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TERMINAL CONTROL AREA COMPLEXITY MEASUREMENT USING SIMULATION MODEL

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ABSTRACT: Traffic density in the terminal control area will increase flight safety risks. One effort to reduce the risk is to minimize the controller's workload when affected by air traffic complexity. This research uses a simulation model to measure air traffic complexity in terminal control areas. The aircraft performance model has been constructed from ADS-B data and represents the aircraft movement in the terminal control area of Soekarno-Hatta International Airport. The simulation model can detect and resolve conflicts to keep separations between aircraft at a specified minimum separation limit. Air traffic complexity measurement uses several indicators, i.e., aircraft density, number of climbing and descending aircraft, aircraft type mixing, conflict control, aircraft speed difference, and controller communication. The weighting factor for each indicator has been obtained from Jakarta Air Traffic Service Center (JATSC) controller perception using an analytic hierarchy process. The simulation results show that the variation of resolution type affects the complexity level significantly. The results of this study can be used as consideration for improving air traffic control procedures and air space structures.

ABSTRAK: Kepadatan trafik di kawasan terminal kawalan bakal menyebabkan peningkatan risiko keselamatan penerbangan. Salah satu cara bagi mengurangkan risiko adalah dengan meminimumkan beban kerja pengawal yang terlibat dengan kesesakan trafik udara. Kajian ini menggunakan model simulasi bagi mengukur kesesakan trafik udara di kawasan terminal kawalan. Model pretasi pesawat telah dibina menggunakan data ADS-B dan ini mewakili pergerakan pesawat di terminal kawalan lapangan terbang antarabangsa Soekarno-Hatta. Model simulasi ini dapat mengesan konflik dan membuat resolusi bagi mengekalkan penjarakan antara pesawat mengikut had penjarakan minimum yang ditetapkan. Beberapa indikator telah digunakan bagi mengukur kerumitan trafik udara, iaitu: ketumpatan pesawat, bilangan pesawat mendaki dan menurun, jenis pesawat, kawalan konflik, perbezaan kelajuan pesawat dan pengawal komunikasi. Faktor pemberat bagi setiap indikator telah diperoleh daripada pengawal persepsi Pusat Servis Trafik Udara Jakarta (JATSC) menggunakan proses analisis hierarki. Keputusan simulasi menunjukkan pelbagai jenis resolusi mempengaruhi tahap kerumitan dengan ketara. Hasil kajian ini boleh digunakan bagi menambah baik prosedur kawalan trafik udara dan struktur ruang udara.

KEYWORDS: *terminal control; air traffic complexity; simulation model; analytic hierarchy process*

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1. INTRODUCTION

The Terminal Control Area (TCA) is airspace with the most complex and dense system compared to other airspace sectors. Three modes of flight operations run simultaneously: arrival, departure, and cross-flight [1]. TCA is highly sensitive to changes in traffic, weather, flight procedures, runway used, and other unusual events. The assessment of the system's performance is important and is affected by the system's complexity [2].

The air traffic complexity rate can be very high due to the traffic intensity and patterns in mutual interactions between different traffic flows and individual aircraft in the TCA. The increasing complexity of the TCA will increase the complexity of controller tasks and result in increased workload [3]. The management of traffic flow and airspace can be carried out correctly to avoid excessive controller workload if the measurement and prediction of air traffic complexity can be carried out accurately [4].

Table 1: Air traffic complexity indicators summary

Air Traffic Complexity Indicators	Arad [8]	Grossberg [9]	Mogford et al. [10]	Pawlak et al. [11]	Laudeman et al. [12]	Majumdar et al. [13]	Chatterji et al. [14]	Koros et al. [15]	Diaconu et al. [4]
Sector design/geometry	√		√			√			
Aircraft density/volume	√	√		√		√	√	√	
Aircraft speed difference				√	√	√	√		√
Emergency operations								√	
Altitude change	√			√	√	√	√		
The horizontal distance between aircraft	√		√	√	√		√		
The vertical distance between aircraft	√			√		√	√		
Aircraft type mixing	√	√	√	√				√	√
Frequency of ATCo's communication		√	√	√					
Flight entering and exiting the sector						√			
Potential conflict control	√		√		√		√		
Number of cruising aircraft						√	√		√
Number of climbing/descending aircraft	√	√	√	√		√	√		√
Weather condition			√	√					√
Aircraft heading change/difference				√	√				
Special flight	√		√	√				√	
Radiofrequency congestion	√		√						
Number of intersecting airways	√								
Restricted airspace	√		√						
The proximity of sector boundary	√			√					
ATC's procedure			√					√	

It is necessary to consider the interactions between individual aircraft and their flight characteristics to determine complexity more precisely. The interactions involve possible conflicts and the tendency for aircraft movement to converge at one point. [5]. There are at least nine references from Mogford et al., Diaconu et al. and Dervic and Rank (2 that mention various indicators of complexity [4,6,7]. Table 1 shows the summary of some complexity indicators.

