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Ergonomic Working Design Model in Reducing Fatigue due to Air Traffic Control (ATC) at Kuala Namu Airport, Indonesia

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ABSTRACT

Generally, humans can work properly and achieve optimal results when supported by good environmental conditions. The effect associated with the inconvenience of the working environment can be experienced over a prolonged period. Therefore, this study aims to determine the ergonomic working design model in reducing fatigue due to Air Traffic Control (ATC) at Kuala Namu Airport, Deli Serdang – Medan, Indonesia. This is because it is necessary to consider the physical condition or health conditions of controllers to enable the company to extend its services' life and profitability. Rapid Upper Limb Assessment (RULA) is the research method used to investigate upper limb disorders. RULA was developed as a method to detect posture, which is a risk factor. This method is designed to assess workers and determine the musculoskeletal loads likely to disrupt upper limbs. Under such conditions, the management is advised to develop 'open management' based on political will, which involves operators in every step of the improvement, because they have adequate ideas of the problems at hand. Participation in ergonomics enables employees with their supervisors and managers to apply adequate knowledge in their workplace to enhance working environment conditions.

1. INTRODUCTION

The design of the systems involving humans and machines traditionally focuses on the hardware or machines only, without considering the human element as an active party. However, in designing machines, it is essential to study human beings as an essential component to determine their limitations. Satisfaction is a person's attitude that can adapt well to work and social relations with workers and others [1].

There are two important interfaces in the human-machine system in which ergonomics plays an important role [2]. The first is a display capable of connecting the engine conditions to humans, while the second interface is a control that tends to adjust to the response obtained from the information displayed earlier. Therefore, between the display and the controls, there need to be interactions.

This research was carried out using the Rapid Upper Limb Assessment (RULA), which is a research method that does not require special equipment in determining the posture of the neck, back, and upper arms. Each movement is given a predefined score [3]. RULA was developed by Mc Atamney and Corlett (1993) as a method used to detect the posture of a risk factor [4]. This method is designed to assess workers and to determine the musculoskeletal burden that is likely to disrupt upper limbs [4].

Work posture analysis of the ATC controller needs to be appropriately carried out to determine the incompatibility between man and machine and the complexity of the work system that continues to provide additional burden.

Several studies have shown that the ATC controller's incorrect work posture causes work-related fatigue, which decreases the productivity of the controller. Therefore, it is necessary to determine a good work posture to minimize the onset of fatigue. This study aims to determine the work postures that lead to the emergence of fatigue, errors, and complaints arising from workers (employees), which causes work-related fatigue. The study also aims to design a strategy capable of minimizing fatigue due to work to create a suitable and comfortable working environment [5] capable of supporting the productivity of workers.

2. LITERATURE REVIEW

Ergonomics is associated with the meeting of various fields of science, such as anthropology, biometrics, work phenomena, occupational safety and health, planning, research, and cybernetics. However, its main specificity is associated with the process of planning for a better way of workings and equipment. In this case, there is a need for cooperation between authors, technicians, and experts on the use of measuring, recording, and testing tools. Furthermore, improved poor and unplanned working conditions are usually costly. Therefore, an ergonomics team needs to carry out efforts that allow the eligible production of machines. Ergonomics can be applied from local to national levels. At the local level, it starts with the initiative of a corporate physician, head of personnel, employers, external supervisors, etc. Furthermore, at this level, services are provided by special institutions or universities. The government can foster ergonomics through regulations, official standards, and specifications.

One of the increasingly important parts of many jobs is the perception and interpretation of the signs that need decision-making processes for the reaction to take place. Ergonomics enables the speed of perception and makes it easier for mental stress, fatigue, vigilance, and physiological disorders and faults to be prevented, thereby enabling the maintenance of productivity. Important factors in the establishment are associated with the threshold of feeling, alertness, differentiation, and interpretation. This tends to work properly when the signs are set to meet certain conditions. Firstly, it is conducted by learning the shape and placement of the signs, the presentation of the quality (scale), and the properties of the mark (optical, acoustic, or tactile). Secondly, it is related to the quality and quantity learning of the signs relating to labor's ability to interpret and remember the sign.

