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The pilot mental workload in flight operation A case study: Indonesian civilian pilot

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Abstract – This type of activity or work with high stress level and requires more concentration and attention, in this case is the aircraft operation. Thereby mental workload is the most dominant than the physical workload. And this is what should have been a concern, because if mental workload endured by pilot is excessive, it will lower down the quality of work and lead to work safety; in this case the aircraft operation. Subjective Workload Assessment Technique (SWAT) method is used to measure mental workload value, this method consists of three dimensions with their levels, there are: time, mental effort, and psychological stress load. The aim of this study was to know the mental workload of the pilot of an aircraft in flight dimensions: phases of time, phase of flight, terrain condition, and weather, and identifies what factors the most dominant for build of mental workload. The results of studies showed that pilot mental workload will increase when a pilot faced with flight conditions do at early morning (00.00-05:59 am), during weekend and enters the peak season period, and the aircraft will be landing procedures, and also in case of change of wind conditions in flight, and will increasingly when pilot exposed to aircraft operating with route condition which has a land surface is mountainious. This study also showed that the time dimension factor (T) significantly affects the mental workload of pilots, indicating that they put more emphasis on this factor when they are considering workloads.

Keyword: Mental Workload, SWAT.

Introduction

Flight operational activities in the operation the aircraft could pose unwanted risks. One risk emerging from flight activities is aircraft accident that may inflict losses to humans and objects, both on land and in the air. An aircraft accident is normally under public scrutinize, despite the probability of accidents which has the odd of one in million flights is extremely small compared to other modes of transportation. In the death per million kilometres, mode of air transport receives an index of (0.05), signifying that in each ten million kilometres travel, there are five people died, in comparison with the index of bus (0.4), train (0, 6), ships (2.6), pedestrians (54.2) and motorbikes (108.9) (Poerwoko, 2011). Aircraft accidents is in fact closely related to aviation safety and security, and does not merely become the responsibility of the pilot alone, but is affected by one or more of a combination of three main factors in aviation, i.e. human, machine and the media. Human factor covers human readiness or the human preparedness, i.e. the readiness of the pilot and other cabin crews. Engine factor refers to the aircraft itself, whilst the media factor includes natural phenomena: weather condition, terrain, altitude and wind.

Human as an operator has limitations in their work. These limitations do not close the possibility of operator error in their job, and so are the pilots. Work error that happens is resulted from workload, either physical workload or mental workload exceeding the ability limits of the operator. This type of activity or work with high stress level and requires more concentration and attention, in this case is the aircraft operation. Thereby mental workload is the most dominant than the physical workload. And this is what

should have been a concern, because if mental workload endured by pilot is excessive, it will lower down the quality of work and lead to work safety; in this case the aircraft operation.

Based on the illustration above, this research was developed with the aim of analyzing which condition puts burden on the pilot if exposed to flight operation condition, consisted of phases of time, phases of flight, terrain condition, weather, and to determine the category of mental workload endured by the pilot through three-dimensional measurement, namely Time, Effort and Stress loads.

Materials and Methods

Materials

The research data were primary data obtained directly from respondents who were civilian aircraft pilots operating scheduled aircraft (Aircraft Operation Certificate (AOC) 121). The research site took place in Jakarta and surrounding areas in the light of many airline operating offices were located in this area. The time duration used in this research was 9 (nine) months for data collection and data processing using SWAT software. Sample selection based on the SWAT method does not specify the number of research respondents, but preferably they have the same profession such as pilots, lecturers, drivers, and captains and the like. Samples taken in this research were 260 pilots. The survey was conducted by distributing SWAT questionnaires to be filled by pilots and it was carried out at the time they were off-duty.

