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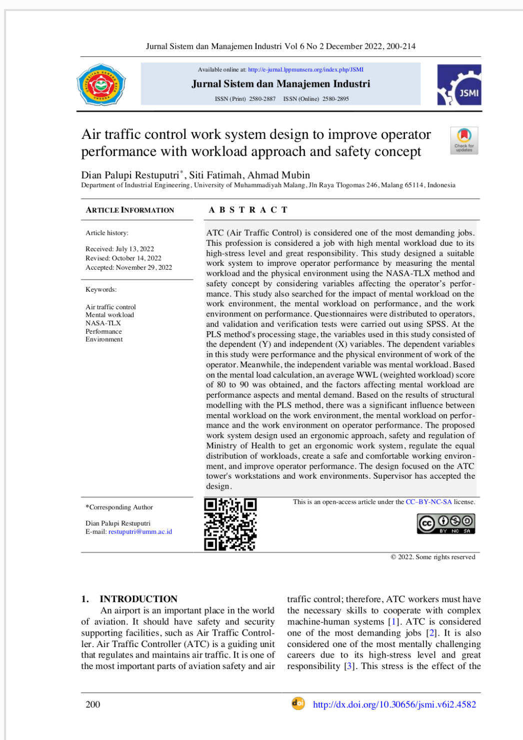

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Air traffic control work system design to improve operator performance with workload approach and safety concept

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A B S T R A C T

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1. INTRODUCTION

An airport is an important place in the world of aviation. It should have safety and security supporting facilities, such as Air Traffic Controller. Air Traffic Controller (ATC) is a guiding unit that regulates and maintains air traffic. It is one of the most important parts of aviation safety and air traffic control; therefore, ATC workers must have the necessary skills to cooperate with complex machine-human systems [1]. ATC is considered one of the most demanding jobs [2]. It is also considered one of the most mentally challenging careers due to its high-stress level and great responsibility [3]. This stress is the effect of the

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Investigation of fatigue in shift work has become a popular topic in various industries. The previous study showed that fatigue could gradually increase during more extended shifts. Several studies showed an increased risk after working 10 hours compared to workers who work 8 hours [5], [6]. A study also showed that accidents occur when you work more than 16 hours [7]. Chang et al. [8] studied the effect of fatigue on ATC workers based on work shifts. It was found that there were different levels of fatigue for each shift. The higher the working hours required, the higher the number of work accidents [9].

As an important subject in aviation safety, the ATC requires workers with the skills to work together in a complex machine-human system [1]. ATC has a system closely related to various ergonomic fields, from control procedures for job allocation and work time [10]. Workers have to interact with components of the ATC system to ensure safety and an orderly and efficient flow of air traffic. ATC workers that cannot interact appropriately can lead to potential human error and risk of air traffic accidents. It is evidenced by a study at ATC Australia, which found that coordination and communication errors are contributed the most to air traffic accidents [11]. Chang & Yeh [12] explained that human performance factors in ATC influence each other through interactions with other humans, software, hardware, environment, and organizations.

Mental workload (MWL) is one of the most widely used concepts in ergonomic study and practice [13]–[17]. Since 1960 mental workload has become an important issue in various industries [18]. Many researchers have used this mental load measurement to evaluate human performance [19]. Stassen et al. [20] said that mental workload measurement could reduce human error and increase safety and worker satisfaction. With the rapid development of technology and sophisticated industrial system, operators often receive high MWL, especially those working through complex operating procedures. Although many systems have been automated these days, the study's results showed that more than 70% of work accidents are caused by human error [21]. MWL can be defined as the amount of mental effort required for a person to perform a particular task [22]. It includes cognitive effort and other factors, such as stress, fatigue, and motivation [23], [24]. Mental workload is not only measured through questionnaires. Still, it can also be combined with physiological work measurements such as those conducted by Charles &Nixon [25], Foy & Chapman [26] and Fallahi et al. [27]. As job demands increase, more resources are used (demanding workers' attention), and performance will stabilize at optimal levels. A further increase in a job will start to burden the worker. Workers will be less productive due to errors, and the response rate will decrease. Then, worker performance will decrease [28], [29].