Air traffic complexity can be measured by experts, who have experience controlling air traffic under various conditions, or by the complexity indicator obtained from air traffic data and the number of interactions between aircraft in a particular sector [16]. Another method to determine air traffic complexity is using a dynamic weighted network model. The nodes represent aircraft, waypoints, and airways in the network model. The total weights of all network edges represent air traffic complexity [17]. Andrasi et al. used an artificial neural networks model to estimate air traffic complexity. The best configuration of artificial neural networks was determined by a genetic algorithm [18].

This research developed an ATM model simulation in the TCA using MATLAB to reflect aircraft movements and the air traffic control process. The simulation model is then used to analyze air traffic complexity in the TCA, specifically at Soekarno-Hatta International Airport, Jakarta. The simulation model has several advantages in describing the air traffic system and its complexity, i.e. the movement of the aircraft can be visualized to analyze and validate it [19]. The simulation parameters also can be modified easily to obtain various scenarios.

2. MODELLING

2.1 System Description

The ATM system model represents arrival and departure operations for Runway 25R and 25L on Soekarno-Hatta International Airport - Jakarta (JAKARTA). The arriving aircraft will enter the TCA from the en-route airspace through the transition points. The aircraft then fly towards the runway following a specific trajectory profile defined by some waypoints. The arrival trajectory profile refers to Standard Terminal Arrival Routes (STAR). The departing aircraft enter the TCA from the aerodrome control area and fly to the airway following the Standard Instrument Departure trajectory profile (SID). The information about STAR and SID can be accessed in the Aeronautical Information Regulation and Control (AIRAC) as a supplement to the Aeronautical Information Publication (AIP) published by the Directorate General of Civil Aviation (DGCA) of Indonesia [20].

With Flight Management Computer (FMC) support, aircraft can automatically fly along with these profiles. Under certain circumstances, the aircraft must follow the instruction from the air traffic controller containing the aircraft's direction (heading), altitude, and speed changes, often referred to as vectoring. Arrival operations have more significant conflict potential than departures because aircraft have trajectories that converge, especially when entering a merging point. Aircraft speed on arrival will also experience a reduction so that the aircraft in front tends to be overtaken by the aircraft behind it. The departure model has a smaller potential for conflict than the arrival because the trajectory tends to be diverging. Potential conflicts with arriving aircraft are also minimal due to differences in altitude and flight path.

There are six TCA sectors related to Runway 25R and 25L are modeled in this study: Jakarta Lower Control North (LN), Jakarta Lower Control Center (LC), Jakarta Lower Control East (LE), Jakarta Terminal West (TW), Jakarta Terminal East (TE), and Jakarta Terminal South (TS). Each sector has boundaries described by latitude-longitude, altitude/flight level, and radius from ATC head radar. Information about the boundaries can be accessed in Standard Operating Procedures Air Traffic Services Approach Control Service published by Airnav Indonesia Branch of Jakarta Air Traffic Service Center (JATSC) [21]. The arrival traffic model has six trajectory profiles, and the departure traffic model has ten. Complete trajectory profiles and TCA sectors related to the Runway 25R and 25L air traffic model are shown in Fig . 1.

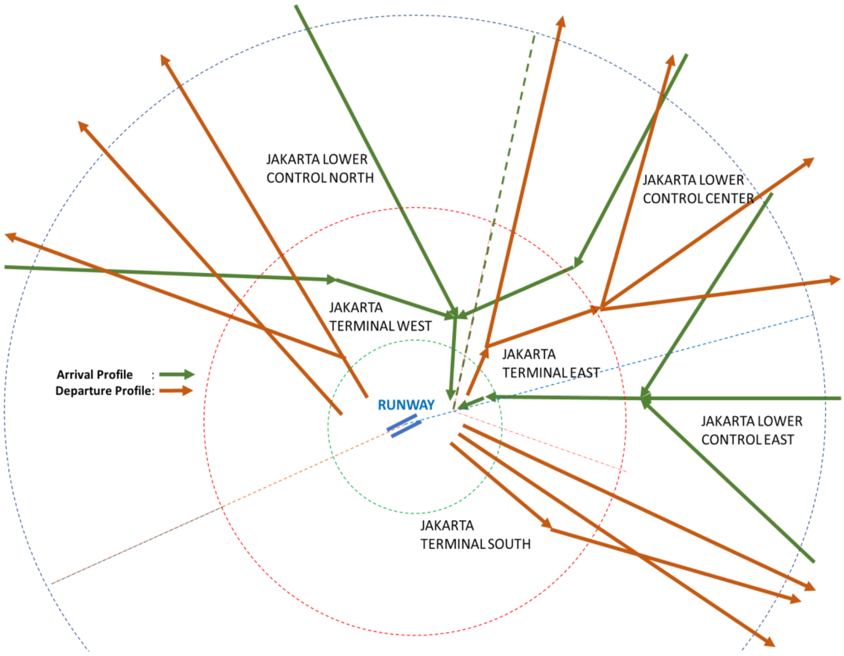

Fig. 1: Trajectory profiles and TCA sectors related to Runway 25R and 25L.