SWAT (*Subjective Workload Assessment Technique*)

Wignjoesebroto and Zaini (2007) define mental workloads as a condition which workers experience in the execution of their duties where there are only limited mental resources. Mental workload measurement needs to be done in order to know the magnitude of the mental workloads whilst on the other hand it can be used as an evaluation tool to prevent work accidents. Such measurement can be done in two ways, namely objective and subjective mental workload measurement. The subjective mental workload measurement is one of the psychological approaches undertaken by developing a psychometric scale to measure mental workloads that can be done either directly (spontaneously) or indirectly (derived from responses in an experiment). Among the methods used in the subjective measurement of mental workloads is the SWAT method. This method was developed by Reid and Nygren and it consists of three dimensions, namely time load, mental effort load, and psychological stress load (Reid, 1989). The SWAT method application procedure consists of two phases, which can be described as follows:

The data processing procedure consists of two stages, namely scale development and event scoring.

1. Scale Development: At this stage the respondents were asked to sort 27 SWAT cards based on the combination of three workload dimensions in order of magnitude (i.e. low, medium, high) where each card had three dimensions. The three dimensions consisted of time, effort, and stress. Each dimension of each SWAT card was given a different scale combination. The scale was based on the lowest to highest levels of mental load and then the scale was presented using statements that can indicate the weight of the mental workload. The lowest scale combination was 1 (time, effort and stress), and the highest scale combination was 3 (time, effort and stress). These SWAT cards were arranged based on the perception of each respondent about their understanding of the workload levels from the lowest to the highest one in performing their work activities. These SWAT cards were arranged in order to realize three objectives, namely prototyping and determination of scales used for each respondent through Kendall's Coefficient of Concordance, the Axiom Test, and Scaling Solution.

2. Event Scoring: At this stage an activity was assessed in order of magnitude (low (1), moderate (2) or high (3)) for each dimension, i.e. time, effort, and stress. The scale value related to the combination (obtained from the scaling stage) was then used as the workload score for the related activity, from this conversion it will be known whether the activities undertaken by the respondents were classified as low, moderate or overload (Wignjoesebroto and Zaini, 2007).

Result & Discussion

The SWAT data collection is conducted through the use of combination cards regarding mental workload, namely a sheet which is specifically made to support the data collection. Afterwards, the respondents are asked to place these cards in order, based on the perception of each of the respondents on the level of the workload from the lowest to the highest. The cards sorted are 27 in total, each of which is a combination of three-dimensional stages of SWAT. The result of SWAT questionnaire

application is used as input for SWAT software for scale development and event scoring which serve as an implementation of steps in SWAT method. At the Scale Development stage, Kendall's Coefficient of Concordance (W) will be obtained for determining the scaling to be conducted. If the value of Kendall coefficient < 0.75 , the data become too heterogeneous and mental workload measurement would be done per respondent, individually, based on Prototyped Scaling Solution (PSS) and Individual Scaling Solution (ISS), where the result cannot be considered represent the value of a pilot mental workload. And if the value of Kendall coefficient produced is ≥ 0.75 , it is carried out by Group Scale Solution (GSS). That is, all respondents in this research have the same characteristics. Results of SWAT software in this research produce Kendall coefficient value (W) on dimensions in aviation, namely phases of time, phases of flight, terrain condition, and weather, i.e. ≥ 0.75 , respectively. Thereby, it can be said that index of agreement in card compilation among the respondents is relatively similar and homogeneous.

The next step is to conduct prototyping. The value of prototype indicates the dominant dimension perceived as mental burden by the respondents. The processing results using SWAT software also generate importance value for each dimension; T (Time), E (Effort), and S (Stress). The data analysis result shows that in all aspects of flight operating condition which comprises of factors of phases of time, phase of flight, terrain condition, and weather, the level of the highest relative importance is dimension of time burden; hence all subjects have an agreement and assume that time load factor is the most crucial factor in determining the level of pilot workload, in which the dimension of time load depends on the availability of time and ability to carry out an activity. It is closely related to whether the subject or the respondent could complete their task in the timeframe given. Once the SWAT scale is formed, every description of respective dimension in flight, namely phases of time, phase of flight, terrain condition, and weather, will be rated by ratings given by each respondent. Ranking given by the respondents will be adjusted to the level at the end of the scale value formed.

