactions	SDIF
Flow structure	Potential horizontal interactions	HDIF
Percentage of vertical interactions to all	Relative indicator of VDIF	RVDIF
Percentage of speed interactions to all	Relative indicator of SDIF	RSDIF
Percentage of horizontal interactions to all	Relative indicator of HDIF	RHDIF

D. NUMBER OF CONFLICTS

Conflict, defined as a pair of flights being detected a loss of vertical or horizontal separation by NEST, is calculated daily with calculations steps of 10 seconds, taking into account average delays of 120 seconds with standard deviation of 120 seconds and 3 NM horizontal separation within the defined Istanbul TMA.

V. RESULTS

A. TRAFFIC NUMBER & FLIGHT HOURS

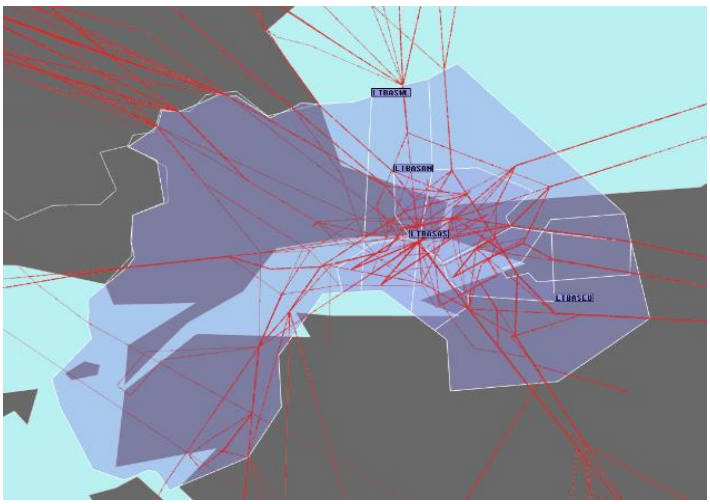

Figure 2. LTBA TMA Initial Traffic (09.07.2018)

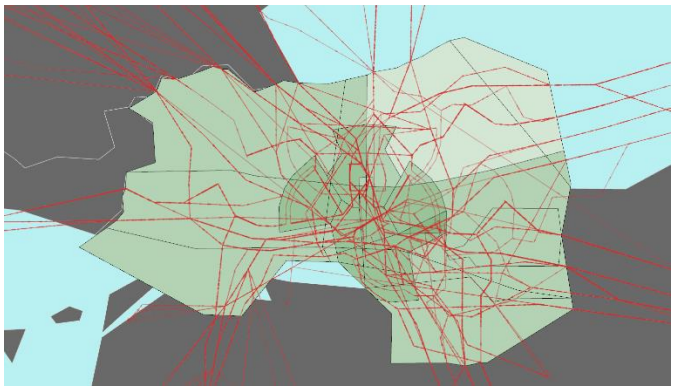

Figure 3. LTFM TMA Initial Traffic (08.07.2019)

The traffic load in LTBA TMA and LTFM TMA based on FTFM (initial) is shown in Figure 2 and Figure 3, respectively. However, the lateral limits of the terminal airspace has changed and enlarged, the vertical limit of terminal airspace does not change.

After the opening of the new airport, on the selected dates, traffic number, regarding to LTFM, LTFJ and LTBA, increases 0.5% on average according to FTFM, and at the same time, the mean number of flight hours, defined as flight time by ACE (2006), has a decrease of 13.5% [8]. This decrease in flight hours occurs even though the mean number of traffic increases. Additionally, the hours of interactions decrease 28.9% on average and this mean is bigger than double of the mean of the decrease in flight hours. Details about these three initial indicators are given in Table III.

