Evaluating the human performance factors of air traffic control in Thailand using Fuzzy Multi Criteria Decision Making method

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ABSTRACT

The paper aims to identify and evaluate the factors influencing the human performance of Air Traffic Control (ATC) in Thailand. The objective of the study has been operationalized utilizing the extended SHEL model of ergonomics. Fuzzy Graded Mean Integration method has been employed to establish the importance and Fuzzy Additive Ratio Assessment method was utilized to measure actual performance of the factors on the response received from all ten air traffic control centers of Thailand. The finding of study facilitates the insights for improvement of various dimensions and constructs for an effective human performance management for ATC in Thailand. The study fulfills the theoretical gap by employing the Fuzzy Multi Criteria Decision Making (MCDM) method of identifying and measuring human performance in ATC.

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1. Introduction

The aviation industry is characterized by a complex structure and dynamic advancement of technology which inherently put forth a challenge to work performance of human pertaining to the ever changing environment, concurrent task demand, time pressure and tactical constraint (Sheridan, 2002). In most of the air accidents, it is observed that slack in human performance plays a vital role (Hawkins, 1993; Chang and Yeh, 2004). As 'Swiss Cheese' model indicates that most of the air accidents are multi-causal in nature, therefore the residual threats for the accidents often result from the interaction of multiple human factors and resulting in the cumulative impact on performance (Edwards et al., 2012). This necessitates the need to identify the multi-factorial model of human performance to build up a safe and reliable aviation system. It is observed that the multi-factorial model of human performance in aviation has been a under-researched topic with special reference to the Air Traffic Control (ATC). There has been a plethora of research in the field of ATC pertaining to the role of human error in the occurrence of accidents, stress and fatigue and aviation safety, but very few studies have been conducted to explore the factors governing the job performance in ATC.

As ATC is a critical assignment pertaining to aviation safety, this requires highly skilled operatives to collaborate in a large and complex human-machine system (Bentley et al., 1995). The ATC officers play the central role, interacting cooperatively with all components of the ATC system, resulting in the safe and efficient flow of air traffic. Hence, the understanding of the factors governing the performance of an ATC officer would enable a safe, efficient and reliable ATC system. The quest to mitigate the human error management in ATC lies on the fact that how soundly the factors governing the human performance are identified and addressed. As the ATC system is highly dynamic faced with continuously technological enhancement; it is desirable to explore the current factors that affect human performance at work. In this context, there is an immense need of conceptual contribution to the literature on the current topic with the objective to explore and identify the critical human performance factors pertaining to the ATC system. The present research would attempt to give managerial implications which would be helpful to aviation stakeholders to build up a safe, efficient and reliable ATC system.

This paper is organized into six sections including the introduction. Section 2 and 3 comprise the literature review of factors identifying human performance and extension of SHEL Model. Section 4 comprises in detail about the incorporated methodology to meet the objective of the study. Subsequently, the results and findings with the implications of the pertaining have been furnished in section 5 and finally, the conclusion is presented at the end.

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2. Factors influencing human performance

This section intends to summarize the literature reviewed on the factors governing the human performance in ATC domain.

Bailey (1996) propounded the human performance model with three elements, understanding of the human, the activity being performed and the context. It was contended that the three elements collectively influence the overall performance of humans on the job. In Bailey's model 'Human' was allocated as the major element to influence performance, 'Factors affecting activity' have the potential to enhance or degrade the performance and finally 'context' refers to the environment in which the job is performed which also influence the performance (Jalil et al., 2012). Later the generic model of Bailey (1996) was enhanced by the inclusion of three more criteria: the need, understanding and awareness on the importance of human performance criteria which brought the more precise result of human performance modeling (Wilson and Norris, 2005; Shahrokhi and Bernard, 2009).

Baines (2005) developed the human performance model for manufacturing system in which sixty-five factors were identified and classified into three broad categories; individual factors, physical environment and organizational environment. The conceptual model of Ergonomics known as SHEL model was propounded by Edwards (1972) which was later utilized by the International Civil Aviation Organization (ICAO) to understand human performance factors in the context of aviation safety. The SHEL model describes a system comprising four interactive components where S symbolizes software (rules, procedures, computer program, symbology etc.), H indicates the hardware (machines), E depicts the environment and L describes the liveware (Human) (Intenational Civil Aviation Organization, ICAO, 1998).

García et al. (2014) contended organizational factor as a prominent component to influence human performance with moderation of good communication. Chang and Yeh (2010) advanced the SHEL model with the inclusion of the organizational factor interaction with the Liveware to gauge the human performance of the ATC system. It is observed through literature that the main component of human performance studies is 'human' itself; which was referred by Baines (2005) as 'individual factors', Bailey (1996) referred as 'Human' and Chang and Yeh (2010) extended the human component by inclusion of two categories 'liveware' and interface of 'liveware-liveware'. The 'liveware' component indicated to personal attributes of the individual controller such as knowledge, experience, attitude, behavior, situation awareness and decision making skills. Whereas, the 'liveware-liveware' interface has been referred to socio-psychological aspects of the team, which includes cooperation, teamwork, leadership and personality interaction.