One of the most widely used measurement tools for subjectively assessing the workloads of individuals operating in high-risk and industry time sensitivity is the National Aeronautics and Space Administration Task Load Index (NASA-TLX). The NASA-TLX Index is a subjective workload rating scale developed for aviation and health fields. The scale is intended to measure the overall workload as a single variable calculated by adding up responses to six items, namely Mental Demand (MD), Physical Demand (PD), Temporal Demand (TD), Effort (EF), Performance (PE) and Frustration (FR). NASA TLX was first introduced by Hart & Staveland [30] and later refined and developed by Hart [31]. Currently, many studies use the NASA TLX method for calculating mental load, for example, Hwang et al. [32] in the nuclear industry, Jacobson Jr et al. [33] in the health industry, Tubbs-Cooley et al. [34] and Restuputri et al. [35] in nurses, Yan et al. [36] in the marine sector, Collet et al. [37] in ATC workers.

Air traffic control is very complex and cognitively demanding [38]. Factors that affect ATC workers' workload, such as traffic volume or congestion frequency, can increase their mental workload, leading to the increased risk of air traffic controller failure [39]–[41]. In general, the workload is limited by several resources needed to complete a job [13], [42] depending on the difficulty and time to complete a job [43]. Air traffic controllers must be able to manage their cognitive load continuously [16], [44]. When involved in cognitive processes, human information processing requires limited cognitive resources for mental processing [45]. With an increasing workload, more resources are needed, leading to workers' reduced mental capacity. Excessive workload will affect workers' performance and may cause errors. These errors can also occur when human memory exceeds its limit [36], [46].

ATC systems that combine human operators and their equipment are increasingly reliable; therefore, incidents usually occur when human error is involved [47]. Pounds & Isaac [48] stated that human error contributes to 75% of ATC incidents. Therefore, ATC workers have an important role in air traffic safety. ATC workers must not make the slightest mistake to minimize aircraft accidents. Mental workload is more affected by the work environment conditions than by each individual's factor [49]. Excessive workload and a detrimental work environment can cause a decreased performance of operators. The previous study using the NASA-TLX method was conducted to obtain an overview of airport employees' workload [3]. This study showed that significant excess workload occurs in the operational and aeronautical work units, resulting in operators' decreased performance [3]. Another study by Huggins & Claudio [50] and Chen et al. [51] was conducted to determine the relationship between workload and work environment. This study showed a significant relationship between workload and work environment [52].

Based on previous studies by Chang et al. [12], it can be concluded that ATC operator performance depends on the workload, workspace design specification, equipment, facilities, and whether the air traffic needs are matched with the work performed by the ATC operator [12]. Therefore, this study created a suitable work system design to improve operator performance by measuring the mental workload and physical workplace environment using the NASA-TLX method and safety concept by considering the variables affecting the performance of the ATC operators.

2. RESEARCH METHODS

The proposal given to Tower ATC was in the form of a work system design that considers the results of the measurement of mental workload, physical workplace environment, and the statistical test processing results using the PLS method that took into account the Ergonomic and concepts for comfort and safety while working. Per the existing problems, work system design can be conducted on the workstation and the physical workplace environment. The design was in the form of a work facility layout and work environment improvement. The new work system design will evaluate the existing work system and adjust it to the standards of Ergonomics, K3 and the Ministry of Health. This work system design aimed to improve the ATC operators' performance.

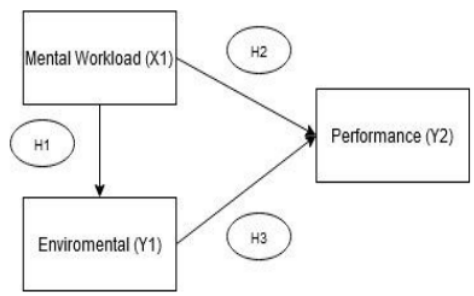

Fig. 1. Conceptual framework

Many studies have shown a relationship between an environment and cognitive workload [53]. Office noise, particularly irrelevant speech with high enough intelligibility, has been demonstrated to impair performance on tasks requiring serial recollection, information search, proofreading, and counting [54]–[57].