TABLE III. THE INITIAL INDICATORS

LTBA	14.06.2018	15.06.2018	16.06.2018	9.07.2018	10.07.2018	11.07.2018
Hours of interactions	2401	2570	2220	2742	2570	2591
Flight hours	5097	5061	4816	5386	5164	5207
Number Of Traffic (Initial)	2172	2093	2033	2210	2125	2146
LTFM	**13.06.2019**	**14.06.2019**	**15.06.2019**	**8.07.2019**	**9.07.2019**	**10.07.2019**
Hours of interactions	1780	1792	1749	1777	1732	1855
Flight hours	4411	4480	4372	4436	4396	4471
Number Of Traffic (Initial)	2141	2174	2110	2137	2120	2152

B. *ADJUSTED DENSITY*

When examined the adjusted density results for LTBA TMA and LTFM TMA according to the components of adjusted density on the left vertical axis, it is seen that both hours of interactions and flight hours are higher for all selected dates. Right axis is about adjusted density. The results are shown in Figure 4. Although a high correlation between the indicators of flight hours and hours of interaction is expected, the decrease in the duration of the potential interactions are much more than the decrease in flight hours, so it is understood that the increase / decrease in the number of potential interactions does not only depend on this relation. There are important factors such as how the traffic is dispersed in the airspace or which instrument approach procedure is established.

The adjusted density results of LTBA TMA and LTFM TMA are shown in Figure 4 on the right vertical axis. The average of the difference of density between LTBA and LTFM TMA is 17.9% for the selected dates. The adjusted density calculated for LTBA TMA is between 46% and 51% while the same indicator of LTFM TMA changes between 39% and 41%. These results show that the new TMA design for LTFM decrease the density of traffic on selected dates.

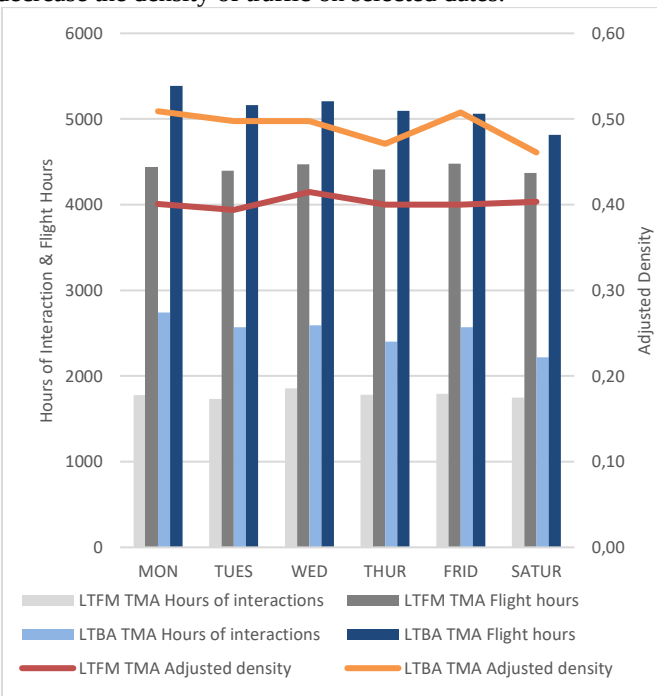

Figure 4. Fight Hours, Hours of Interaction and Adjusted Density

Lastly, the relationship about how the adjusted density indicators vary with the number of flight hours for LTFM TMA and LTBA TMA is examined. In Figure 5 and Figure 6, the bars represent the adjusted density and the dots represent the traffic level expressed in flight hours. In LTBA TMA, the adjusted density and flight hours are much more closely linked in most of the days whereas this correlation seems to decrease with a new airspace design in LTFM TMA. As a matter of fact, the Pearson's correlation coefficient between adjusted density and flight hours in LTBA TMA is found as 0.76 while the same correlation in LTFM TMA (0.52) is not as high as in LTBA, These findings show that the new TMA design breaks the strong positive relationship between the traffic level expressed in flight hours and the density of the traffic.