3. The SHEL model and its extensions

The SHEL model was first developed by Edwards (1972) to examine the ergonomics issues in regard to system resources. Later Hawkins (1984) modified to signify the interactive nature of liveware to liveware relationship. The Environment component of SHEL model helps in analyzing the human performance modeling from the organizational, regulatory and social aspect (Hawkins, 1993; Issac and Ruitenberg, 1999). Kirchner and Laurig (1971) emphasized on organization related factors such as job design, workload, organizational work-condition and job satisfaction as a key area of ergonomics to design an effective ATC system. Reason (1990, 1997) suggested addressing the organizational structure needs to understand and mitigate the human error in aviation. In the same line, Maurino (2000) contended that Human and organizational performance are two inseparable components in the context of aviation safety. In the same line, Durso and Alexander (2010) also contended that organizational factors are critical determinants of human performance in aviation. Chang and Yeh (2010) extended the SHEL model with inclusion of organizational aspect of the ATC system in which the controllers (liveware) as a human performance factor interacts with other human performance factors, including controllers (liveware), physical resources (hardware), non-physical resources (software), physical settings (environment), and non-physical settings (organization). The components of the extended SHEL model comprise of six interfaces of which Liveware (L) is the key element which indicates the personal attributes of the individual, including knowledge, experience, attitude, behavior, situation awareness, decision-making skills and health are briefly described below. The second Liveware-Liveware (L-L) interface refers to the factors pertaining to other liveware affecting the individual controller's performance, including cooperation, teamwork, leadership and personality interactions. The Liveware-Software (L-S) interface has assumed as the third factor related to non-physical aspects affecting the individual controller's performance, such as procedures, rules, checklists, documentation, charts and computer software. The fourth Liveware-Hardware (L-H) interface includes the factors related to the physical aspects (hardware) which affect individual liveware including control and monitor equipment, automation facilities, maintenance & recovery facilities and visual aids. The fifth interface of the extended SHEL Liveware-Environment (L-E) indicates toward the factors with respect to the operating environment in which the individual controller performs the task, including workplace design, noise, temperature, lighting, air quality and relaxation facilities. And the sixth interface Liveware-Organization (L-O) demonstrates the interaction between factors related to the organizational aspects of the ATC system and individual human performance, including workload allocation, organizational structure, policies and rules, communication, safety culture and training (Chang and Yeh, 2010).

Various studies have established significant relationships between emotional intelligence and workplace performance outcomes (Fiori and Antonakis, 2011; Lopes et al., 2006; Slaski and Cartwright, 2002; Sy et al., 2006). Although emotional intelligence has been widely discussed in the literature, however, there is no study found observing emotional intelligence as a factor influencing human performance in the specific context of ATC. Thus, the current study attempts to bridge the mentioned theoretical gap. The factor emotional intelligence has been designated under L-L interface in the extended SHEL model.

Several empirical studies have shown that the experience of work-life balance is positively related to employees' performance (Harrington and Ladge, 2009; Parkes and Langford, 2008). Work-life balance has been shown to have positive outcomes, such as low turnover intention, improvement of performance, and job satisfaction (Cegarra-Leiva et al., 2012; Nelson et al., 1990; Scandura and Lankau, 1997). Work-life balance contributes to increasing employees' in-role performance (Magnini, 2009). The experience of psychological well-being and harmony in life helps employees to concentrate on their job task, resulting in better performance. With the established significance of the work-life balance as a factor affecting in-role performance, the current study incorporates it as a factor item in the extended SHEL model under the 'L-L' interface aiming to fulfill the observed theoretical gap.

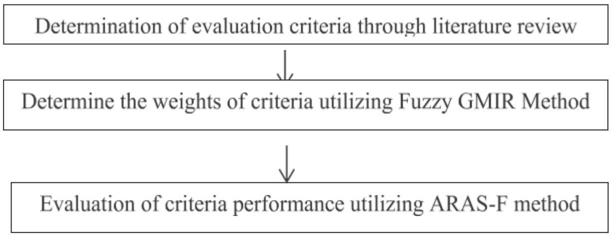
The current study would be utilizing the construct in line with Chang and Yeh (2010) to identify the critical human performance factors in regards to ATC, with the inclusion of two prominent dimensions, Emotional Intelligence and Work Life Balancing.