According to reviews of Hancock et al. [58] and Pilcher et al. [59], room temperature can also impact cognitive performance. Short-term free recall tasks [60], addition and visual tasks [61] and working memory tasks [62] have all shown that cognitive function suffers at higher temperatures. So the hypothesis in this study is :

H1: There is a significant influence between mental workload variables on the work environment

Several studies have stated that mental effort will affect performance. Mental efforts that workers bring into work activities can bring about job performance [63]. Mental effort can be a successful compensation to maintain performance [64]. So the hypothesis in this study is :

H2: There is a significant influence between mental workload variables on performance

Job performance significantly impacts an organization's profitability [65]. Organizational success depends on employee performance; hence performance is crucial. Performance is also crucial

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for people because completing duties can be a source of happiness [66]. Performance is the outcome of a person's or a group's work in an organization at a specific time, reflecting how successfully the individual or group meets the requirements of a position in a mission to accomplish the company's goals. The equipment and physical work environment are only two examples of the many variables that could affect an employee's success on the job [67]. The physical work environment and its impact have been extensively examined because it can impede, interfere with, or place restrictions on the variety of work behaviours expressed, which could then impact how well tasks are completed. So the hypothesis in this study is :

H3: There is a significant influence between work environment variables on performance

The Conceptual framework in Fig. 1 explains the relationship interaction or influence between mental workload on work environment (performance) and work environment and performance. The statistical test stage used the PLS (partial least square) method. It is a method used to test the prediction effect between variables and assess whether there is a strong relationship or influence between variables used in a study. The PLS method was processed using the SmartPLS software. At the PLS method's processing stage, the variables used in this study consisted of the dependent (Y) and independent (X) variables. The dependent variables in this study were the physical environment (Y1) of work and the performance (Y2) of the operator.

Meanwhile, the independent variable was mental workload. Variables in mental workload are generated from NASA-TLX by Hart & Staveland [30]. Meanwhile, variables in the work environment are generated by Robbins & Judge [68]. Robbins & Judge explain employee performance is the level to which employees achieve job requirements [68]. The factors that affect employee performance are quality and skill quantity, effectivity and efficiency, work behavior and ethic, discipline, supporting facilities and initiative. Variables in the work environment are generated from Wignjosoebroto [69]. The physical environment is one of the external factors that affect humans in work, such as temperature, lighting, noise and humidity. The Table 1 show variables used in the indicators.

Table 1. Variable in conceptual framework

Mental workload (X)	**Work environment** (Y1)	**Performance** (Y2)
Mental need	Room temperature	Quality and skill
Physical need	Lighting level	Quantity
Time need	Noise Level	Effectivity and efficiency
Performance	Air Humidity	Work behavior and ethic
Effort		Discipline
Frustration level		Supporting facilities
		Initiative