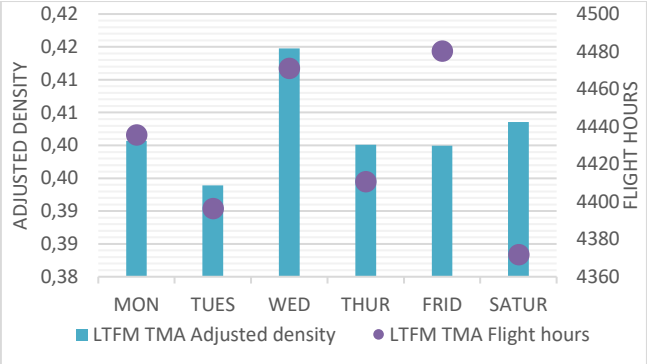

Figure 5. LTFM TMA - The Number of Flight Hours and Adjusted Density

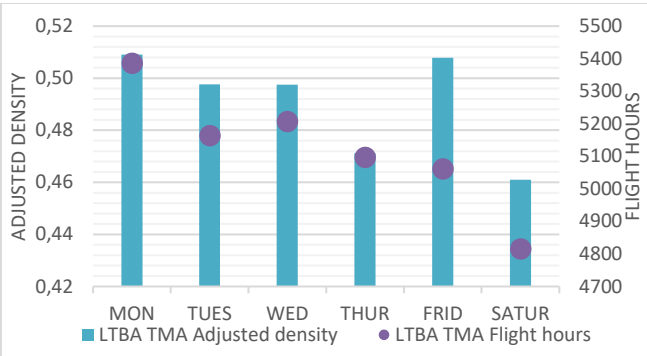

Figure 6. LTBA TM - The Number of Flight Hours and Adjusted Density

C. STRUCTURAL INDEX

Structural index indicator depends on relative values of different types of interactions. These relative values are free from the effect of the traffic volume and they only relate with the traffic flows. The components of structural index results are shown in Figure 7 and Figure 8.

The values of RHdif, RVdif and RSdif are not so much different from each other in LTBA TMA and LTFM TMA. The mean of RHdif values calculated for LTFM 0.32 whereas the same mean is 0.34 in LTBA. It shows that approximately 32-34% of possible interactions are between aircrafts with different headings (above 20° difference). The mean of relative Vdif (RVdif) in LTFM is 0.19 while the same indicator in LTBA is found as 0.20. This means that approximately 19-20% of aircraft pairs are involved in vertical interactions in Istanbul TMA. Lastly, the relative Sdif (RSdif) of 0.18 is found on average in LTFM and 0.15 on average in LTBA. To summarize, approximately 18% of the possible interactions occurring in LTFM are between aircrafts with different speeds (above 35 knots), that is higher than the mean of the indicator in LTBA.

Overall, the structural index, which is calculated as the sum of the relative (normalized) indicators, is 70% on average in LTFM, while this mean of 69% is found in LTBA. This result shows that the flow of traffic has not changed so much, which is in accordance with our expectations.

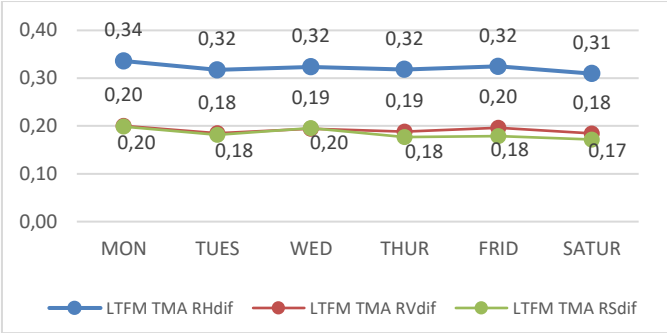

Figure 7. LTFM TMA - The Components of Structural Index

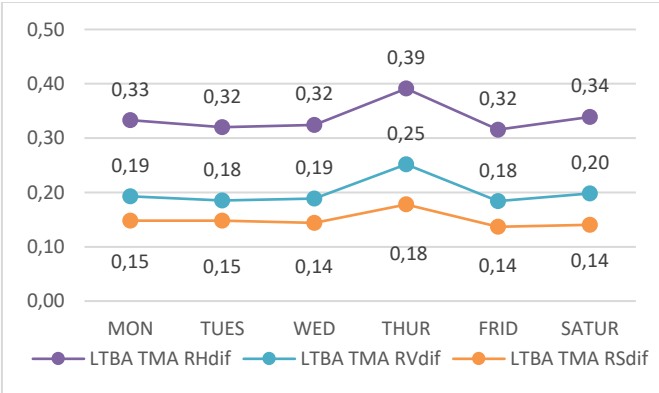

Figure 8. LTBA TMA - The Components of Structural Index

D. COMPLEXITY SCORES

Complexity score is related to structural index and adjusted density; it makes the benchmark available between different airspaces on the same scale.