Several factors affect the work environment and cause disruption, such as physical, chemical, biological, and psychological factors [6, 7]. According to Al-Omari and Okasheh in 2017, workers need a comfortable working environment for optimal functionality and productivity [8]. Therefore, the working environment needs to be handled or designed in such a way that the working position becomes conducive for the workers to perform their activities safely.

The muscle mass of the human body is designed to perform daily work activities. On the one hand, work tends to improve achievement significantly, thereby increasing the possibility of achieving a productive life. On the other hand, working means the body receives a burden for its owner.

Fatigue is a body mechanism that protects it from further damages due to lack of energy or adequate rest, thereby leading to the need for recovery through rest. The brain centrally regulates fatigue, and the term is usually associated with each individual's different conditions. It also leads to a loss of efficiency, as well as a decrease in work capacity and endurance. Fatigue is classified into muscle and general fatigue.

Several studies have shown that the fatigue caused by static work differs from those due to dynamic jobs. In static, the muscle exertion is 50% with a timeframe of 1 minute, while those less than 20% physical labor exertion tend to last long enough. However, in dynamic, the muscle exertion is 15-20%, causing fatigue and pain when loading takes place throughout the day. The muscle's duration depends on the amount of energy developed and the maximum percentage of energy attained by muscles.

Nordic Body Map (NBM) is used to determine the parts of muscles with the greatest level of complaints ranging from discomfort (pain) to very sick. By analyzing the body maps, workers' type and skeletal muscle complaints can be estimated. This method is very simple and less thorough because it contains high subjectivity. Therefore, to suppress the possible bias, the measurement needs to be carried out before and after the work activities (pre and post-test).

In general, the human-machine system can be defined as a "set of objects comprising the relationship between the objects and their attributes." A system tends to occur within a given environment, and changes in this environment affect the system and its elements. A system can be divided into sub-systems, while in humans, it is divided into job operations (sub-system), position (job sub-system), duties (components), tasks (units), sub-task, and task elements (behavioral elements). The human-machine system is a combination of humans and machines that interact with each other to produce outputs based on the inputs obtained. The machine has a broad meaning, including all physical objects such as equipment and facilities that produce work. There are three kinds of relationships in the human-machine system, namely manual man-machine, semi-automatic, and automatic man-machine.

RULA is a research method used to investigate disturbances in the top chart members. This method does not need special equipment in assessing the posture of the neck, back, and upper arms because each movement is associated with a predefined score. RULA was developed to detect posture, which is a risk factor. In facilitating the assessment, the body is divided into 2 group segments. Group A consists of the upper arm (upper arm), lower arm (lower arm), and wrist (wrist), while group B consists of the neck (neck), back (trunk), and legs (legs).

3. ANALYSIS AND DISCUSSION

3.1 Work posture assessment from the NBP and RULA questionnaire

Observations on work postures, methods, and interviews were carried out directly with ATC controllers to facilitate the analysis performed when interacting with the work equipment used, as shown in Figure 1.

Data obtained from NBP questionnaires' recapitulation are grouped into several categories of complaints, namely not sore, rather sore, and sore as shown in Table 1 to Table 3. Strata carry out this assessment against each complaint, which is presented by a histogram.

The filling questionnaire results on the NBP indicate that some controllers have disrupted muscle tension. The dominant symptom of skeletal muscle is in the buttocks (67%), waist, upper and lower neck (60%), back (57%), right shoulder (50%), and other limbs (less than 50%).

Figure 1. Controller interaction with tools

Table 1. Unresolved complaints recapitulation from NBP questionnaire on ATC controller

No	Types of Sore	Not Sore (People)	(%)
1.	Sore on the upper neck	4	14
2.	Sore on lower neck	5	17
3.	Sore on the left shoulder	16	54
4.	Sore on the right shoulder	8	27
5.	Sore on the left upper arm	22	74
6.	Sore on the right upper arm	16	54
7.	Sore on back	7	24
8.	Sore on waist	6	20
9.	Sore on posterior	5	17
10.	Sore on buttocks	7	24
11.	Sore on left elbow	22	74
12.	Sore on right elbow	20	67
13	Sore on left wrist	22	74
14	Sore on right wrist	17	57
15	Sore on right hand	18	60
16	Sore on left hand	20	67
17	Sore on left thigh	22	74
18	Sore on right thigh	20	67
19	Sore on left knee	23	77
20	Sore on right knee	21	70
21	Sore on left calf	24	80
22	Sore on right calf	21	70
23	Sore on left ankle	23	77
24	Sore on right ankle	23	77
25	Sore on left leg	23	77
26	Sore on right leg	17	57