2.2 Air Traffic Model

The air traffic model was built using MATLAB software by combining discrete-event and agent-based models. The wind speed model was added as an environmental element influencing the system. The wind speed consists of wind velocity and direction represents the weather condition. Each aircraft has a fixed parameter that will not change during simulation: aircraft type and trajectory profile based on SID/STAR. There are also dynamic parameters that will change during simulation; these parameters are:

- Position: In the form of local NED (North, East, Down) coordinates with a reference point at the NOKTA waypoint (X, Y, Z);
- Airspeed: Airspeed in the local NED direction (Vx, Vy, and Vz);
- Waypoint: present the waypoint to which the aircraft is headed;
- Heading: Heading aircraft relative to local north;
- Distance to waypoint: the distance of the aircraft to the next waypoint;
- Right of Way: priority of aircraft when heading/being on the same track;
- Conflict status: free from conflict or not;
- Resolution: selected conflict resolution mode (vectoring, speed control, or altitude control);
- TAS and GS: aircraft true airspeed and ground speed;
- Vertical speed: vertical aircraft speed when climbing (+) or descent (-); and
- RADAR radius: radius from RADAR.

Each trajectory has a unique profile based on STAR and SID published in Aeronautical Information Publication (AIP) [20]. Each aircraft will move along the trajectory with the waypoint as profile guidance. The aircraft distance relative to the waypoint is obtained by the equation [22]:

$$dx_t = X_{wp} - X_t \tag{1}$$

$$dy_t = Y_{wp} - Y_t \tag{2}$$

$$dz_t = Z_{wp} - Z_t \tag{3}$$

$$d_{s,t} = \sqrt{(dx_t)^2 + (dy_t)^2 + (dz_t)^2} \tag{4}$$

With,

X_t, Y_t, Z_t: aircraft coordinates on each coordinate axis;
X_{wp}, Y_{wp}, Z_{wp}: waypoint coordinates on each coordinate axis;
dx_t, dy_t, dz_t: distance to the waypoint on each coordinate axis;
$d_{s,t}$: aircraft distance relative to the waypoint.

After getting the distance relative to the waypoint using the above equation, then the heading angle can be calculated relative to the waypoint (θ_t) apply the equation:

$$\theta_t = \tan^{-1}\frac{dx_t}{dy_t} \tag{5}$$

The aircraft heading angle relative to the waypoint is used to calculate the relative aircraft speed on each axis (Vx, Vy, Vz) using the equation below:

$$Vx_t = \begin{cases} = V_t \cos\theta_t\,, & dz_t = 0 \\ \neq \left(\sqrt{{V_t}^2 - {Vz_t}^2}\right)\cos\theta_t & dz_t \neq 0 \end{cases} \tag{6}$$

$$Vy_t = \begin{cases} = V_t \sin\theta_t\,, & dz_t = 0 \\ \neq \left(\sqrt{{V_t}^2 - {Vz_t}^2}\right)\sin\theta_t & dz_t \neq 0 \end{cases} \tag{7}$$

$$Vz_t = \begin{cases} = 0, & dz_t = 0 \\ \neq 0 & dz_t \neq 0 \end{cases} \tag{8}$$

Furthermore, it can be determined the position of the aircraft for each axis at a time (t + 1) through the equation:

$$X_{t+1} = (Vx_t * \delta t) + X_t \tag{9}$$

$$Y_{t+1} = (Vy_t * \delta t) + Y_t \tag{10}$$

$$Z_{t+1} = (Vz_t * \delta t) + Z_t \tag{11}$$

The separation between aircraft is maintained by using conflict detection and resolution models. It is necessary to calculate horizontal (d_{hor}) and vertical (d_{ver}) separations between aircraft (a and b) to check whether the separation between aircraft is still safe (does not exceed the minimum limit) using the following equation:

$$d_{hor} = \sqrt{(X^a - X^b)^2 + (Y^a - Y^b)^2} \tag{12}$$

$$d_{ver} = \sqrt{(Z^b - X^a)^2} \tag{13}$$

X, Y, and Z are the aircraft coordinates a and b on each coordinate axis.

After the separation between aircraft is known, whether the separation is still safe or if there has been a potential conflict (smaller than the specified minimum separation buffer) can be checked. Conflicts at TCA more often occur when the plane is heading to the merging point. If several aircraft experience conflict, it will be determined which aircraft gets the Right of Way (ROW) based on the closest distance to the merging point. The aircraft that gets the first ROW continues to fly following the specific trajectory without resolving conflict. The other aircraft should make specific maneuvers as part of conflict resolution.

The flowchart of the aircraft's movement in the simulation model is shown in Fig. 2. The model has three conflict resolution modes: vectoring, airspeed control, and altitude control.