As shown in Figure 9, the complexity metrics of LTBA TMA are always higher than the metrics of LTFM TMA on the selected dates. The range of difference between the complexities of two TMAs is between 0.03 and 0.11. On average, the PRU complexity score of LTFM TMA is 0.28 while the PRU complexity score of LTBA TMA is 0.34. This means that the complexity of Istanbul TMA has decreased approximately 20% after the new airspace deployment process. Also, the range of complexity indicator is larger in LTBA TMA (from 0.31 to 0.39) than in LTFM TMA (from 0.27 to 0.30). This may show the consistency and predictability of the new instruments approach procedure, PMS, when compared with the previous procedure.

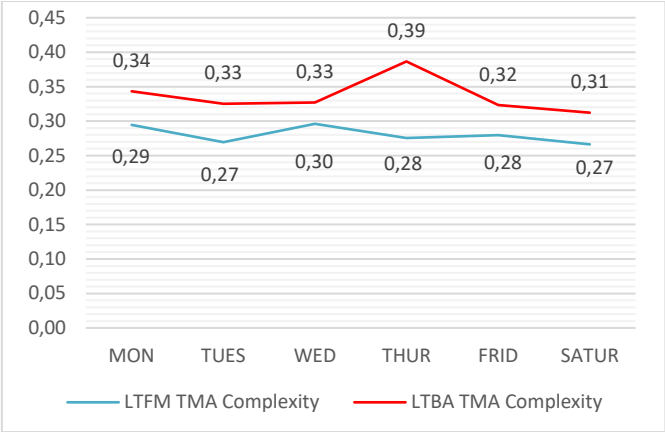

Figure 9. The Complexity Metrics

The results of the correlation analysis are shown in Table IV. To find out the correlation between the complexity and its components, firstly, the Pearson's correlation coefficients are found similar to each other between complexity and structural index (for LTFM TMA it is 0.93 and for LTBA TMA it is 0.91). Secondly, the relationship between traffic flow (flight hours) and PRU complexity is investigated and a positive trend is found after the deployment process of the new airport. The magnitude of the positive correlation has increased from 0.30 to 0.74. Lastly, the sign of the relationship between adjusted density and complexity has changed after the new TMA design. In LTBA TMA, there is a weak negative relationship between these two indicators (-0.19), this means that the complexity of the LTBA TMA is independent from the traffic density and there should be other factors to be investigated for the high complexity score of TMA. The correlation between adjusted density and complexity in LTFM TMA is 0.67, meaning a moderate-strong positive relationship between two metrics. This sign change, from negative to positive, means that the factors making the airspace more complex in LTBA TMA were identified and eliminated.

TABLE IV. THE PEARSON CORRELATION COEFFICIENTS BETWEEN INDICATORS

Correlation	Structural Index	Flight Hours	Adjusted Density
LTFM TMA Complexity	0.93	0.74	0.67
LTBA TMA Complexity	0.91	0.30	-0.19

E. CONFLICT NUMBERS

NEST defines a conflict as a pair of flights being detected a loss of vertical or horizontal separation and it classifies conflicts as either actual or initial conflicts [13]. Actual conflicts are calculated according to the CTFM while initial conflicts are detected according to the FTFM.

The initial conflict numbers differentiate in a range of 883 to 1024 conflicts per day in LTBA TMA over the period and the lowest number of the actual conflicts is 379 whereas the highest number is 543. In the new TMA, LTFM TMA, these numbers have decreased considerably; the lowest number of initial conflict numbers is 730 while the highest number is 783 and, at the same time, the range of the number of actual conflict numbers is between 282 and 346. These results point out an important increase in this safety indicator which is captured by conflict numbers. The details are shown in Figure 10.