Table 2. Unresolved score from NBP questionnaire on ATC controller

No	Type	Movement	Score	Change Score
1	Top arm score RULA	20 forward or backward	1	+ 1 if shoulders rise
		> 20 (to the back) or 20-45	2	+1 if arm rotates/bent
		45 – 90	3	
		> 90	4	
2	Lower arm score RULA	60 – 100	1	+1 If the forearm works through/outside of the body
		< 60 or > 100	2	
3	RULA wrist score	Neutral position	1	+1 if the wrist away from the middle side
		0-15	2	
		>15	3	
4	RULA neck score	0-10	1	+1 if the neck is spinning/bent
		10-20	2	
		> 20	3	
		extension	4	
5	RULA back score	Normal position	1	+1 if the neck is spinning/bent +1 if the body is bent
		0-20	2	
		20-60	3	
		> 60	4	
6	RULA foot score	Normal/balanced position	1	
		Not balanced	2	

Table 3. Category of action of RULA

Action Category	Level	Action
1-2	Minimum	Secure
3-4	Small	It takes some time to come.
5-6	Medium	Action in the near future
7	High	Action right now

3.2 Working posture resulting in fatigue from work

Various internal and external complex factors influence the relationship between work posture and capacity. For external factors: (i) tasks performed, both physically and mentally, (ii) organizational works, such as rotational jobs, length of working time, rest time, reward and punishment, etc., also (iii) work environment, such as physical, chemical, biological, physiological, and psychological work environment. For internal factors: (i) somatic factors, such as sex, age, body size, health condition, and nutritional status [9], and (ii) psychic factors, such as motivation, perception, trust, etc.

Work postures capable of leading to fatigue are associated with the working controller frequency, which is static and dynamic. A controller working in a static sitting position for a long time finds the job boring and tiring. Faulty seating due to inconsistency with the wearer's anthropometry also adds to the stresses and tends to be the main cause of back problems. Inconsistencies that need attention include the height of the headrests, backrest, seat, and the turning angle of the chair. The mismatch between head and back height with sitting and shoulder height causes skeletal muscle disorders on the neck and shoulders. This pain eventually spreads to the back and waist. Popliteal heights lower than the chair make the foot in a hanging position and causes skeletal muscle disorders in the calf.

Working dynamic muscles occur in the upper and lower parts of the neck. This is worker needs to be upright when reading with the forearm used in typing and holding the mouse. Working dynamic muscles does not negatively affect the controller because the muscles dynamically act as a pump for blood circulation.

3.3 Workplace determination which can cause work post error

In the human-machine system, there are basic elements that interact with each other. These elements include human operators, hardware, software, firmware, and the environment [10]. The elements, such as tools, working strategies, and environment are influential on job performance. Therefore, to achieve high performance, these elements need to be fully harmonized with the abilities, permissibility, and limitations of workers [11]. In this case, the human-machine system in the ATC room, particularly the ACC section, comprises high-tech and complex techniques. Each controller needs to interact with multiple hardware, such as a monitor, display, controller, communication tool, etc. This tends to provide an additional burden both physically and mentally. Figure 2 and Figure 3 displays and controls used by the current ATC controller.

Displays or props are needed to convey information to workers in various ways and to make the tasks smooth. Therefore, it is defined as a communication system that connects work facilities and machines with humans as the engine controller. Visual displays generally assist the information received by workers. In certain situations, it can be assisted with display-related hearing. This means that a good display design needs to prioritize functional factors capable of conveying human information in carrying out their job properly without errors. Factors that can lead to work accidents due to poor design of props are read errors, slowness in interpreting data or information, etc.