Based on the results of converting the SWAT rating to the SWAT scale, the workload of each respondent can be revealed. If the SWAT rating is ≤ 40 , it means that the mental workload of the respondents belongs to the low category. Meanwhile, if it ranges from 41 to 60, it means that the mental workload of the respondents belongs to the moderate category, and if it ranges from 61 to 100, it means that the mental workload of the respondents belongs to the high category (overload). To determine the highest mental workload endured by pilots while conducting flight operation is done by calculating the mean value of pilot mental workload at each level of the existing factors. The condition that has the highest value of mental workload can be seen in Table 1 below:

Table 1. Burdened condition

		Flight Condition	Mean of Mental Workload Value
Phases of Time	of	1. Hour Period	
		- Morning (6:00 am - 11:59 am)	59,7
		- Afternoon (12:00 - 17:59 pm)	47,9
		- Night (18:00 - 23:59 pm)	58,7
		- Early Morning (0:00 – 5:59 am)	66,4 *
		2. Day Period	
		- Weekend (Saturday to Sunday)	59,9 *
		- Weekday (Monday to Friday)	43,1
		3. Periode musim	
		- Peak season (Eid Mubarak and Summer holiday)	66,6 *
		- Non Peak Season	41,1
Phase of flight	of	- Take Off	82,9
		- Climb	46,8
		- Cruise	28,2
		- Descent	41,2
		- Approach	69,6
		- Landing	86,8 *
Terrain Condition		- Plateau	63,3
		- Mountainous	75,7 *

	Flight Condition	Mean of Mental Workload Value
Weather	- Flat	42,4
	- Wind	84,6 *
	- Visibility	79,5
	- Pressure	41,7
	- Cloud	74,3
	- Temperature	41,8
	- Ceiling	50,9

Based on the results of the SWAT analysis (Table 1), figures marked with an asterisk (*) indicate the levels with the greatest workload for each condition. From the table, it can be described that:

Phases of time towards mental workload

In the world of aviation, the dimension of phases of time is more focused on passenger flow cycle and air peak traffic hour or more specifically is the operational time of aircraft in flight. From the calculation result using SWAT analytical method to determine the value of the respondents' mental workload, it is found that the most burdened condition or the highest mental workload for pilots, viewed from hour period is the flight operations in early morning, i.e. from 00:00 am to 05:59 am, with the mean value of mental workload at 66.4 (overload). This is because humans are naturally born to be a day creature not a nocturnal creature, it means that at noon with the presence of the sun causing the environment to be bright, people tend to have an instinct to work and perform activities, and vice versa because of absence of sunlight (dark nights) people tend to have an instinct to rest or sleep at night. This life follows a rhythm of biological life called the circadian rhythm, if this cycle/rhythm is disrupted as a result of changes in work hours where the human body which should be in the phase of resting/relaxing has to perform some work, making it unable to rest. When the cycle/rhythm is disturbed as a result of changes in working hours in which the body is supposed to be in a phase of rest are required to work, causing the loss of sleep time. In the case of human staying awake to perform task or the effect waking suddenly, directly affect to human condition especially human performance and fatigue (Saputra, et.al. 2015c). It is common knowledge that work efficiency during the night is not the same as during the day. Although in modern society artificial lighting makes it possible to have light for the whole 24 hours span, body function (hormonal, metabolic, digestive, cardiovascular, mental etc.) are still influenced mainly by the natural light/dark cycle, showing periodic oscillations that have, in general, peaks (acrophases) during the day time and troughs at night (Costa, 1999). On night flight schedule, in particular, pilot must change their normal sleep or wake pattern and adjust their body functions to inverted rest or activity periods, having to work when they should sleep and sleep when they should stay awake. The results study from Krauchi and Wirz (1994) also shows that operating long haul flights during the night (whether or not they are transmeridional) frequently conflicts with human circadian regulation and severely affects physiologic and psychological functions in-flight performance. Body temperature drops most during the early morning, reaching its minimum at about 05:00 am (Van Dongen, 2006), which suggests that this factor may affect crew member performance, due to the low level of physical and cognitive aspects during this period. Meanwhile, if being viewed from the week period, the highest mental workload value is in the moderate category if the flight is made during a holiday or weekend. As for the season period, the highest load occurs in the peak season with an average value of 66.6 which is included in overload category, this because in the world of aviation, especially in Indonesia, there is a term called the passenger flow cycle, i.e. a season with an abundant number of passenger (*peak season*), which usually occurs during school holidays, year-end holidays, Eid holidays or weekend. Moreover, at his period extra flights are also offered by the flight operator to anticipate the increasing number of passengers. This increasing number of flights is directly proportional to the increase in the air traffic, especially in Indonesia, all of which may affect the performance of pilots in carrying out their task.