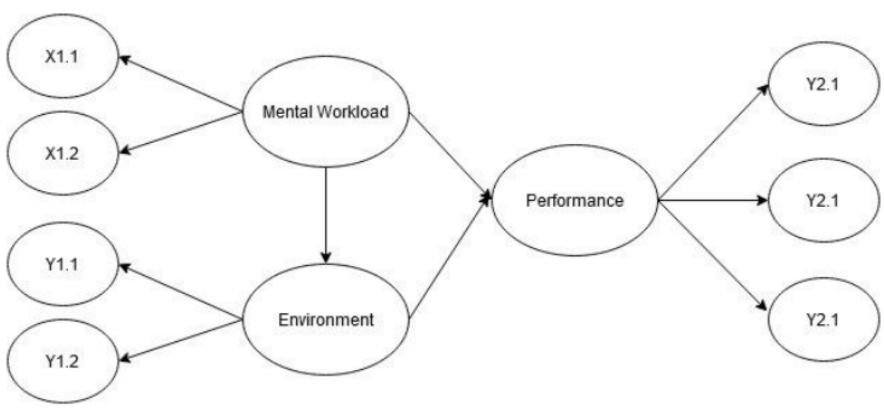

Fig.2. Conceptual framework of mental workload and work environment variables

Table 2. Explanation of conceptual notation

Variable	**Indicator**	**Statement/Item**
Mental Workload	Mental Need	Working with mental activities such as thinking, deciding, calculating or remembering at work is not a burden for me (X1.1)
	Performance	I create maximum work results to complete the assigned task (X1.2).
Work environment	Temperature Level	The workspace's room temperature follows the physical environment recommended for the ATC workspace (Y1.1).
	Noise Level	The workspace noise level follows the physical environment recommended for the ATC workspace (Y1.2).
Performance	Quality	I perform the work following the existing Standard Operating Procedure (SOP)(Y2.1).
	Punctuality	I completed the assigned task on time(Y2.2)
	Quantity	I complete the assigned tasks according to the given target(Y2.3)

This study was conducted with 9 operators, the population of ATC of Abdulrahman Saleh Airport Malang. Data collection was conducted by interview, observation, questionnaire distribution, and documentation. There were two types of questionnaires in this study. The first was the NASA-TLX questionnaire used to measure ATC operators' mental workload. In this questionnaire, Respondents were asked to choose one of the indicators that they felt was more dominant in causing mental workload in their work. Respondents were also asked to provide weighting values from 0 – 100 [70]. The Interpretation Score of NASA TLX for Low 0-9, Medium 10-29, Somewhat high 30-49, High 50-79 and Very high 80-100 [71]. The second questionnaire was the Likert scale questionnaire used to determine operator performance. In filling out this Likert scale, Respondents were asked to provide a score of 5, 4, 3, 2, or 1 to any available indicators. The Likert scale (typically) provides five possible answers to a statement or question, allowing Respondents to indicate their positive-to-negative strength of agreement or feeling regarding the question or statement. The interpretation score for the Likert scale is 5 for strongly agree, 4 for agree, 3 for sometimes, 2 for disagree, and 1 for strongly disagree. Questionnaire distribution was carried out after Respondents finished monitoring tasks in the morning and evening shifts.

This mental workload measurement for ATC operators used the NASA-TLX method, carried out in the following steps. First, calculate the comparison of each indicator (paired comparison). Second, scoring the work (event scoring). Third, calculating the indicator score. Fourth, calculating the WWL (weighted workload), and fifth, calculating the average WWL. Fig. 2 shows the conceptual framework of mental workload and work environment variables. Hypothesis 2 and 3 are shown by the line between mental workload, environment, and performance (H2 and H1). Hypothesis 1 shows the line between the mental workload and the environment. Table 2 shows the explanation of the conceptual notation

The Physical environment of work was measured in ergonomics, which directly measured noise, lighting, humidity, and room temperature factors using sound mater, light mater, hygrometer and room temperature measurement tool in the ATC office space.

3. RESULTS AND DISCUSSION

The results of the ATC operator questionnaire then it is recapitulated and weighted according to the indicators in the NASA-TLX method. Table 3 shows the weighting values for each indicator according to the NASA-TLX questionnaire. It was previously distributed to Respondents. There are two indicators comparisons in the questionnaire, and the Respondent must choose one. The results of the selected indicator will be calculated and weighted according to the indicators in the NASA-TLX method. Event scoring is done after the weighting is done. At this stage, the mental workload indicator rating of the ATC operator will be recapitulated.

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Table 3. NASA TLX indicator comparison results

No	Respondent	Indicator Comparison						
		MD	PD	TD	P	EF	FR	Total
1	Respondent 1 (Asst. Controller)	5	3	2	2	1	2	15
2	Respondent 2 (Ground Controller)	1	1	4	5	3	1	15
3	Respondent 3 (Tower Controller)	4	3	3	2	2	1	15
4	Respondent 4 (Tower Controller)	3	0	1	4	2	5	15
5	Respondent 5 (Asst. Controller)	5	1	2	3	2	2	15
6	Respondent 6 (Tower Controller)	3	2	1	4	5	0	15
7	Respondent 7 (Ground Controller)	3	0	2	4	3	3	15
8	Respondent 8 (Clearance Delivery)	4	1	5	3	2	0	15
9	Respondent 9 (Asst. Controller)	2	1	3	4	5	0	15