4. Methodology

4.1. Research process

When focusing on prioritizing the factors governing the human performance in a system, often the opinions are expressed in the form of imprecision. This necessitates the use of fuzzy logic (Pandey, 2016). The proposed fuzzy multi-criteria decision-making model was formed following the process elucidated in Table 1 basing on the aim to identify the respective weight of the criteria and measure the performance of the alternatives. The first step of the research process starts with extensive literature review on Human Performance factor which has been done to identify the pertinent variable with special reference to ATC. In

Table 1
Research process of Fuzzy MCDM.



the second step the identified variables have been gauged for their respective weight on the basis of the opinion of the expert team. Finally in the third step, the performance of ATC Centers has been measured on the basis of the established weighted construct.

Initially, the construct for the measuring the human performance was drawn from the extended SHEL model of Chang and Yeh (2010) in which two unique dimensions, Emotional Intelligence and Work-Life balance were included keeping in view the crucial importance of the factors. The hierarchical analysis structure utilized to gauge the human performance in ATC is rendered in Table 4. After determination of constructs, respective dimensions and criteria to gauge human performance along with respective criteria weighting were done utilizing the Fuzzy Graded Mean Integration Representation (GMIR). The criteria weights were determined based on the survey response received from the Air Traffic Controllers. Finally, the evaluation of the conceptualized human performance model was done employing the Fuzzy-Additive Ratio Assessment Method (ARAS-F).

4.1.1. *Survey instrument and sampling framework*

A questionnaire was designed in line with the extended SHEL model of Chang and Yeh (2010) including the dimensions of emotional intelligence and work life balancing. The survey contains the construct 'L' with five dimensions and 12 criteria, the construct 'L-L' with seven dimensions and 18 criteria, 'L-S' construct with four dimensions and eight criteria, the construct 'L-H' with four dimensions and 14 criteria, 'L-E' construct with three dimensions and 9 criteria and the construct 'L- O' with seven dimensions and 17 criteria which are detailed in Table 4. The evaluation of each human performance criterion for an ATC is gauged using the linguistic variable scale which is labeled as 'very poor', 'poor', fair, 'good' and 'very good' and their respective rating as indicated in Table 3. The linguistic variables utilized to measure the importance of the respective criteria are labeled as 'not at all important', 'slightly important', 'moderately important', 'very important' and 'extremely important' and is indicated in Table 2.

The data were collected from the ATC officers stationed at all ten air traffic control centers in Thailand, namely Suvarnabhumi, Don Mueang, Chiang Mai, Phuket, Hatyai, Phitsanulok, Surat Thani, Udon Thani, Hua Hin and Ubon Ratchathani. The survey was conducted throughout the month of February 2016 by employing stratified sampling method. A sample response of 35 ATC Officers was obtained from the each ATC center, aggregating 350 responses in total which is higher than sample size estimated using Browner et al. (2013) formula of 324 respondents. 400 questionnaires were distributed in the survey for which response rate obtained was 87.5%.

Table 2
Linguistic variables for the criteria importance.

Not at all important	(0.0, 1.0, 2.0)
Slightly Important	(1.0, 2.0, 3.0)
Moderately Important	(2.0, 3.0, 4.0)
Very Important	(3.0, 4.0, 5.0)
Extremely Important	(4.5, 5.0, 5.0)

Table 3
Linguistic variables for the criteria performance.

Poor	(0.0, 1.0, 2.0)
Fair	(1.0, 2.0, 3.0)
Good	(2.0, 3.0, 4.0)
Very Good	(3.0, 4.0, 5.0)
Excellent	(4.5, 5.0, 5.0)

4.2. *Fuzzy theory and linguistic fuzzy evaluation scale*

Human performance model scales the rating for importance and measurement of the respective criteria. Often the rating is done on the basis of the crisp numerical value which may often result in vague and imprecise results (Pandey, 2016; Pandey et al., 2018a, 2018b). Since the measurement of human performance factor encompasses intrinsic complexity, hence Fuzzy Set Theory renders an effective approach to gauge it using interval based linguistic variable.

The concept of the fuzzy set was founded by Zadeh (1973) with the purpose to measure the human preference more pragmatically by the help of the linguistic term (Pandey, 2016). Fuzzy Set Theory renders a strict mathematical framework in which imprecise conceptual phenomenon can be measured precisely (Zimmermann, 2001; Zadeh, 1973; Bellman and Zadeh, 1970; Zadeh, 1975; Hwang and Yoon, 1981; Liang and Wang, 1991; Hsu and Chen, 1997; Chiadamrong, 1999; Chien and Tsaia, 2000; Chen, 2001; Enrique, 2004; Pandey, 2016; Garg, 2016; Pandey et al., 2018a, 2018b).

A fuzzy set is a set without a crisp, clearly defined boundary and contains elements with only a partial degree of membership (MathWorks, 2012). MathWorks (2012) defines a membership function (MF) as a curve that explains how each point in the input space is mapped to a membership value (or degree of membership) between 0 and 1. The concepts of a linguistic variable can be quantified by fuzzy numbers using suitable membership functions. Various types of membership functions such as triangular, trapezoid, linear, sigmoidal, pie type and Gaussian are utilized and the most widely applied membership function is a triangular membership function (Pandey, 2016). Triangular fuzzy numbers can be defined as (l_1, m_1, u_1) where $l_1 \leq m_1 \leq u_1$ and it can be represented in terms of membership functions (Jia et al., 2015).