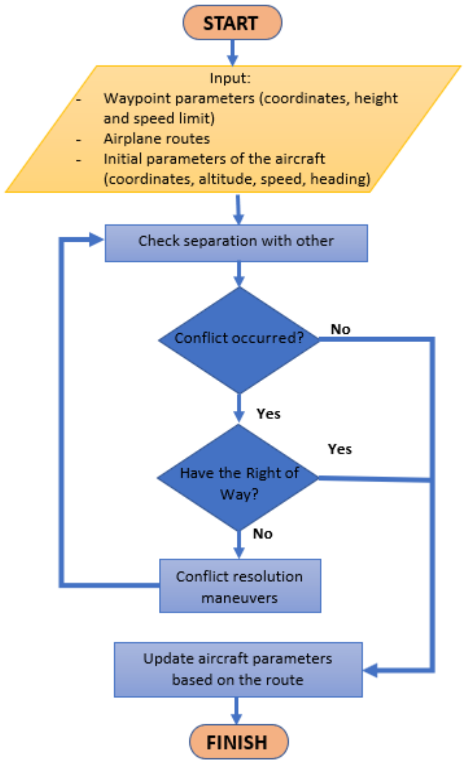

Fig. 2: Flow chart of aircraft movements in the simulation model.

2.3 Flight Parameter Model

Flight parameter models were extracted from ADS-B data provided by FlightRadar24. The ADS-B data was collected from more than 38800 flights that departed and landed at Soekarno-Hatta International Airport, Jakarta [23]. The models included five aircraft flight parameters: Airbus A320, Boeing B737, Airbus A330, Boeing B777, and Boeing B787. Machine learning was used to handle a large quantity of ADS-B data to identify the phase of the flight and the time when the aircraft flew across specific waypoints. One advantage of this technique is that ADS-B data can be efficiently and cost-effectively gathered over the internet. ADS-B data was combined with weather data from Aviation Meteorological Information System in Meteorological, Climatology, and Geophysical Agency (BMKG) to develop the flight parameter model [24].

The waypoints used for analysis were the waypoints flown by aircraft using Runway 25R and 25L for departing and arriving. The waypoint information was obtained from the Soekarno Hatta International Airport Terminal Chart published by the Indonesia DGCA [20]. The K-Nearest Neighbor algorithms processed flight parameters from ADS-B data when the aircraft had the nearest position to specific waypoints within a radius of 1 NM. The altitude and the vertical speed were processed straight from the ADS-Data. The true airspeed was generated from the ground speed and wind speed data from weather data.

Three probability distribution functions (Normal Distribution, Beta Distribution, and Gamma Distribution) approached flight parameter models using maximum likelihood estimation. The best distribution was determined using Kolmogorov-Smirnov Test. The flight parameters for this research used the mean value from the models. Validation was carried out on previous research by comparing the estimated parameters with flight

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parameters from the Eurocontrol Aircraft Performance Database [25] and the reference parameter from the JAKARTA (WIII) Terminal Chart issued by the Indonesia Directorate General of Civil Aviation [26]. Table 2 shows some of the aircraft's flight parameter models when flying by specific waypoints.

Table 2: Flight parameter models for each type of aircraft when flying by waypoints

Waypoint	Altitude (feet)					True Airspeed (knot)					Vertical Speed (m/s)				
	A320	B737	A330	B777	B787	A320	B737	A330	B777	B787	A320	B737	A330	B777	B787
ABILO	35834	35834	35834	35834	35834	436	436	436	436	436	836	836	836	836	836
AJUNA	7758	7339	7131	6492	7208	287	283	279	285	278	2524	2473	2484	2115	2283
ALAMO	38228	38228	38306	38228	38228	450	450	450	477	477	425	425	425	524	524
ARKAP	2227	2215	2368	2350	2300	190	180	187	190	183	216	239	263	366	305
BUNIK	22799	22771	21798	22370	22788	395	373	389	389	391	1838	1630	1619	1543	1562
CA	10107	10929	11161	11161	11161	455	454	454	455	455	777	696	1193	1193	1193
CARTA	14032	14032	14032	13618	14101	314	336	335	330	326	1558	1789	1465	1396	1407
CORIL	8482	9483	9483	9483	9483	464	458	458	458	16	890	1096	1096	1096	1096
DAPIK	1262	1310	1320	1381	1291	217	214	208	212	207	371	560	384	601	397
DENDY	24419	24419	24124	23850	24169	378	378	390	392	393	1259	1259	1389	1554	1511
DOLTA	27591	29814	28087	26436	32599	446	453	443	470	473	1007	1171	1377	1479	1918
ESALA	3316	3317	3371	3627	3489	288	286	285	286	282	1271	1256	1227	1141	1251
FRIDA	32125	33409	33409	33409	33409	463	456	463	463	463	776	731	776	776	776
GAPRI	6909	6682	6912	7103	7335	375	365	378	375	362	1699	1538	1494	1105	1119
GASPA	9155	9335	8314	9020	9056	449	384	430	429	431	1180	775	1714	1750	992
HLM	4093	4203	4363	4620	4620	354	361	20	361	374	1987	2263	2093	3375	3375
IMU	8813	8765	8964	9254	9254	425	423	424	438	438	1350	1450	1554	1823	1823
KURUS	9418	8932	9079	9273	9273	447	432	460	469	469	2046	1715	1961	2338	2338
LARAS	21015	21015	19140	22357	19524	397	397	402	434	405	1778	1778	1578	1968	1856
LEPAS	29868	29868	29868	34739	31644	457	457	457	480	483	874	874	874	211	1040
NABIL	4425	4217	4121	4298	4298	356	346	350	350	367	2111	2259	1924	2338	2338
NADIN	7942	7670	7944	8185	8185	405	394	401	399	399	1731	1554	1591	1362	1362
NOKTA	11931	12443	12207	12385	13008	290	284	290	295	295	1403	1185	1185	1136	1132
PRIOK	3537	3712	3395	3425	3309	218	216	215	212	211	643	802	582	648	663
PW	7538	7847	9144	9144	9144	433	423	423	437	437	1235	966	1738	1738	1738
RAMAL	17531	17660	16867	17489	17576	342	329	338	343	345	1636	1426	1543	1535	1559
RAMBU	6905	6998	6768	7241	7202	255	256	259	262	262	1050	1112	1005	1088	1186
RATIH	15998	15998	16475	18685	16634	377	377	373	400	379	2034	2034	1737	2071	1870
SIKAD	18000	17300	17675	17675	17675	358	362	414	414	414	2100	2300	2800	2800	2800
TEGAR	2122	2146	2110	2115	2031	247	249	245	247	246	902	1027	813	899	857
WETES	5062	4967	5088	5284	5043	331	327	333	330	320	1596	1511	1604	1453	1335
WINAR	6157	5757	5409	5016	5271	278	274	264	273	271	2635	2595	2535	2144	2429