Table 4. ATC operator rating data

No	Respondent	Rating Data					
		MD	PD	TD	P	EF	FR
1	Respondent 1 (Asst. Controller)	90	60	80	80	90	50
2	Respondent 2 (Ground Controller)	90	80	90	90	100	50
3	Respondent 3 (Tower Controller)	80	90	100	90	90	90
4	Respondent 4 (Tower Controller)	90	60	80	80	80	80
5	Respondent 5 (Asst. Controller)	90	90	90	90	90	90
6	Respondent 6 (Tower Controller)	80	60	70	80	90	60
7	Respondent 7 (Ground Controller)	90	90	90	90	90	90
8	Respondent 8 (Clearance Delivery)	80	80	80	80	90	30
9	Respondent 9 (Asst. Controller)	85	75	85	95	95	75

Table 5. Average weighted workload of ATC operators

No	Respondent	Indicator							
		MD	PD	TD	P	EF	FR	WWL	Average
1	Respondent 1 (Asst. Controller)	450	180	160	160	90	100	1140	76
2	Respondent 2 (Ground Controller)	90	80	360	450	300	50	1330	89
3	Respondent 3 (Tower Controller)	320	270	300	180	180	90	1340	89
4	Respondent 4 (Tower Controller)	270	0	80	320	160	400	1230	82
5	Respondent 5 (Asst. Controller)	450	90	180	270	180	180	1350	90
6	Respondent 6 (Tower Controller)	240	120	70	320	450	0	1200	80
7	Respondent 7 (Ground Controller)	270	0	180	360	270	270	1350	90
8	Respondent 8 (Clearance Delivery)	320	80	400	240	180	0	1220	81
9	Respondent 9 (Asst. Controller)	170	75	255	380	475	0	1355	90

From Table 4, it is known that the results of giving values to each indicator given by the Respondents. The value given is adjusted to the workload felt by the ATC operator while working. The rating range is between 0 – 100, which shows the workload from the lowest to the highest. Calculating each indicator's value is done by multiplying the weight by the rating. The calculation of WWL is obtained by adding up the six indicator values. The average WWL calculation is obtained by dividing the WWL by the total weight, which is 15. The results of the calculation data of the Average Weighted Workload of ATC Operators can be seen in Table 5.

After classifying the mental workload, the next stage was calculating the comparison of the NASA-TLX score elements to find out the most dominant aspects, as shown in Table 6.

Table 6. NASA-TLX score element comparison

Factors	Percentage (%)
MD	22.41
PD	7.77
TD	17.24
P	23.27
EF	19.84
FR	9.47

From the NASA-TLX score elements comparison results, it was found that the most influencing aspect of mental workload in ATC operators was the performance at 23.27%, followed by mental demand and effort aspects at 22.41% and 19.84%, respectively. Then, temporal demand, frustration, and physical demand were 17.24%, 9.47%, and 7.77%, respectively.

In addition to measuring mental workload, the physical workplace environment was also measured. The results of workplace physical environment measurement on the ATC tower are shown in Table 7.

Table 7. Measurement results of physical environment condition in the ATC tower

No	Physical Environment Factor	Measurement Result	Standard of Minister No. 48 of 2016
1	Lighting	200 Lux	300 Lux
2	Noise	83 dB	74 dB
3	Room Temperature	30℃	18℃
4	Humidity	58% Rh	40 - 60% Rh

The measurement results of the physical workplace environment found that the lighting and sound levels in the ATC work environment did not meet the standards set by the Ministry of Health. The substandard workplace physical environment conditions increase fatigue risk, reducing the operator's performance.

Furthermore, each variable was analyzed to test the predictive effect between variables and assess whether there was a strong relationship or influence between the independent variables (X) on the dependent variables. The independent variable in this research was mental workload (X1). Meanwhile, the dependent variables were work environment (Y1) and performance (Y2). At this stage, the PLS (Partial Least Square) method was used with the SmartPLS software. Fig. 3 shows the conceptual framework of mental workload and work environment attribute from PLS.

The image of the variable conceptual framework on operator performance describes the relationship between mental workload variable and work environment on operator performance. The aim was to find out whether there was a strong relationship or influence between independent variable (X) on dependent variable (Y). The data processing using SmartPLS software was resulting in a conceptual framework design with the PLS (Partial Least Square) method.