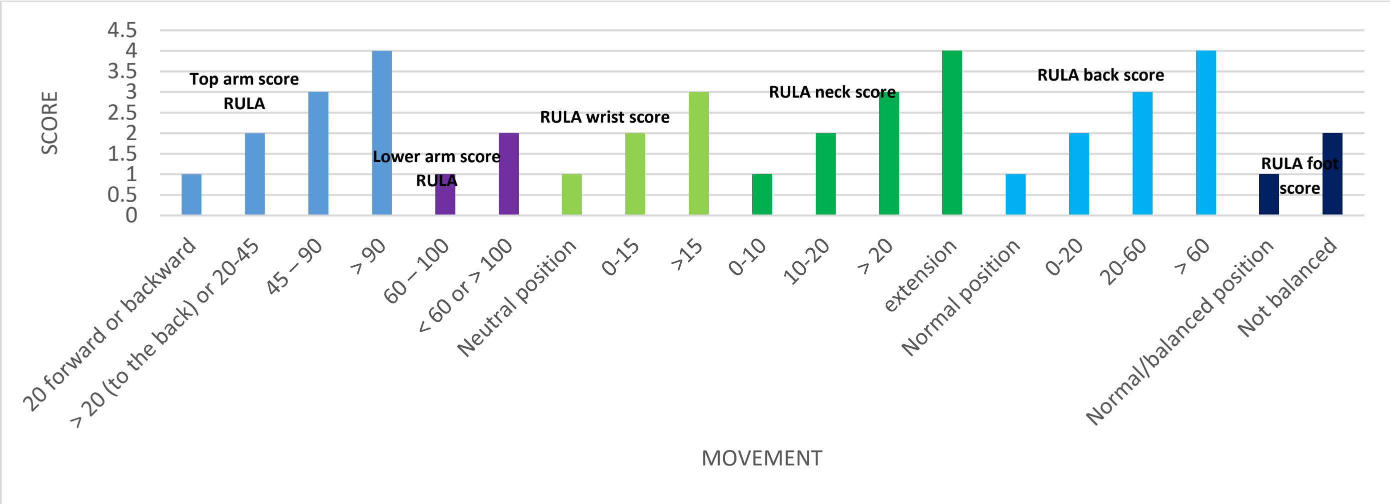

Figure 2. Histogram unresolved score from NBP questionnaire on ATC controller

Figure 3. Controller interaction with tools

Figure 4. Layout supporting facilities that are unsafe condition and can inhibit movement

Figure 5. Back (Spine) does not reach the backrest

The color display in ATC Kuala Namu Deli Serdang – Medan Field is monochrome with a black background, red symbol, and white space, which can be changed according to the controller. According to Gavriel Salvendy, hundreds of colors are used more effectively for drawing and solid modeling in computer-aided design. However, for simple code and information, more than 10 colors cause problems. Therefore, the letters' size needs to be adjusted to the distance of view to ensure readings of existing information are more easily and quickly understood. The current font size also does not match the controller's maximum viewing distance, thereby leading to an unnatural (forced) behavior in the reading display. Furthermore, the controller prefers to set the contrast and brightness on the monitor screen to prevent it from glaring.

The observations made by the controller indicate that the ATC needs to accept additional loads due to the complexity of the interaction of the work system, such as incremental loads of hardware incompatibility and unsafe conditions due to the unmanageable wiring arrangements that disturb the clearance legs. In addition, the groundwork used for the placement of control devices, telephones, etc. is too narrow, thereby stacking up some communication devices. In addition, all seats used by the controller have a high armrest that ranges from 66-69 cm from the floor.

The chairs used by the workers seen in Figure 4 and Figure 5, have inadequate backrest height, because when workers want to put their heads to rest in uncomfortable conditions. So that all chairs used by the controller have high armrests ranging from 66-69 cm from the floor, which is declared uncomfortable.

3.4 Conceptual design of working posture

The working posture of ATC controllers that do not rest their back on a special seat leads to complaints on the buttocks (67%), waist, upper and lower neck (60%), back (57%), and right shoulder (50%). This data was obtained from the results of the NBP questionnaire. Therefore, the work posture of the ATC controller needs to be in a sitting position.