2.4 Air Traffic Complexity

The calculation of air traffic complexity at TCA begins by determining the indicators affecting the complexity and relevance of the airspace sector. After that, the weight of each indicator needs to be determined using the analytic hierarchy process (AHP) method.

The most mentioned indicators relevant to the TCA airspace sector can be selected based on Table 1. Hence, air traffic complexity measurement in this paper uses seven indicators: air traffic density (N_{in}), number of climbing (N_{clb}) and descending (N_{des}) aircraft, aircraft type mixing (T_{typ}), potential conflict control (crossing and overtaking conflict, T_{trf}), aircraft speed difference (T_{spd}), and frequency of controller's coordination or communication (T_{com}). The weight of each indicator was obtained using an analytic hierarchy process (AHP) method.

The first step in the AHP method was to collect input data with pairwise comparisons of the indicators. Complexity indicators were paired with a rating that determined which indicator was more critical. This data was collected by a survey involving respondents from experts and practitioners. The questionnaire was created to assess the relative importance (weight value) of the target respondents, experts, and air traffic controllers from Airnav Indonesia, notably the Jakarta Air Traffic Services Center (JATSC). The questionnaire was filled out by respondents using online media. The second step was to average the input comparison values using the Row Geometric Mean Method (RGMM). The average r_i value was determined using the following equation.

$$r_i = exp\left[\frac{1}{N}\sum_{j=1}^{N} ln(a_{ij})\right] = \left(\prod_{i=1}^{N} a_{ij}\right)^{\frac{1}{N}} \tag{14}$$

The comparison matrix A = a_{ij} with dimensions of N×N, N = 7 (number of indicators). The third step was calculating the first eigenvector of matrix A (Eigen 1 in the E1 matrix). The fourth step was calculating the second eigenvector (Eigen 2 in the E2 matrix). Then proceed to the fifth step, calculating the difference between E1 and E2. The sixth step was to assess the consistency of the respondent's answers in the following way.

a. Calculate the Weighted Sum Vector (WSV) by multiplying the rows of matrix A by matrix E1.
b. Divide each element of the WSV matrix by each element of the E1 matrix to obtain the Consistency Vector (CV).
c. Calculate the lambda (λ) by averaging CV and calculating the Consistency Index (CI) using the following equation.

$$CI = \frac{\lambda - N}{N-1} \tag{15}$$

d. Divide CI by the Random Consistency Index to get the Consistency Ratio (CR) (RI).

$$CR = \frac{CI}{RI} \tag{16}$$

Table 3 shows the RI value for a given N value.

Table 3: Random consistency index [4].

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0,58	0,9	1,12	1,24	1,32	1,41	1,45	1,49

After knowing the value of each indicator and its weight of importance, the general equation for the function of air traffic complexity at TCA can be calculated.

$$F_c = (W_{in} \times N_{in}) + (W_{clb} \times N_{clb}) + (W_{des} \times N_{des}) + (W_{typ} \times T_{typ}) + (W_{rtf} \times T_{rtf}) + (W_{spd} \times T_{spd}) + (W_{com} \times T_{com}) \tag{17}$$

Air traffic complexity values were calculated for several scenarios. The scenarios were varied on the inter-arrival time (IAT) and the percentage of possible resolution types (speed control, altitude control, and vectoring).

3. RESULTS AND DISCUSSION

The simulation animation is used to validate the model by observing the model's behavior while the simulation is running [27]. Some entities (aircraft) are observed moving from the time they enter the system to the time they leave the system to determine whether the aircraft moves correctly according to the predetermined modeling concept and whether the conflict detection and resolution have been applied.