From the analysis above, it is known that the most burdensome condition perceived by the pilot is when they face flight operational condition. Viewed from the dimension of phases of time, the flight made early morning (00:00 - 05:59 am), during weekend and peak season is known to create overly high mental workload which will lead to boredom and burnout dubbed psychological fatigue (boredom), a complex condition, characterized by decreasing nerve centers activation, accompanied by the emergence of exhaustion, fatigue, lethargy and reduced level of vigilance. The ability of a pilot in making judgments and

taking decisions (pilot judgment) is highly important in the safety of flight operations. Pilot judgment is one significant and centermost link in flight, particularly in the face of emergency situation or dangerous situation. In a state of fatigue, a pilot tends to be rigid in making a decision and action, and non-flexible in observing a variety of the safest alternative actions to do (Mustopo, 2012). Such condition may give rise to the opposite effect of what was expected, and certainly would be fatal to the safety of flight operations.

Phase of flight towards mental workload

Phase of flight is the phase of flight of an aircraft, from taking off until the next landing, but not included technical landing. Phases of flight are the taxi, take-off, climb, cruise, descent, approach and landing (ICAO, 2006). Based on the computation result using the SWAT analytical method, it is known that the mental workload of all pilots is classified in the category of high workload (overload). That is, if being interpreted, the mental workload of pilot will increase (the highest level) when the aircraft is about to do the landing procedure. The landing phase has the highest value of mental workload due to the fact that the landing phase is the one taking place nearby the ground, resulting in a greater risk in terms of safety in flight operation. The aircraft landing process is a transfer process, from one area or dimension to another. In this case is the transfer of aircraft from area or dimension of space which is not confined to an area or much more limited dimension, on land. In addition to the landing phase, pilot must also perform numerous aircraft configuration procedures for aircraft operation, including: lowering down the landing gear, setting up the flap position, lowering down the aircraft speed, braking and many others. The level of complexity of the various systems that must be operated by pilots in this phase will also affect the mental workload; hence the possibility of errors made by the pilot may occur and intensified (Saputra, et al, 2015d).

Another observable thing and may occur at landing phase is the tendency of occurrence of negligence or errors that appear when a pilot begins to approach or enter the landing area. Such effect in the world of aviation is often referred to as "end deterioration" effect (Dhenin, et.al, 1978, in Mustopo, 2011). The understanding of this effect is intolerable pilot's fatigue to rest or relax when the aircraft approaches the end of the landing. At a flight which full of conditions that allow a pilot to experience stress, boredom and depression, it will make them to experience huge fatigue or exhaustion to rest. And if such desire grows unbearable, it will make them to recklessly get into the final destination of the flight. And the consequence of such thing is the decrease in the level of vigilance and alertness of the pilot himself, posing danger in flight operations (Saputra, et al, 2015d). Based on the analysis conducted, it is known that the mental workload of all pilots is classified in the category of high workload (overload) when the aircraft is entering landing procedure. The overly workload (overload) is an important stressor in aviation which can inflict negative impacts to the level of fatigue. As known, two of the main causes of aircraft accidents caused by humans are stress and fatigue factors happening to a pilot. The manifestation of fatigue can be a feeling of tiredness or drop performance, and if left unattended it could be the source of airplane accidents (Mustopo, 2012).