The conceptual design of the working posture of the ATC controller with a sitting position minimizes and overcomes the following work-related aches and fatigue complaints: (i) The chair's position needs to be arranged to enable adequate space for free movement of the limbs. (ii) Sitting needs to be carried out with the waist straight, shoulders behind, and buttocks touching the chair's back. (iii) The seat height needs to be set with the foot forming an angle of 90° and pressing the pressure at the thighs' bottom evenly. (iv) The forward and backward on the backrest need to be made as comfortable as possible. The back needs to be on an adjustable chair back. (v) Both legs do not need to hang or cross each other. Furthermore, the footrest needs to be as high as 5-10 cm from the floor. (vi) Working attitude needs to be performed by sitting and standing after each other.

3.5 Complaints analysis and work errors of the operator

The highest level of work posture errors occurred in the older controllers with prolonged tenure. A total of 10 controllers from the 30 ATC were observed as shown in RULA data processing compared to the working period and controller's age.

Controller complaints and errors lead to work-related fatigue and stress, thereby decreasing performance and productivity.

The American Optometric Association called Computer Vision Syndrome (CVS) [12] stated that the eye cannot be permanently damaged due to the computer's continuous use. However, temporary damage is reduced when computer usage is stopped. Furthermore, some symptoms arise when using a computer. Some of the CVS symptoms include (i) Myopia: This is the temporary inability to see distant objects for some minutes to several hours after using the computer. (ii) Tired eyes: This tired eye condition is due to the use of small font size when reading a document on a monitor, which leads to an imbalance of contrast between the text and background, thereby leading to a dry eye. (iii) Blurred vision: This is caused by physiological changes (due to aging or disease). Blurred vision is also caused by seeing a continuous object at a distance of 12 inches and reading with less light. (iv) Dry eyes, irritation, and watery eyes. This situation occurs due to a lack of fluid. The moisture is applied to the eye by blinking. The amount of eye blinks varies according to the activity being performed and decreases due to contracts. Eyes become red and watery when using the computer and tend to reduce the number of flickers. (v) Increased sensitivity to light. (vi) Headache, backache, neck pain, and muscle spasms.

The musculoskeletal disorders caused by the use of a computer or controller include muscle weakness and tendon or neck and back pain up to cumulative trauma. This cumulative trauma is associated with a persistent motion called Repetitive Strain Injury (RSI). The ATC controller's causes of musculoskeletal disorders include unsuitable postures that occur continuously when using the computer, inappropriate back support, sitting in the same position for prolonged periods, and poor ergonomic design.

3.6 Posture analysis of ATC

The most of the time, air traffic controllers work in a seated position. The wrong work posture analysis on the ATC controller is caused by machine, human, method, environment, and equipment factors. (i) Machine: This factor is less ergonomic because the machine or monitor is too close to the controller, thereby making the equipment layout narrow and less good for the eyes. (ii) Man: The controller's difficulty to work due to the narrow working platform creates an additional load for the controller, thereby decreasing its productivity. Complaints due to wrong sitting position, prolonged working hours with the same position (fixed), and static muscles in certain parts of the spine and upper arms cause discomfort to the musculoskeletal system. (iii) Method: PT. Angkasa Pura II has a proper Standard Operation Procedure (SOP). However, the controller is not concerned about the SOP that has been determined, therefore, it is not properly realized. (iv) Environment: Noisy environments arise from existing speaker sounds, conversations between controllers, and talks between aircraft pilots and controllers on the ATC [13]. This noise tends to complicate the reception of the controller-provided information to the pilot or vice versa. This leads to the occurrence of something that is not desirable because an error in the receipt of information tends to cause an accident.

There are several things to note in addition to environmental noise factors, there are also the lack of fresh air, such as smoking in an air-conditioned room, also leads to illness. This results in non-smoking controllers becoming passive cigarette smokers because, in most cases, the room is not properly facilitated with an adequate exhaust fan to filter the cigarette smoke. A monotonous and unattractive room also makes the controller cramped while inside. In addition, poorly maintained cleanliness causes equipment to become dusty. This affects the state of the machine, such as its age. (v) Equipment: The existing seats are adjustable, therefore, the problems that arise come from people that lack discipline, thereby leading to a wrong work posture.

3.7 Workplace analysis in ATC section

Another factor to consider when choosing an optimum workplace is the environment. In the human-machine system in the ATC room, work involves high and complex technology. Each operator needs to interact with multiple hardware, such as a monitor, display, controller, communication tool, etc. Observation showed that the controller needs to get a load of hardware incompatibility.