The animation observations show that the entity followed its arrival and departure trajectory according to the predetermined trajectory route. The data validation and operational graphics results also show that the model correctly implemented the applied conflict detection and resolution. No aircraft violated the minimum separation rules when the simulation ran in normal conditions.

The waypoint modeling for Soekarno-Hatta International Airport is based on local coordinates of NED with NOKTA as a reference point. The model is used to simulate the air traffic in the TCA, especially at JAKARTA TCA for Runway 25R and 25L. The model visualized 2-dimensional forms that moved for each unit of time. Flight parameters were estimated from ADS-B data for specific waypoints.

The movement of the aircraft in the simulation were repreented by a green dot when there was no conflict, a yellow dot when there was a potential conflict, and a red dot when there was a conflict with other aircraft. The simulation had twelve entry points and ran for 7200 units or the equivalent of 7200 seconds. There were three scenarios, each was running for just one resolution mode choice to solve the traffic conflict. Air traffic complexity was measured by calculating seven complexity indicators recorded during the simulation. Visualization of the simulation model is shown in Fig. 3.

A total of 119 questionnaire respondents from the JATSC controller provided information to determine which complexity indicator was more critical among the indicators that have been paired. The questionnaire results were then processed by AHP to obtain the weighting value for each indicator, as shown in Table 4.

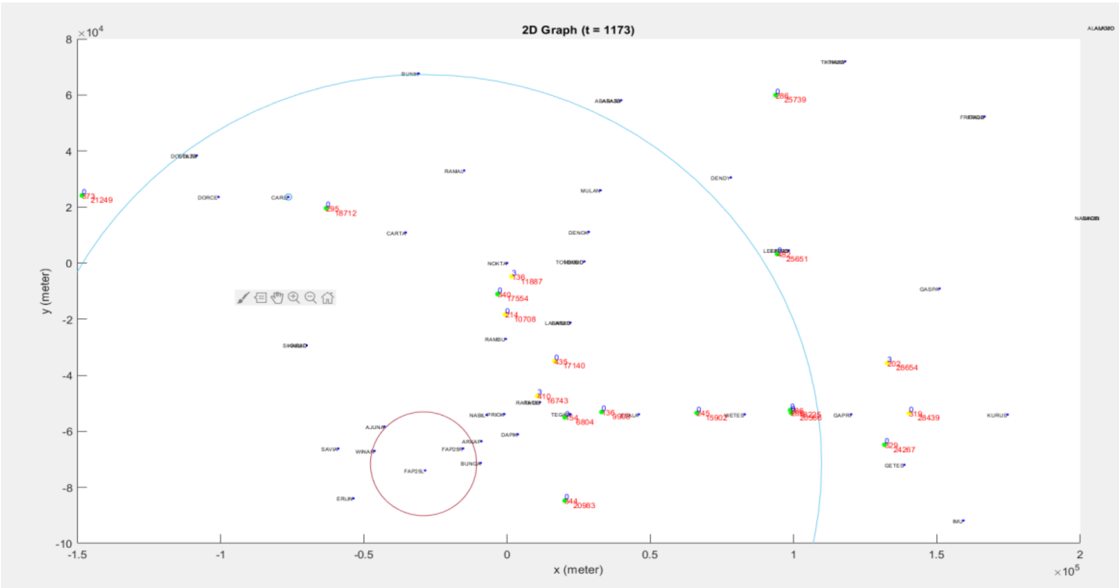

Fig. 3: Visualization of the simulation model with aircraft movement representation.

The level of consistency (Consistency Ratio) of the AHP was 0.72% which means that the answers were consistent (CR < 10%). This CR value indicated that the weighting values that were obtained could be used in the simulation. As shown in the table, the indicator that most influences complexity is the potential conflict control for crossing and overtaking conflict, with a weighting value of 38.87%. The indicator with the smallest weighting value

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is the number of climbing aircraft (8.99%). Thus, the general function for air traffic complexity at JAKARTA TCA can be written as follows.

$$F_c = (0.1218 \times N_{in}) + (0.0899 \times N_{clb}) + (0.1078 \times N_{des}) + (0.1015 \times T_{typ}) + (0.3887 \times T_{rtf}) + (0.0924 \times T_{spd}) + (0.0980 \times T_{com}) \quad (18)$$

Table 4: Weighting value of each complexity indicator

Complexity Indicators	Weighting Value
Air Traffic Density (N_{in})	12.18%
Number of Climbing Aircraft (N_{clb})	8.99%
Number of Descending Aircraft (N_{des})	10.78%
Aircraft Types Mixing (T_{typ})	10.15%
Potential Conflict Control (T_{rtf})	38.87%
Aircraft Speed Difference (T_{spd})	9.24%
Frequency of Air Traffic Controller's Coordination or Communication (T_{com})	9.80%

Function (18) shows that the number of descending aircraft is more critical than the number of climbing aircraft in influencing air traffic complexity. It is also shown that the aircraft type mix is more important than the aircraft speed difference. This result is different from Diaconu et al. (2014) in which the climbing was more important than the descent, and the aircraft speed difference was more important than the aircraft type mix [4]. The controller's significant preference with the same indicator may vary for different air traffic service units. So it is necessary to analyze the weighting value of the complexity indicator for related air traffic service units before measuring the air traffic complexity in specific airspace sectors.