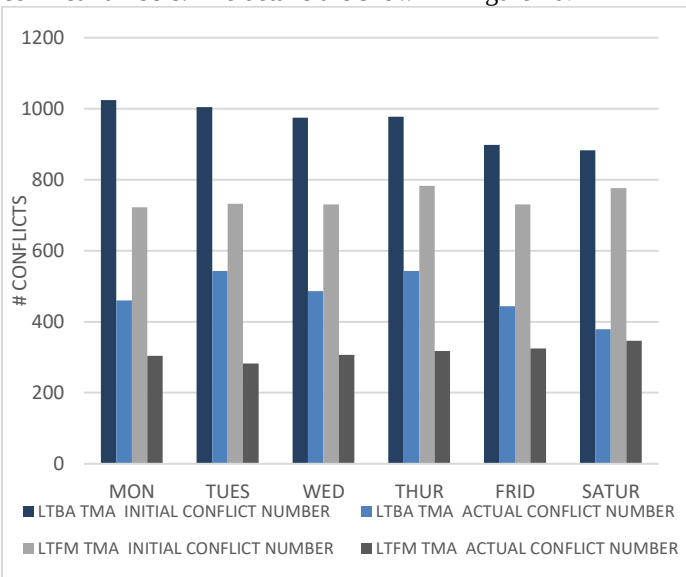

Figure 10. The Initial and Actual Conflict Numbers

On average, the number of conflicts based on FTFM (initial) is 960 in LTBA TMA, while this is 746 in LTFM TMA. The number of conflicts based on CTFM (actual) in LTBA TMA and LTFM TMA is respectively 476 and 314 on average. The ratio of the difference between difference of initial and actual conflict numbers to the initial conflict numbers gives some clue about the predictability of the airspace, and the average of this ratio in LTBA TMA over period is 0.51 whereas the same number is 0.58. This means that in LTBA TMA 51 percent of the conflict numbers based on FTFM is captured by the conflicts based on CTFM. This percentage is higher in LTFM TMA, making the airspace more suitable with the predictions.

Figure 11 shows the conflict number per aircraft. As a result of the fact that the traffic number on average has increased and also the conflict numbers based on FTFM have decreased, the conflict number per aircraft has decreased to 0.35 in LTFM TMA while this number is calculated as 0.45 in LTBA TMA. These results tell us that the safety level of TMA, which should be measured by possible separation losses created by the airspace design and traffic flow, has been increased by launching the LTFM TMA.

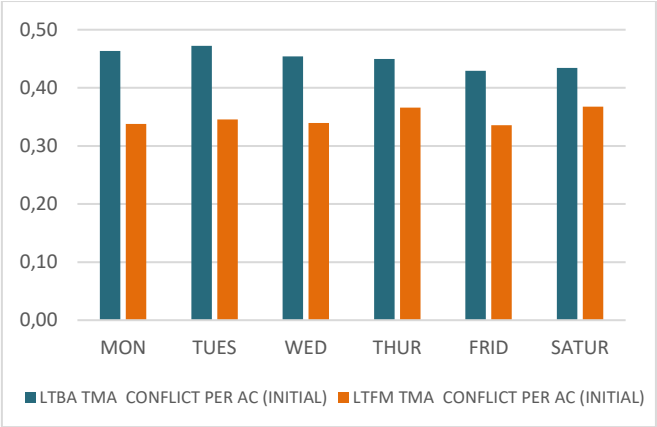

Figure 11. The Conflict Number Per Aircraft (Initial)

A short summary of the results is found in Table V. The number of initial traffic, conflict number per aircraft based on initial plans and complexity scores are three indicators used for a short abstract. On the selected dates for months of June and July, the traffic numbers have not changed dramatically between these two periods, but the conflict number per aircraft has decreased after changing the airspace structure totally. In the same time, the range of PRU complexity of the Istanbul TMA has decreased to 0.27 - 0.30 from 0.31 – 0.39.

TABLE V. THE SELECTED INDICATORS

LTBA TMA	**DATE**	**14.06.2018**	**15.06.2018**	**16.06.2018**	**9.07.2018**	**10.07.2018**	**11.07.2018**
	# TRAFFIC (INITIAL)	2172	2093	2033	2210	2125	2146
	CONFLICT PER AC (INITIAL)	0,45	0,43	0,43	0,46	0,47	0,45
	COMPLEXITY	0,39	0,32	0,31	0,34	0,33	0,33
LTFM TMA	**DATE**	**13.06.2019**	**14.06.2019**	**15.06.2019**	**8.07.2019**	**9.07.2019**	**10.07.2019**
	# TRAFFIC (INITIAL)	2141	2174	2110	2137	2120	2152
	CONFLICT PER AC (INITIAL)	0,37	0,34	0,37	0,34	0,35	0,34
	COMPLEXITY	0,28	0,28	0,27	0,29	0,27	0,30