The interviews conducted with ATC controllers showed that the current disadvantages of displays and controls are found from the incompatibility between the controller and the engine as: (i) the controllers find it difficult to receive voice information from aircraft pilots due to spelling errors. The controller's noise conditions cause this because the ATC's work environment includes control centered area (ACC), and provision of approach control (APP) in one room, thereby adding additional load to the controller. (ii) The cold air temperature makes the controller feel cold and stiff, especially at night, because they need to adjust the machine's condition, and (iii) the controllers are often disturbed by ATC machines, which makes them panic while on duty, especially when the traffic is solid.

The weakness of the controller's work other than those due to hardware incompatibility, microclimate factors, such as air temperature, humidity, velocity, and intensity of lighting, also need to be within comfortable limits. This is to ensure the microclimate condition does not provide an additional burden to the controller.

3.8 Proposed (model) conceptual design posture in ATC section

Currently, the ATC controller's work posture with a sitting position is still not good because they sit with the position of the spine, which is not on the back of the chair, especially at the waist. Therefore, the design on work posture ATC controller with a sitting position is conducted to overcome this error and minimize work-related aches and fatigues are as (i) the chair's position needs to be arranged to ensure there is adequate space to move the limbs freely. The controller can lie down when the traffic is not crowded, using a chair equipped with headrests. (ii) The controllers need to sit with the waist straight, shoulders behind the buttocks, and touch the chair's back. This is carried out to ensure the controllers avoid sitting in a wrong posture to avoid pain in the lower back. (iii) The seat height needs to be set to ensure that the foot forms an angle of 90º and the pressure at the bottom of the thigh is evenly distributed. This is carried out to ensure the fatigue on the thigh has a sitting position that can be spared, to ensure the controller works comfortably and safely. The uneven pressure on the thighs causes pain and numbness in the controller's foot due to improper blood circulation. (iv) Allows for comfortable forward and backward movement. The back needs to be on an adjustable chair. Working posture with the best attitude is obtained by adjusting forward and backward on the seat for the controller to ensure the muscles feel good. (v) Both legs do not need to hang or cross each other. Therefore, the controllers need a footrest as high as 5-10 cm from the floor. This is carried out to prevent sores' occurrence in the legs because the work posture in the right sitting position does not lead to the emergence of fatigue. Furthermore, the legs do not hang due to the incorporation of a fixed Table 4. (vi) Perform working attitude by sitting and standing after each other. Work posture with a prolonged sitting position causes sore in the waist, back, buttocks, upper neck, and arms. This situation is overcome with a working attitude and the possibility of sitting, interspersed with standing, thereby ensuring that the muscles that contract continuously can relax, leading to a decrease in fatigue and work-related stiff complaints.

Table 4. Recommended of proper sitting posture

Proper sitting posture	Size
Seat Height Range	40.25 cm to 45.60 cm
Sitting Elbow Height Range	65.20 cm to 68.58 cm
Sitting Eye Height Range	105 cm to 127 cm
Visibility to screen	51 cm to 76 cm
Degree of tilt of the screen	15 cm to 20 cm
Floor distance to headrest position	105 cm to 127 cm

4. CONCLUSIONS

The results of filling the questionnaire using NBP showed that some controllers have musculoskeletal system disorders (muscle tension). There is a less harmonious interaction between the human-machine on the ATC controller, which is evidenced by the persistence of many forced attitudes on work time controllers, such as movement reaching the phone, looking at the monitor with a viewing angle that is too small, and the spine is not leaning well when sitting. From the recapitulation of the score for the assessment of work posture using RULA, it is concluded that of the 30 controllers observed, the grand value of the smallest scores is 3 and 4. The level value for this grand score is 2, which means that the controller's work posture requires a change of posture. Therefore, the work posture on the ATC controller needs to be continuously conducted. The layout of supporting facilities, such as cables and control devices, is less precise, thereby leading to insecurity and discomfort in working. There are no changes in the level of speed, accuracy, and work changes. High-speed rates cause the level of accuracy and work low. Controllers in ATC, including human multitasking, are performed by individuals capable of handling more than one task at a time. Since the 1990s, experimental psychologists have started experimenting on natural boundaries and human multitasking.

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