Controller task load is represented by controller communication time in the function through the frequency of the controller's coordination or communication (T_{com}). The complexity rate will increase the more frequently the controller coordinates or communicates with the pilot and another controller. The weighting of communication time in the complexity function is more critical than the number of climbing aircraft (N_{clb}) and Aircraft Types Mixing (T_{typ}). In addition to task load, other factors such as equipment capability, individual preferences, and cognitive controller strategies are required to obtain a complete picture of the correlation between complexity and workload [28].

The simulation run for ten repetitions with aircraft type mix is a 9:1 ratio for Medium type (Boeing B737 and Airbus A330) and Heavy type (Airbus A330, Boeing B777, and Boeing B787). When entering the arrival point, time separation is set to 4 minutes, and departure is about 6 minutes. This gives high traffic density to the model. The minimum separation is 5 NM with a buffer of 15 NM to solve the potential conflict. A graphic of complexity measurement from a simulation (altitude control mode only) for each TCA sector is shown in Fig. 4.

From Fig. 4, Jakarta Lower Control North and Jakarta Terminal West have a high rate of complexity relative to the other sectors. Jakarta Terminal East has the lowest complexity rate compared with the others on Runway 25R and 25L operation. The model can show the complexity rate comparison between sectors. It can be used to assess what sector has a higher rate of complexity for a particular runway operation, and the management should take some action to balance it.

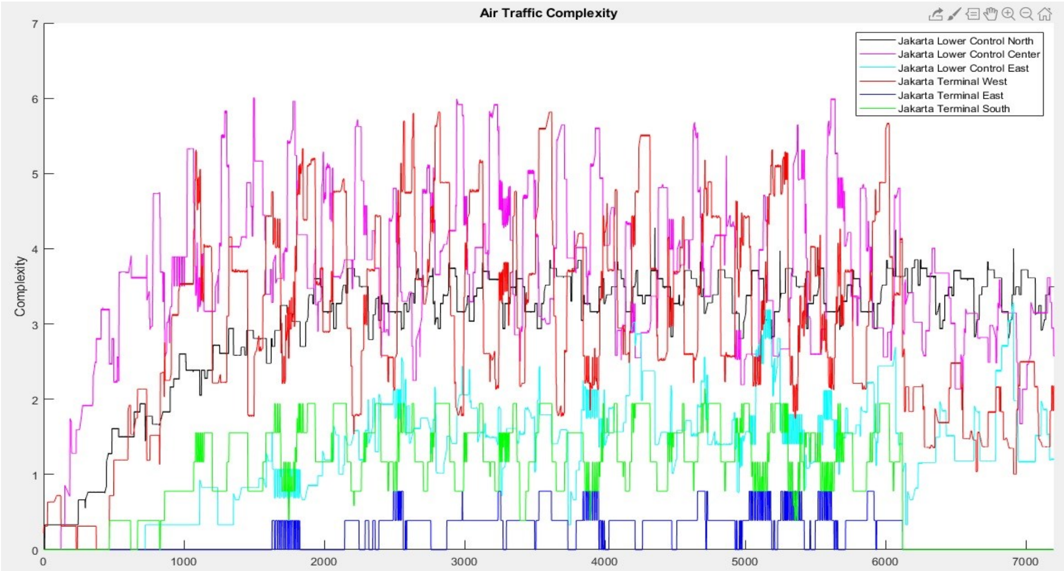
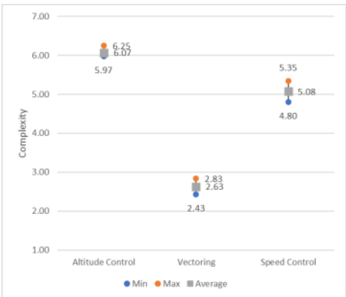
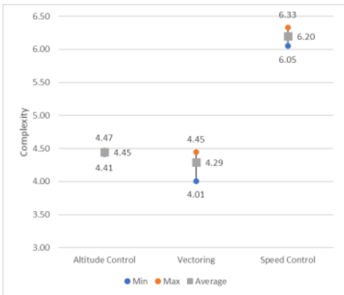


Fig. 4: Result of complexity measurement (altitude control mode only).

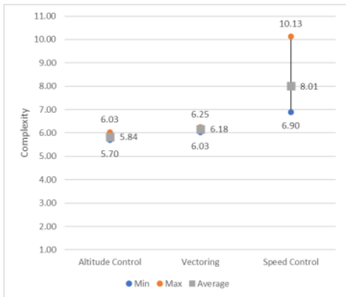
Simulation results of air traffic complexity measurement and the number of potential conflicts for specific resolution mode scenarios in each sector are shown in Fig. 5 and 6.



