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Skills Assessment Criteria for Aircraft Maintenance Technician in the Context of Industrial Revolution 4.0

T. Nanthakumaran Thulasy[1,*], Puteri Nor Ellyza Nohuddin[2,3], Istas Fahrurrazi Nusyirwan[1], Noorlizawati Abd Rahim[1], Astuty Amrin[1], Stephanie Chua[4]

1.Universiti Teknologi Malaysia – Razak Faculty of Technology and Informatics – Kuala Lumpur – Malaysia. 2.Higher Colleges of Technology – Faculty of Business – United Arab Emirates. 3.Universiti Kebangsaan Malaysia – Institute of Industrial Revolution 4.0 – Bangi – Malaysia. 4.Universiti Malaysia Sarawak – Faculty of Computer Science and Information Technology – Kota Samarahan – Malaysia.

*Correspondence author: tnanthakumaran@graduate.utm.my

ABSTRACT

Professional certification is required for aircraft maintenance technicians in order to undertake sophisticated maintenance tasks that need a wide set of skills and competencies. Due to the increasing demand for workforce preparedness for Industrial Revolution 4.0, numerous publications stress only a subset of aircraft maintenance skills criteria in their skills assessment curriculum. The purpose of this paper is to review previous research publications on skill and competency evaluation in the aircraft maintenance industry in order to develop a comprehensive set of skill and competency assessment criteria through a systematic review of the literature. It applies the PRISMA approach in selecting and evaluating the included articles. The papers were retrieved from five journal databases using a set of Boolean search terms related. The filtered fifteen articles are systematically reviewed for talent evaluation criteria applicable to the aircraft maintenance work scope in order to deal with the Industrial Revolution 4.0 (IR4.0). Certain articles concentrate on a subset of assessment criteria for enhancing and tracking critical skills assessment criteria for the aircraft maintenance workforce, rather than on IR4.0 skill standards specifically. This paper summarizes seven skill criteria gathered in order to develop a comprehensive skill assessment framework for aircraft maintenance workforce.

Keywords: Industry Revolution 4.0; Aircraft maintenance technicians; Skill gaps; Skills assessment criteria.

INTRODUCTION

The Fourth Industrial Revolution (IR4.0) is changing the aviation sector to incorporate new technology into its aircraft and human capital (Aziz 2018). Artificial intelligence, machine learning, robots, sensors, and remote control are all revolutionising the aviation industry. Due to the complexity of repairing modern aircrafts, engineers and technicians must possess a varied set of skills and competencies. The technicians should acquire critical thinking and creativity, active learning and pedagogical methods, imagination and initiative, logical thinking and research, technical knowledge, system analysis and evaluation, and a variety of other skills. The *Malaysian Aerospace Industry Blueprint 2030* reported certain education and training systems are not

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successfully developed or addressed on employee skill mismatches or gaps between academia and industry (Zainal *et al.* 2017). Graduates of academies lack some necessary skills to fill jobs in the labour market (Gehrke *et al.* 2015). In recent years, one of the most prominent personnel management issues in the aviation industry are skill mismatch and gaps among aircraft maintenance workforce (Balaraman and Kamalakannan 2016).

In the context in which aviation organizations operate, the knowledge and efficiency of aircraft maintenance companies and maintenance specialists benefit both safety and cost. If the task works as intended, it provides value to all processes; but, if the task fails to execute as planned, the negative consequences may be quite destructive (Olaganathan *et al.* 2020). While it is commonly recognised that aircraft maintenance is vital for aviation safety, the availability of skilled technicians, as well as recruitment and selection methods, may be insufficient to meet the expanding demand for qualified human resources in the modern operational aviation sector. International aircraft maintenance technician training presents difficulties as organisations face a shortage of competent technicians (Güneş *et al*. 2020).

The Royal Malaysian Air Force (RMAF) faces analogous personnel management challenges as the organisation upgrades in terms of asset acquisition and managerial maturity. The RMAF, as the country's major air force, is dedicated to safeguarding the country's sovereignty, integrity, and interests through the effective use of military assets (Yusof and Abd Rahim 2017). Military operations encompass everything from combat to peacekeeping and evacuation programmes, as well as humanitarian assistance and disaster relief. Malaysia's 2018 budget allotted more than US$ 3.1 billion to the Malaysian Armed Forces, including US$ 671 million for equipment acquisition and upkeep. Along with the equipment, RMAF must ensure that its personnel are properly trained and maintained as asset components (Aziz 2018). As a result, it is vital to ensure the quality of aircraft maintenance technicians' skills, competences, and capacities throughout their employment with RMAF.

The objective of this research was to assess several relevant studies on the evaluation of aircraft maintenance specialists' skills and competencies. A thorough literature search was done to synthesise scholarly papers and studies on aircraft maintenance technician skills and knowledge. From the literature, it is hoped that some skill components and criteria for skill assessment would be found. Additionally, the examination reveals the procedures currently used to assess the competence of aircraft maintenance technician.

BACKGROUND AND RELATED WORKS

Globally, IR4.0 reshapes the economy, society, and manufacturing. The Internet of Things (IoT), a critical component of IR4.0, has spawned a flood of new technology applications. It does this by connecting computers, people, and systems in such a way that these components may communicate, issue commands, and act autonomously (Schumacher *et al.* 2016). In Malaysia, the aviation industry, whether public or private, is still adapting and embracing IR4.0 through aircraft asset fleets, training curriculum and skills on aircraft maintenance principles, on-the-job skill and competency, and advancement of the skills assessment model.