This study model consisted of three latent variables which include mental workload, work environment, and performance. Measurement model evaluation was a stage to test the validity and reliability of a latent variable. Furthermore, a questionnaire test was given to the operator.

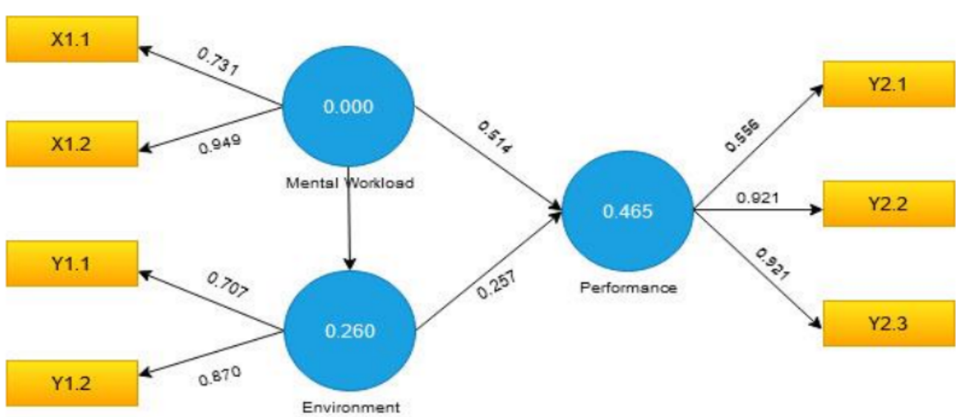

Fig.3. Result of SmartPLS

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The validity test was conducted by calculating convergent validity and discriminant validity. Convergent validity was used to determine whether or not the indicator was valid in measuring variables and was shown through the loading factor. An instrument is said to meet the concurrent validity test if it exceeds the 0.6 loading factor. The results of the concurrent validity test are presented in Table 8, and validity using cross-loading is presented in Table 9 which all variables and indicators are valid.

Table 8. Validity recapitulation using Loading factor

Variable	Indicator	Loading Factor	Note
Mental	X1	0.731	Valid
Workload	X2	0.949	Valid
Work	Y1.1	0.707	Valid
environment	Y1.2	0.870	Valid
	Y2.1	0.556	Valid
Performance	Y2.2	0.921	Valid
	Y2.3	0.921	Valid

Table 9. Validity recapitulation using cross loading

Indicator	Mental Workload	Work environ ment	Perfor mance	Note
X1	**0.731**	0.173	-0.377	Valid
X2	**0.949**	0.576	-0.655	Valid
Y1.1	0.521	**0.707**	-0.140	Valid
Y1.2	0.331	**0.870**	-0.609	Valid
Y2.1	-0.559	-0.273	**0.556**	Valid
Y2.2	-0.500	-0.485	**0.921**	Valid
Y2.3	-0.500	-0.485	**0.921**	Valid

The calculation that can be used to construct reliability is composite reliability. The test criteria stated that the structure was reliable if the composite reliability value was more significant than 0.7. Table 10 shows the results of composite reliability.

Next was assessing the Goodness of fit Model. It is used to determine the ability of exogenous variables to explain the diversity of endogenous variables or to determine the contribution of exogenous variables to endogenous variables. The goodness of fit model in the PLS analysis is carried out by using coefficient determination (R-Square) and using Q-Square predictive relevance (Q2) for the structural model and measuring how well the model generates the observed values. The Goodness of fit Model results is summarized in Table 11.

Table 10. Reliability recapitulation

Latent Variable	Composite Reliability	Note
Mental Workload	0.833	Reliable
Work environment	0.769	Reliable
Performance	0.853	Reliable

Table 11. Results of goodness of fit model

Endogenous	R-squared
Work environment	0.260
Performance	0.465
$Q^2 = 1 - (1 - R_1^2)(1 - R_2^2) \rightarrow$	
$Q^2 = 1 - (1 - 0.260)(1 - 0.465) = 0.604$	

The Q-Square predictive relevance (Q^2)was 0.604 or 60.4%. It shows that the contribution of mental workload and work environment variable to the performance variable is 60.4%. In comparison, the remaining 39.6% is the contribution of other variables not discussed in this study.