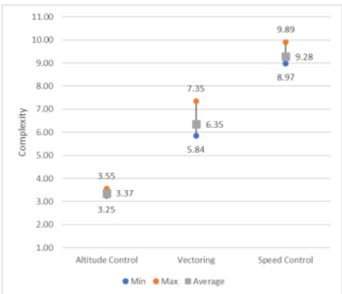
(a) Jakarta Lower Control North



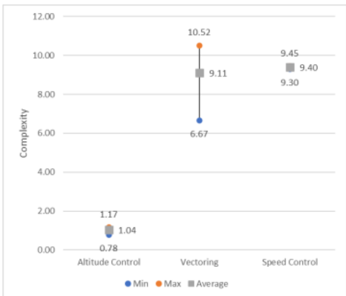
(b) Jakarta Lower Control Center



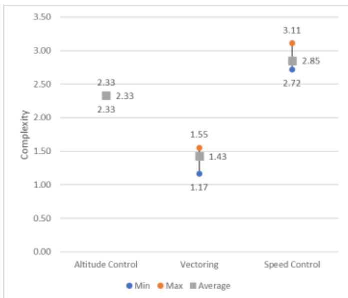
(c) Jakarta Lower Control East



(d) Jakarta Terminal West



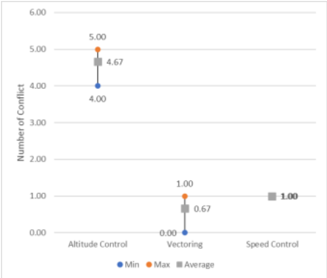
(e) Jakarta Terminal East



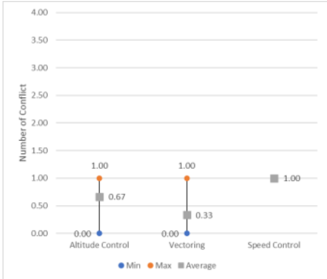
(f) Jakarta Terminal South

Fig. 5: Values of air traffic complexity on sectors for specific resolution mode's scenario.

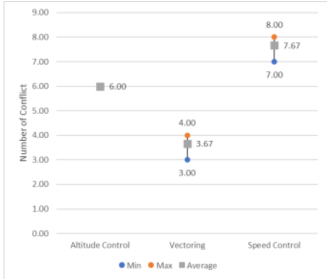
https://doi.org/10.31436/iiumej.v24i1.2223



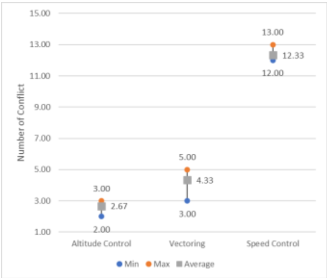
(g) Jakarta Lower Control North



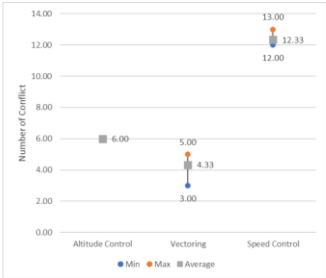
(h) Jakarta Lower Control Center



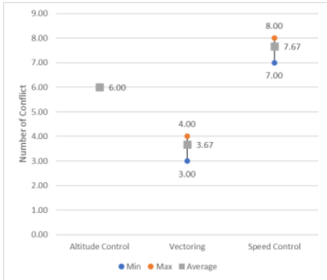
(h) Jakarta Lower Control East



(i) Jakarta Terminal West



(j) Jakarta Terminal East



(k) Jakarta Terminal South

Fig. 6: Number of potential conflicts on sectors for specific resolution mode's scenario.

Figure 5 shows that the speed control mode assigns a higher complexity rate for all sectors except Jakarta Lower Control North. For lower rate complexity, vectoring mode gives the lowest complexity than the other resolution mode, as seen in Jakarta Lower Control North, Jakarta Lower Control Centre, and Jakarta Terminal South. Altitude control mode gives a higher rate of complexity and more potential conflict if applied to the sector with many departure trajectories like Jakarta Lower Control North. Fig. 5 and 6 elaborate that speed control to solve the conflict increases complexity and creates more potential conflict for almost all sectors. Vectoring mode gives the least potential conflict than the other modes except on Jakarta terminal West.

The simulation result can compare the complexity between sectors in a TCA and its effect on potential conflicts. However, the model cannot yet determine how this complexity affects aviation safety risks. As we know, complexity will affect the controller's workload level [5]. Representation of the human factor is needed to measure the controller workload, and its effect on safety risk factors can be observed. Future research needs methods to represent the human factor in a simulation model, including adding a controller to the simulation (human in the loop simulation) [16] or developing a controller workload model [29].

4. CONCLUSION

The weighting value of seven air traffic complexity indicators has been calculated using the AHP method in this study. The indicator that most significantly affects the air traffic complexity is the potential conflict control. The consistency of respondents' answers is less than 10%, indicating that these results are consistent. It can determine the air traffic complexity rate in the JAKARTA TCA model.

The simulation has been run to measure the air traffic complexity of JAKARTA TCA in a high-density situation. The simulation result explains that the resolution mode selection influences the complexity rate and potential conflicts. The simulation model requires further development by representing the human factor in the model so the model can be used to analyze safety risks.

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