4.3. *Fuzzy method for determination of weights of criteria*

Kusumawardani and Agintiara (2015) developed a fuzzy MCDM model for decision making in the human resource manager selection process. Dursun and Karsak (2010) utilized Fuzzy MCDM for effectively solving the personnel selection process. Zhang et al. (2013) developed Fuzzy MCDM for evaluation of human performance management in academic institutions. Shukla (2018) utilized Fuzzy MCDM to evaluate systems thinking in educational leadership.

For the ranking of fuzzy numbers, graded mean integration representation method was explored by Chen and Hesieh (1998). Further, Chou (2003) identified a canonical representation of the multiplication operation on two triangular fuzzy numbers (TFNs') by graded multiple integration representation method. Chou (2006) applied inverse function arithmetic representation for multiplication operation of multiple trapezoidal fuzzy numbers and later the framework was employed to solve MCDM problem. (Chou, 2007).

This paper determines the weights of criteria by employing graded mean integration method. Later the fuzzy weights were utilized in Additive Ratio Assessment method (ARAS-F) to evaluate the factors of human performance for ATC in Thailand.

All the ATC human performance criteria are indicated in Table 4, and their respective importance is assessed using a linguistic scale and TFN indicated in Table 2. By employing the graded mean integration

Table 4
Hierarchical analysis structure for evaluation of Human Performance in ATC.

Goal	Construct	Dimension	Criteria	Alternative
Measurement of Human Performance in Air Traffic Control	Liveware	Attitude	Trust on colleague (L1)	Air Traffic Control Centers of Thailand
			Proactive in solving problems (L2)	
			Believe in team work (L3)	
		Situation Awareness	Safety risk awareness (L4)	
			Understanding of ATC and pilot's job (L5)	
		Knowledge and Experience	Suffice Language Proficiency (L6)	
			Suffice Competence and experience (L7)	
			Suffice navigational competence (L8)	
		Decision Making Skills	Ability to take decisions pertaining to the routine ATC job (L9)	
			Ability to take decisions pertaining to the critical ATC job (L10)	
		Health	Health and fitness to perform the ATC tasks (L11)	
			Frequency of sick leave (L12)	
	Liveware-Liveware	Peer communication	Slip of the tongue while communicating (LL1)	
			Active listening while performing the job (LL2)	
			Proactive in sharing information with team members (LL3)	
			Clear and precise in communication (LL4)	
			Standard phraseology for task related communication (LL5)	
		Teamwork	Good attention to team member's work (LL6)	
			Share tasks of team members in peak period (LL7)	
			Help team members often on the work (LL8)	
		Personality Interaction	Effective in teamwork interaction (LL9)	
			Proactive in team decision making (LL10)	
		Leadership	Supervisors guide team members to effectively perform the job (LL11)	
			Adherence of discipline while on job (LL12)	
		Inter-team Coordination	Effective mutual interaction to perform tasks (LL13)	
			Interact with colleagues with full trust (LL14)	
			Coordinate well with other ATC Team (LL15)	
			Work well with other ATC Team (LL16)	
		Emotional Intelligence	Understand and evaluate the self-thoughts before communicating (LL17)	
		Work Life Balance	Keep appropriate balance in job and family task (LL18)	
	Liveware-Software	Checklist	Design of work checklist appropriate (LS1)	
			Work checklist process is reasonable (LS2)	
		Procedure	Design of operations procedure is appropriate (LS3)	
			Operations procedure is reasonable (LS4)	
			Operations procedure is highly regulated (LS5)	
		Software and Documentation	Operations facilitated with the advance softwares (LS6)	
			Operations are well documented (LS7)	
		Rules	Operations are strictly governed by organizational rules (LS8)	
	Liveware Hardware	Equipment	Sufficient ATC equipments (LH1)	
			Layout of ATC equipment is reasonable (LH2)	
			Supply of supporting facilities sufficient (LH3)	
			ATC equipments are based on advanced technology (LH4)	
			ATC equipments undergo routine checks for maintenance (LH5)	
		Automation	The automation system is effective (LH6)	
			Automation system design is effective (LH7)	
			Automation system has reduced monitoring (LH8)	
			Automation system at ATC is reasonable (LH9)	
		Maintenance	Maintenance and backup system is effective (LH10)	
			Maintenance and backup system is easy to operate (LH11)	
			Maintenance and backup system undergo routine checks (LH12)	
		Visual Resources	Control room equipped with appropriate visual resources (LH13)	
			Control room visual resources are of best quality (LH14)	
	Liveware-Environment	Workplace Design	Workplace is well designed (LE1)	
			Work place is designed with facilities to accommodate all modern facilities (LE2)	
		Workplace Quality	Workplace is facilitated with necessary conveniences (LE3)	
			Appropriate temperature of control room (LE4)	
		Workplace Quality	Appropriate air quality of control room (LE5)	
		Relaxation setting	Safety at control room (LE6)	
			Layout of control room is appropriate (LE7)	
			Appropriate relaxing facilities (LE8)	
			Appropriate relaxing space (LE9)	
		Workload	Shift rotation is reasonable (LO1)	
			Work schedule is reasonable (LO2)	
	Liveware-Organization	Workload Policies	Work allocation is equitable (LO3)	
		and Rules	Appropriate compensation and reward policy (LO4)	
			Appropriate performance appraisal policy (LO5)	
		Policies and Rules	Appropriate work condition (LO6)	
		Communication	Appropriate employee welfare policy (LO7)	
			Existence of bottom-top communication (LO8)	
			Supervisor keeps informed about work condition (LO9)	
		Organizational Structure	Effective span of control (LO10)	
			Effective delegation of authority (LO11)	
		Safety Culture	Best practices for safety (LO12)	
			Organization collects safety concern (LO13)	