Terrain condition towards mental workload

The understanding the location in the world of aviation is more focused on the condition of a terrain, i.e. the surface of the earth which contains features occurred naturally, such as mountains, hills, valleys, waters, permanent ice and snow. But not including the "obstacles", i.e. objects or buildings built by humans (Sukajaya, et.al. 2010). In this research, terrain location is consisted of mountainous terrain, plateau, and relatively flat land. From the computation of the subjectively mental workload using SWAT analytical method, it is found that in the dimension of location or terrain condition, the pilots feel burdened or have the highest mental workload value when they face aircraft operation conditions to which the land surface has mountainous contour, either in flight route or airport location. In mountainous areas, an aircraft flying through the mountainous area will be exposed to danger if it comes off the slopes under the wind, as it will be impacted by negative lifting angle, thus lifting force grows smaller and results in the collision. Besides, mountain areas also pose dangers not found in plains or flat land; for instance, wind changes that produce mountain wave, both severe updraft and downdraft that may lead to turbulence. The clouds can develop rapidly to the extent of coating the visibility and unavailable flat areas for forced landing. High mental workload in such condition is able to create fatigue (Saputra, et.al 2015a). A fatigued pilot will have a decreased level of alertness in carrying out flight tasks which can contribute to aircraft accidents.

Weather towards mental workload

In modes of transport, air transport is the mode that highly depends on the changes in the weather, whether during the take-off, during the plane in the air/cruise, and during the landing. Weather condition covers precipitation, visibility, wind speed and direction as well as air humidity. Those are important information to identify by the cabin crew, especially aircraft pilots. Weather forecast is provided at any time when the aircraft has flight plan adapted to the flight schedule in order to anticipate the changes in weather condition. In the world of aviation, weather has two extremely essential roles; on one hand is the information about weather which has contributed to the efficiency and effectiveness of aviation activities and safety. However, on the other hand, it possesses the potential to endanger flight operations. Meteorological disorders from impacts of weather elements always catch special attention in the aviation world, and may bring negative impacts on flight operation, both in-flight and ground operation.

From the analysis results using SWAT method, the most burdensome condition/the pilot's workload mental will increase (the highest level) when the aircraft endures changes in condition or wind phenomena with mental workload value with an average of 84.6, seen from the dimension of weather, including several weather elements; wind, visibility, pressure, cloud types, ceiling and temperature. In the aviation world, the phenomenon of changes in wind direction and speed is defined as wind shear. This change occurs abruptly, especially when subjected to head wind, and can change all of sudden at 180°, which is accompanied by changes in wind speed. Wind shear endangers flight operations if happens nearby or surrounding the airport/runway. Wind shear in the world of aviation is deemed highly intrusive, either in the process of take-off or landing that may result in misalignment of landing, or take-off caused by cross wind, head wind or tail wind while landing or take-off. And it may result in overly long usage of the runway and obstructs the planes in the air, since the wind shear having great energy or power is capable of defeating the energy or power produced by aircrafts. Changes in weather condition, in this regard is changes in wind direction, can affect mental workload to a pilot (Saputra, et al, 2015b).

Conclusions

Based on the analysis result, it can be concluded that the pilot mental workload will increase when a pilot faced with flight conditions do at early morning (00.00-05:59 am), during weekend and enters the peak season period, and the aircraft will be landing procedures, and also in case of change of wind conditions in flight, and will increasingly when pilot exposed to aircraft operating with route condition which has a land surface is mountainous. Meanwhile, in overall, among each of dimension of aviation operations, i.e. phases of time, phases of flight, terrain condition, and weather; the level of the highest relative importance is the time load dimension, indicating that they put more emphasis on this factor when they are considering workloads.

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