Then, direct hypothesis testing was carried out to test whether exogenous variables had a direct effect on endogenous variables. The test criteria stated that T statistics > T table (1.96) means that there is a significant effect of exogenous variables on endogenous variables. The results of the hypothesis testing are shown in Table 12.

Next was the hypothesis testing of the indirect effect, which was carried out to test whether or not there was an indirect effect of exogenous variables on endogenous variables through intervening variables. The test criteria stated that t statistics> T table (1.96) means that exogenous variables had a significant effect on endogenous variables through intervening variables. The results of the hypothesis testing of the indirect effect are shown in Table 13.

The last one was the dominant influence test which was used to determine which exogenous variables have the most dominant effect on endogenous variables. Exogenous variables that have a dominant influence on endogenous variables can be identified through the largest total effect regardless of the positive or negative coefficient signs, as shown in Table 14.

Table 12. Results of hypothesis testing of direct effect

Exogenous	Endogenous	Path Coefficients	SE	T Statistics	Note
Mental Workload	Work environment	-0.514	0.077	6.640	H1 accepted
Mental Workload	Performance	0.509	0.084	6.107	H1 accepted
Work environment	Performance	-0.257	0.115	2.245	H1 accepted

Table 13. Results of hypothesis testing of indirect effect

Exogenous	Intervening	Endogenous	Indirect Coefficient	Standard Error	T Statistics
Mental Workload	Work environment	Performance	-0.131	0.063	2.127

Table 14. Dominant effect hypothesis testing results

Exogenous	Endogenous	Total coefficients
Mental Workload	Work environment	-0.509
Mental Workload	Performance	-0.514
Work environment	Performance	0.257

Based on Table 14, it was found that the mental workload variable was the most dominant influence on performance. Total coefficients of (+) mean increasing, while total coefficients of (-) mean decreasing operator performance. It can be informed that the direct effect coefficient of mental workload on the work environment is -0.509*, which states that mental workload has a negative and significant effect on the work environment. This means that the higher the mental workload, the less conducive the work environment. The study results supported other studies that mental workload adversely affected the work environment. If the worker works in a comfortable environment, has a good work-space and equipment, and has good relations with other employees and superiors [72].

The direct effect coefficient of mental workload on performance is -0.514*, stating that mental workload has a negative and significant effect on performance. This means that the higher the mental workload, the lower the performance. In other words, a high mental workload is accompanied by reduced work ability and performance (26). Some studies suggested that too high or low mental workload will result in the decline of employees' work ability [73], [74].

The direct effect coefficient of the work environment on performance is 0.257*, stating that the work environment has a positive and significant effect on performance. This means that the more conducive the work environment, the higher the performance. The coefficient of the indirect effect of mental workload on performance through the work environment is -0.131*, stating that mental workload has a negative and significant effect on performance through the work environment. This means that the lower the mental workload causes, the more conducive the work environment and the higher the performance. The increase in workload could decrease operator performance. Excessive workload could degrade performance to a suboptimal level. Psychological anxiety, mental distraction, and fatigue may suffer as the consequences of a high workload, which can force performance to decline [75].

Dominant influence is used to determine which exogenous variables have the most dominant influence on endogenous variables. Exogenous variables that have a dominant influence on endogenous variables can be known through the largest total effect without paying attention to the positive or negative coefficient sign. Table 14 shows that the analysis results of variables with the largest total effect on performance are mental workload with a total effect of -0.514. Thus, the mental workload is a variable that has the most dominant influence on performance.

The next step was the work system design. The work system design was carried out with an ergonomic approach to obtain an ergonomic work system design [76]. This work system design focused on work layout to analyze several aspects, such as the workstation layout, which was designed by considering the relationship between

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the operator and the work process, delivering equal distribution of workloads, creating a safe and comfortable working environment and improving operator performance. The work system design was carried out at workstations and work environments because ATC operators' performance depends on the specifications of the workspace design, equipment, and facilities and whether the air traffic needs were matched with the work performed by ATC operators [53]. The following is the Work System Evaluation in the ATC Tower.