(*continued on next page*)

Table 4 (*continued*)

Goal	Construct	Dimension	Criteria	Alternative
		Safety Culture	Prioritize safety while performing job (LO14)	
		Training	Sufficient training to perform task (LO15)	
			Training rendered to handle emergency (LO16)	
		Training	Training programs are well designed and organized (LO17)	

method a TFN $Y_1 = (c_1, a_1, b_1)$ is represented utilizing Equation (1). The same representation is employed on all human performance criteria for the rating of respective importance and performance.

$$P(Y1) = \frac{1}{6}(c1 + 4a1 + b1) \tag{1}$$

The performance and importance scores of ith human performance criterion (i = 1,2, … … w) which is rated by nth respondent (n = 1,2, … … n) for kth location (k = 1,2, … … m) are denoted by TFNs' respectively and are fuzzified utilizing the graded mean method explained above. The importance score is represented by w_{in}, which indicates the importance of score given by nth respondent for ith human performance criterion.

For defuzzification, the first step followed is to calculate the ratio AW_{ik} which is obtained using the formula indicated by equation (2).

$$AWik = \frac{\sum_{n=1}^{N} win}{\sum_{i=1}^{I} \sum_{n=1}^{N} win} \tag{2}$$

4.4. Fuzzy method for evaluation of alternatives

For the current research additive ratio assessment (ARAS) method has been utilized for the measurement and evaluation of human performance criteria in ATC. In the ARAS method, a multi-criteria utility function's value determines the relative efficiency of an alternative (Zavadskas and Turskis, 2010; Keršulienė and Turskis, 2011). Due to the lack of precise information, it is better to apply the ARAS method with the fuzzy criteria values to solve different management problems under uncertainty (ARAS-F) (Turskis and Zavadskas, 2010; Nguyen et al., 2016).

The method could be described as a six step-wise procedure.

Step 1. A fuzzy decision-making matrix for m alternatives rated on n criteria was formed:

$$\tilde{X} = \begin{bmatrix} \tilde{x}_{01} & \dots & \tilde{x}_{0j} & \dots & \tilde{x}_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \tilde{x}_{i1} & \dots & \tilde{x}_{ij} & \dots & \tilde{x}_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \cdots & \tilde{x}_{mj} & \cdots & \tilde{x}_{mn} \end{bmatrix}; \quad i = \overline{0, m}; \quad j = \overline{1, n}, \tag{3}$$

where m – number of alternatives, n – number of criteria, $\tilde{x}_{ij}$ – fuzzy performance value of the i alternative in terms of the j criterion, $\tilde{x}_{0j}$ – optimal value of j criterion.

If optimal value of j criterion is unknown, then

$$\tilde{x}_{0j} = \max_i \tilde{x}_{ij}, \quad \text{if } \max_i \tilde{x}_{ij} \text{ is preferable}, \quad \text{and}$$
$$\tilde{x}_{0j} = \min_i \tilde{x}^*_{ij} \quad \text{if } \min_i \tilde{x}_{ij} \text{ is preferable}. \tag{4}$$