VI. CONCLUSION

The main goal of an ANSP is to provide service with a high quality degree in a safely and efficiently designed airspace. To reach this goal, it is an important fact that complexity should be taken into consideration when analyzing ANS performance regardless of the strength of the relationship. Because complexity has direct effects on ATCO workload, utilization degree of resources, productivity, cost-efficiency and lastly the degree of quality provided by ANSP. There is a reciprocal relationship between safety and complexity in airspace design. Considering these relationship, for the first time, the redesign of a big and complex TMA with introduction of PMS and a new large international airport, LTFM, is assessed on a basis of complexity benchmarking.

In conclusion, in this paper, the drastic and reformative changes in Istanbul's new TMA (LTFM TMA) are introduced and the overall benefit is presented with a snapshot of the safety and complexity, comparing to the LTBA TMA. On the selected dates, the hours of interactions and flight hours have decreased in LTFM TMA though the traffic numbers have increased. The results of this study show that the complexity of LTFM TMA has decreased (0.28 on average) compared to LTBA TMA (33.5 on average). In addition, the safety level of new TMA has increased, in terms of conflict number per aircraft reducing from 0.45 to 0.35. Moreover, the third hypothesis, introduced in Section 4, cannot be rejected; the adjusted density of LTFM TMA has decreased considerably. Lastly, the correlation results and safety statistics show that implementing the point merge system successfully and the efficient redesign of LTFM terminal airspace with radical and innovative changes have increased the predictability and consistency of one of the most fast-growing and busiest terminal areas.

REFERENCES

[1] ICAO, International Civil Aviation Organization "Doc 4444, Procedures for Air Navigation Services, Air Traffic Management", ISBN 978-92-9258-081-0. Sixteenth edition, 2016.

[2] L. Boursier, B. Favennec, E. Hoffman, A. Trzmiel, F. Vergne, K. Zeghal, "Merging Arrival Flows Without Heading Instructions", 7th USA / Europe Air Traffic Management R&D Seminar, Barcelona, Spain, July 2007.

[3] B. Favennec, E. Hoffman, A. Trzmiel, F. Vergne, K. Zeghal, "The point merge arrival flow integration technique: towards more complex environments and advanced continuous descent". In: 9th AIAA Aviation Technology, Integration and Operations Conference, (September):1–12, doi: 10.2514/6.2009-6921, 2009.

[4] B. Hilburn, "Cognitive complexity in air traffic control a literature review", Eurocontrol Experimental Centre", Project COCA - Complexity and Capacity. EEC Note No. 04/04, 2004.

[5] C.G. Davis, J.W. Danaher, M.A. Fischl, "The influence of selected sector characteristics upon ARTCC controller activities", Contract No. FAA/BRD-301, Arlington, Virginia: The Matrix Corporation, 1963.

[6] E.S. Stein, "Air traffic controller workload: An examination of workload probe" (Report FAA/CTTN90/60). Atlantic City, New Jersey: FAA, 1985.

[7] C. Meckiff, R. Chone, J-P Nicolaon, "The tactical load smoother for multi-sector planning" Proceedings of the 2nd FAA/Eurocontrol ATM R&D Seminar. Orlando, Florida., December 1998.

[8] ACE, "Complexity metrics for ANSP benchmarking analysis. Eurocontrol Report of the ACE Working Group on Complexity" April 2006.

[9] N. R. Tague, The Quality Toolbox, Second Edition. Milwaukee, WI: ASQ Quality Press, 2005. ISBN 978-0873896399.

[10] Eurocontrol, Monthly Network Operations Report- Analysis - July 2018

[11] Eurocontrol, Network Operations Report - 2018 -Annex III -Airports.

[12] Eurocontrol, Monthly Network Operations Report, Analysis - July 2019.

[13] Eurocontrol, NEST (Network Strategy Tool) User Guide 1.6. Eurocontrol pp. 2013-2019.