The Fig. 4 above shows that the work facilities layout was not well organized and had not considered the relationship between the work process and the job desk of each operator. The monitoring tool used was radio frequency; therefore, the operator did not know the aircraft's exact position. The air conditioner in the workspace often breakdown and did not have a silencer to dampen the sound from the aircraft engine. Rest facilities for operators were long chairs and did not have emergency stairs, and there was only one ladder to go up. There was no storage rack for documents.

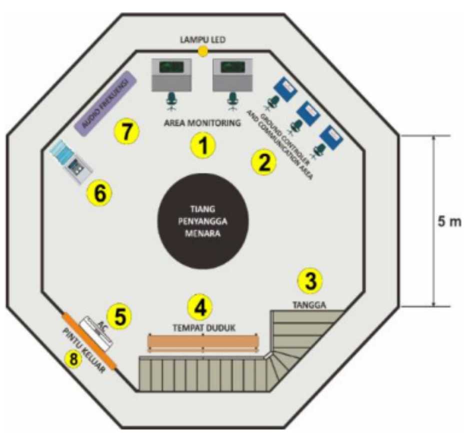

Fig. 4. The layout before updated

The proposed layout was made by considering the relationship between work processes and the job desk of each operator (Fig. 5). Installation of additional air conditioning was proposed to lower the room temperature of the workspace to a more comfortable temperature. It was also proposed to install sound absorbers to reduce the sound level of aircraft engines and update the monitoring tools with radar; therefore, ATC operators can know the aircraft's exact position. It was also necessary to establish rest facilities for operators who have finished monitoring smoking areas for operators. Document storage rack facilities were also needed to make the workspace neat and well-organized with the 5S concept. The tower walls should be painted white to make it look spacious, then add an elevator and emergency stairs facilities. It was proposed to add the number of lamps for night lighting and the number of operators to reduce mental workload [77]. It was reorganizing working hours and dividing job desks, making them clearer so that operators could focus on their work

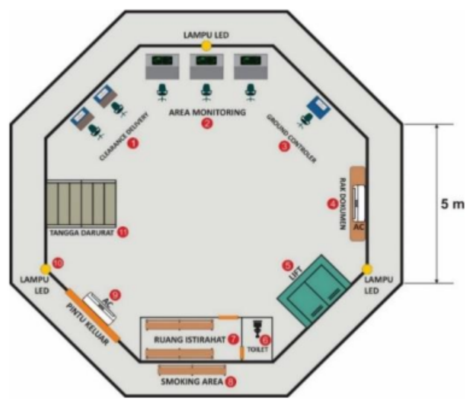

Fig. 5. The layout before updated

The limitation of this research, the questionnaire is may not enough to conclude significant research. For further research, some planned experiments, advanced apparatus, and validation of this research could be done.

4. CONCLUSION

The measurement and analysis of the mental workload of ATC operators based on NASA-TLX showed that the average operator has a very high workload. Out of 9 operators, seven have the highest average WWL (weighted workload) value; namely, 80 to 90 and performance and mental demand were two factors that affected the mental workload the most. Meanwhile, workplace physical environment measurements on ATC towers showed a result that did not meet the Ministry of Health standards. The measurement results found that the noise factor and room temperature were 83 dB and 30°C. Based on the results of structural modelling with the PLS method, there was a significant influence between mental workload on the work environment, the mental workload on performance and the work environment on operator performance. This means that the more conducive the work environment is and the lower the mental workload on the operator, the better the operator's performance.

The proposed work system design uses an ergonomic approach, safety and regulation of Ministry of Health Number 1405/MENKES/SK/XI/2002 and number 48 of 2016 to get an ergonomic work system and regulate the equal distribution of workloads and create a safe and comfortable working environment as well as improve operator performance. The design focused on the ATC tower's workstations and work environments. The supervisor has accepted the design. For further research, the ATC being researched should be an ATC with a larger number of employees and on a large scale (e.g. Juanda Airport ATC or Soekarno Hatta Airport ATC); the variables studied can be added to the physical workload.

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Air Traffic Control Work System Design to Improve Operator Performance with Workload Approach and Safety Concept

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