Step 2. Normalized criteria values $\bar{x}_{ij}$ presented in normalized decision-making matrix $\bar{X}$:

$$\bar{X} = \begin{bmatrix} \bar{x}_{01} & \dots & \bar{x}_{0j} & \dots & \bar{x}_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \bar{x}_{i1} & \cdots & \bar{x}_{ij} & \cdots & \bar{x}_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \bar{x}_{m1} & \cdots & \bar{x}_{mj} & \cdots & \bar{x}_{mn} \end{bmatrix}; \quad i = \overline{0, m}; \quad j = \overline{1, n}. \tag{5}$$

$$\bar{x}_{ij} = \frac{\tilde{x}_{ij}}{\sum_{i=0}^{m} \tilde{x}_{ij}}, \quad \text{if } \max_i \tilde{x}_{ij} \text{ is preferable, and} \tag{6}$$

$$\tilde{x}_{ij} = \frac{1}{\tilde{x}^*_{ij}}; \quad \bar{x}_{ij} = \frac{\tilde{x}_{ij}}{\sum_{i=0}^{m} \tilde{x}_{ij}}, \quad \text{if } \min_i \tilde{x}_{ij} \text{ is preferable.} \tag{7}$$

Step 3. Normalized-weighted matrix - $\hat{X}$ defined:

$$\hat{X} = \begin{bmatrix} \hat{x}_{01} & \dots & \hat{x}_{0j} & \dots & \hat{x}_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \hat{x}_{i1} & \cdots & \hat{x}_{ij} & \cdots & \hat{x}_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \hat{x}_{m1} & \cdots & \hat{x}_{mj} & \cdots & \hat{x}_{mn} \end{bmatrix}; \tag{8}$$

Normalized-weighted values of the criteria calculated as follows:

$$\hat{x}_{ij} = \bar{x}_{ij}\tilde{w}_j; \tag{9}$$

Step 4. The values of additive utility function $\tilde{S}_i$ determined:

$$\tilde{S}_i = \sum_{j=1}^{n} \hat{x}_{ij}; \qquad i = \overline{0, m}, \tag{10}$$

Step 5. The values of optimality function defuzzified:

$$S_i = \frac{1}{3}(S_{i\alpha} + S_{i\beta} + S_{i\gamma}); \tag{11}$$

Step 6. The utility degree of optimality function values with a comparison to the ideally best one S_0:

$$K_i = \frac{S_i}{S_0}; \qquad i = \overline{0, m}, \tag{12}$$

where S_i and S_0 are the optimality criterion values, obtained from Eq. (12).

5. Findings

This paper aims to identify and evaluate the human performance factors in the ATC setting of Thailand utilizing the extended SHEL model based on the fuzzy logic method. Table 5 below indicates the evaluation score of human performance and importance factors for all ten air traffic control centers in Thailand. It is observed that out of six constructs only 'L' and 'L-L' have a higher score for actual performance than expected. The expected and the actual performance score of the construct 'L' is 0.167 and 0.19 respectively. For the construct 'L-L' the expected and the actual performance score obtained is 0.204 and 0.33 respectively. However, the construct ‘L-S’, ‘L-H’, ‘L-E’ and ‘L-O’ have performed below the expectations. The construct LS have the expected and actual performance score of 0.105 and 0.08 respectively. Similarly, the expected and performance score of the construct L-H is 0.182 and 0.14 and L-E is 0.119 and 0.089 respectively. The construct L-O has scored the least in the terms of the difference between expected and actual performance with scores of 0.224 and 0.17 respectively.

The construct ‘L’ has five dimensions, ‘attitude’, ‘situation awareness’, ‘knowledge and experience’, ‘decision-making skills’ and ‘health’ of which ‘attitude’ and ‘health’ have performance score higher than expected. The expected and performance score of the dimension ‘attitude’ is 0.28 and 0.0528 while for ‘health’ is 0.019 and 0.038 respectively.

However, ‘situation awareness’, ‘decision-making skills’ and ‘knowledge and experience’ have expected score higher than actual,

Table 5
Evaluated Importance and Performance scores of Human Factors of ATC centers in Thailand.

Construct	Dimension	Criteria	Criteria Weight	Dimension Weight	Construct Weight	Criteria Performance Score	Dimension Performance Score	Construct Performance Score
Liveware	Attitude	L1	0.008	0.028	0.167	0.020	0.0528	**0.19**
		L2	0.009			0.017		
		L3	0.011			0.015		
	Situation Awareness	L4	0.017	0.034		0.014	0.0271	
		L5	0.017			0.013		
	Knowledge and experience	L6	0.017	0.053		0.015	0.0439	
		L7	0.018			0.015		
		L8	0.018			0.014		
	Decision Making Skills	L9	0.017	0.032		0.014	0.0285	
		L10	0.016			0.015		
	Health	L11	0.010	0.019		0.020	0.0383	
		L12	0.009			0.018		
Liveware-Liveware	Peer Communication	LL1	0.009	0.046	0.204	0.020	0.0979	**0.33**
		LL2	0.010			0.017		
		LL3	0.009			0.020		
		LL4	0.009			0.020		
		LL5	0.009			0.020		
	Teamwork	LL6	0.016	0.043		0.018	0.0559	
		LL7	0.017			0.017		
		LL8	0.010			0.020		
	Personality Interaction	LL9	0.010	0.019		0.020	0.0392	
		LL10	0.009			0.019		
	Leadership	LL11	0.008	0.017		0.019	0.0382	
		LL12	0.009			0.019		
	Interteam Coordination	LL13	0.011	0.047		0.019	0.0747	
		LL14	0.009			0.019		
		LL15	0.017			0.016		
		LL16	0.010			0.020		
	Emotional Intelligence	LL17	0.015	0.015		0.011	0.0114	
	Work Life Balancing	LL18	0.015	0.015		0.012	0.0119	
Liveware-Software	Checklists	LS1	0.016	0.030	0.105	0.010	0.0208	**0.080**
		LS2	0.014			0.011		
	Procedures	LS3	0.016	0.044		0.012	0.0351	
		LS4	0.019			0.014		
		LS5	0.009			0.009		
	Software and documentation	LS6	0.011	0.021		0.009	0.0163	
		LS7	0.010			0.008		
	Rules	LS8	0.010	0.010		0.008	0.0076	
Liveware-Hardware	Equipment	LH1	0.017	0.074	0.182	0.011	0.0610	**0.14**
		LH2	0.018			0.018		
		LH3	0.018			0.012		
		LH4	0.010			0.014		
		LH5	0.011			0.007		
	Automation	LH6	0.015	0.049		0.013	0.0431	
		LH7	0.016			0.013		
		LH8	0.009			0.008		
		LH9	0.010			0.009		
	Maintenance	LH10	0.016	0.041		0.013	0.0295	
		LH11	0.016			0.012		
		LH12	0.009			0.004		
	Visual Resources	LH13	0.008	0.017		0.005	0.0094	
		LH14	0.009			0.005		
Liveware-Environment	Workplace Design	LE1	0.010	0.020	0.119	0.006	0.0112	**0.089**
		LE2	0.010			0.006		
	Workplace Quality	LE3	0.009	0.027		0.008	0.0221	
		LE4	0.018			0.014		
	Relaxation setting & Workplace Quality	LE5	0.017	0.072		0.012	0.0559	
		LE6	0.017			0.017		
		LE7	0.016			0.012		
		LE8	0.012			0.007		
		LE9	0.010			0.007		

(*continued on next page*)

Table 5 (*continued*)

Construct	Dimension	Criteria	Criteria Weight	Dimension Weight	Construct Weight	Criteria Performance Score	Dimension Performance Score	Construct Performance Score
Liveware-Organization	Workload	LO1	0.011	0.026	0.224	0.009	0.0259	**0.17**
		LO2	0.015			0.017		
	Workload Policies and Rules	LO3	0.010	0.031		0.010	0.0173	
		LO4	0.010			0.004		
		LO5	0.011			0.004		
	Policies and Rules Communication	LO6	0.010	0.055		0.005	0.0409	
		LO7	0.010			0.008		
		LO8	0.017			0.015		
		LO9	0.018			0.012		
	Organizational Structure	LO10	0.009	0.019		0.005	0.0111	
		LO11	0.011			0.006		
	Safety Culture	LO12	0.016	0.031		0.010	0.0194	
		LO13	0.015			0.010		
	Safety Culture Training	LO14	0.015	0.046		0.020	0.0455	
		LO15	0.015			0.013		
		LO16	0.015			0.013		
	Training	LO17	0.016	0.016		0.008	0.0081	

necessitating the management to fulfill the identified gap. The dimension 'situation awareness' has expected a score of 0.034, higher than actual performance score of 0.0271. The dimension 'knowledge and experience' have expected performance score of 0.053 higher than actual performance score of 0.0439. 'Decision-making skills' has expected and an actual performance score of 0.032 and 0.0285 respectively.

The construct 'L-L' has seven dimensions of which the dimensions 'emotional intelligence' and 'work-life balancing' have expected scores higher than actual. The expected and actual performance score of 'emotional intelligence' is 0.015 and 0.014 respectively, while the dimension 'work-life balancing' has expected and an actual score of 0.015 and 0.0119 respectively. The managers need to strengthen the 'emotional intelligence' and 'work-life balancing' dimensions to maximize the ATC's human performance. While for the dimensions, 'peer communication', 'teamwork', 'personality interaction', 'leadership' and 'inter-team coordination' the actual performance score is higher than the expected.

'L-S' has four dimensions, 'checklists', 'procedures', 'software and documentations' and 'rules' and all dimensions have actual performance score lower than expected. The dimension 'checklists' have expected and an actual performance score of 0.030 and 0.0208 while 'procedures' have a score of 0.044 and 0.035 respectively. The dimension 'software and documentation' have expected and performance score of 0.021 and 0.0163 respectively while the corresponding scores for the dimension 'rules' are 0.010 and 0.007 respectively. Over the entire observation of all the dimensions of the construct, L-S needs improvement to maximize the human performance.

The construct L-H encompasses four dimensions 'equipment', 'automation', 'maintenance' and 'visual resources'. It is observed that all the dimensions of this construct have actual performance score lower than expected, necessitating the improvement impetus. The expected and actual score for the dimension 'equipment' is 0.074 and 0.061, for 'automation' is 0.049 and 0.043, for 'maintenance' is 0.041 and 0.0295 and for 'visual resources' is 0.017 and 0.009 respectively.

The construct L-E includes the dimensions of 'workplace design', 'workplace quality' and 'relaxation setting and workplace quality'. It is observed that all the dimensions of this construct have a lower score for actual performance than expected. The dimension 'workplace design' observed with expected and actual performance score of 0.02 and 0.011respectively, 'workplace quality' has a score of 0.027 and 0.022 and 'relaxation setting and workplace quality' has a score of 0.072 and 0.055 respectively. It is also noted that 'relaxation setting and workplace quality' has the highest gap between actual and expected scores among three.

The construct L-O comprises of seven dimensions, 'workload', 'workload policies and rules', 'policies and rules communication', 'organizational structure', 'safety culture', 'safety culture training' and 'training'. It is observed that only two dimensions 'workload' and 'safety culture training' have actual performance score higher than the expected. The actual and expected performance score of 'workload' is 0.026 and 0.025 respectively, while for 'safety culture training' the score is 0.046 and 0.045 respectively. The obtained result pertaining to these dimensions may be attributed to the regulated standards of the aviation industry.

However, there is need to address other four dimensions of the L-O construct in which the actual performance score is lower than expected. The actual and expected performance score for 'workload policies and rules' is 0.031 and 0.017, 'Policies and rules communication' is 0.055 and 0.041, 'organizational structure' is 0.019 and 0.011, 'safety culture' is 0.031 and 0.019 and 'training' is 0.016 and 0.008 respectively.

6. Conclusion

This paper attempts to identify and evaluate the human performance factors for ATC in Thailand based on extended SHEL model andutilizing Fuzzy MCDM method. The findings provide the pragmatic insights in managing human performance factors of the ATC in Thailand. The study furnishes the model which can be used to evaluate the human performance factors of ATC. The model developed in the study contains 78 criteria spread across 31 dimensions and six interfaces of SHEL model. The importance score of the criteria has been aggregated utilizing Fuzzy based MCDM method. The prioritized model has been utilized to evaluate the performance of ATC in Thailand.

Upon evaluating the human performance of ATC in Thailand, it was found that only constructs 'L' and 'L-L' interface are having actual performance score higher than expected. Whereas all remaining constructs require improvement in performance standard to maximize the Human performance of ATC professionals in Thailand. With regard to the construct 'L', the dimensions 'situation awareness', 'decision-making skills' and 'knowledge and experience' require improvement. The second construct 'L-L' requires improvement on the dimensions 'emotional intelligence' and 'work-life balancing'; third construct 'L-S' requires improvement on the dimensions 'checklists', 'procedures', 'software and documentations' and 'rules'; the fourth construct 'L-H' requires improvement on 'equipment', 'automation', 'maintenance' and 'visual resources'; fifth construct 'L-E' needs improvement on the dimensions 'workplace design', 'workplace quality and relaxation setting' and 'workplace quality'. And the sixth construct, 'L-O' entails improvement on 'workload policies and rules', 'policies and rules communication', 'organizational structure', 'safety culture' and 'training'.

The contribution of the paper is threefold. Firstly, the paper contributes in identifying and measuring human performance in ATC utilizing Fuzzy MCDM method. As measuring the human performance based on crisp value can often be misleading hence the use of fuzzy MCDM method gives a more realistic and precise measurement. Since there is a dearth of research measuring the human performance of ATC by employing Fuzzy MCDM method; hence the paper contributes theoretically and methodologically to fill the gap to above pertaining and found that the Fuzzy MCDM method is promising and pragmatic in measuring the Human Performance factors of ATC. Secondly, to capture human performance deficiencies the paper contributes by including two additional prominent dimensions, emotional intelligence and work life balancing to the extended SHEL model. And lastly, the proposed model and its implications can be utilized by ATC stakeholders in Thailand for improvement of Human performance factor. The developed model can also be utilized in the context of the other countries for evaluation of the human performance factor.

The future scope of study comprises the multi-fold perspectives such as the different fuzzy based MCDM approach may be utilized for a similar problem where results can be matched to identify the best suitable fuzzy logic approach to capture the human performance in ATC. In the similar line benchmarking study may be undertaken to understand the best facilitation for maximized Human performance in ATC. The extended SHEL research model can be applied to explore complex interactions between human performance factors and technology-intensive systems. Also, the demonstrated human performance model in the paper can be tested and validated in varied geographical settings. The factors of the human performance model may also be investigated in mediation and moderation effects of the organizational intervention, cross-cultural influence and individual personality differences with the fuzzy methodological application.

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