Aviation Maintenance Tasks

Professionals in aviation maintenance conduct a variety of highly specialized fields, including aircraft structural and engine maintenance, as well as system maintenance, such as navigation and communication components. Technical technicians are responsible for ensuring the safe and reliable operation of aircraft. Additionally, aircraft maintenance is a fast-paced job. Aircraft maintenance will continue to evolve in the future (Lappas and Kourousis 2016). This is because of the introduction of new aircraft designs and materials, as well as the interaction of sophisticated advanced technologies, such as mission control computers, fly-by-wire systems, structured fuel control systems, and scheduled maintenance systems, such as hydraulics, flight controls, and propellers or blades systems. When an aircraft reaches a specified number of flying hours since its last maintenance check, it should be subjected to a daily maintenance check. There are calendar time and take-off limit constraints, although they are rarely employed, because flying time constraints apply more quickly (Saltoğlu *et al.* 2016). Similarly, RMAF performs a variety of different types of maintenance, which are backed up by a three-tiered maintenance program, as depicted in Table 1.

Table 1. Types of aircraft maintenance in RMAF.

Type of maintenance	Details
1st level maintenance (Organizational level)	This on-site maintenance check includes inspection, repair, and part replacement.
2nd level maintenance (Intermediate level)	This inspection is performed on-site and entails a more complete examination, repair, and replacement of components than the first level of maintenance. a. The components must meet the deterioration characteristic requirements, which indicates that the probability of experiencing a failure mode increases over time. b. Additional effective measures must be available to prevent the parts from failing on a regular basis.
3rd level maintenance (Depot level)	This examination is conducted by specially trained specialists in specialised facilities. It requires more repair and replacement parts than the other two categories.

Source: Adapted from Thulasy *et al.* (2021).

While all aviation system maintenance can be classified as corrective, preventive, or surveillance, it can also be classified as scheduled, unscheduled, or condition maintenance.

Impact of Industrial Revolution 4.0 on Aircraft Maintenance

Globally, IR4.0 is projected to transform how people live, work, and communicate; it is also expected to alter what humans value and how they value it in the future. According to the World Economic Forum, 66% of today's high school graduates will work in yet-to-be-established jobs (Schwab *et al.* 2016). Given the importance of data analytics and artificial intelligence in IR4.0, it is more pertinent to replace specific groups of people with new workers who possess the necessary competences or with task-specific robots. New maintenance programs in aviation, as well as in a variety of other engineering domains, represent Industry 4.0 concepts. IR4.0 identifies several critical enabling technologies that will create difficulties for aircraft maintenance. Such advancements as networking, access to massive amounts of data, the ability to delocalize and customise production, networks of connected micro sensors, intelligent and intuitive visualisation of data in remote activities, and computerization are all applicable to manufacturing plants, but also to aviation.

The IR4.0 facilitates the translation of Industry 4.0 concepts from modern to aviation space, thereby assisting with design, maintenance, in-flight structural health monitoring, and flight management. Air transport is a difficult and time-consuming subject to build and maintain (Guyon *et al.* 2019). Valdés *et al.* (2018) state that Industry 4.0 innovations such as automation, IoT, artificial intelligence, cognitive computing, big data analytics, and digitization may result in a shift in the aeronautics industry's outlook, resulting in the development of new instruments to make it more effective and secure. Furthermore, structural health monitoring systems can automatically process data, assess structural condition, and prompt aircraft technicians. On-board health monitoring systems regularly check structural integrity to prevent fault propagation and failure. On-board distributed sensor systems can also reduce maintenance costs by removing time-consuming human inspections and costly disassembly (Farrar and Worden 2007; Roach and Rice 2018).

Thus, aircraft maintenance involving elements of cutting-edge aviation systems necessitates advanced skills and capabilities. Technicians, on the other hand, must upgrade their technical knowledge and abilities in order to undertake the complex obligations associated with aviation maintenance. To maintain modern aircraft, the technical capabilities suggested that appropriate training courses for the workforce were in high need.

Aircraft Maintenance Core Skills

Maintenance technicians come in a variety of forms. They include aircraft mechanics, assistant technicians, and repair workers. The technician's job description may include inspection, repair, modification, service, or aircraft ground handling tasks (Güneş *et al.* 2020). Aircraft maintenance technicians acquire the technical knowledge, abilities, skills, and attitudes necessary to perform work duties in the context of aircraft maintenance and repair operations. The willingness to perform any mission safely and effectively is also regarded an unwritten work requirement for personnel responsible for the RMAF's airworthiness. This tendency is expected to continue, as they have historically developed into a task-based discipline that earned proficiency through instructor-led teaching before becoming proficient at the duties through repetition. As listed in Table 2, an aviation maintenance technician's talents and professional working characteristics should include communication, problem solving, self and time management, cooperation, manoeuvring, judgement, and envisagement.

Table 2. Ideal skills and professional working traits of an aircraft maintenance technician.

Skills	Descriptions
Communication	1. Recognize and comprehend text; 3. Read and grasp work-related papers; 4. Speak clearly to the audience; 5. Write clearly and concisely so others understand ideas; 6. Pay attentive and ask questions.
Problem solving	1. Understand when something is wrong or likely to go wrong; 2. Arrange goods or occurrences according to a plan; 3. Assess ideas' advantages and weaknesses using reasoning; 4. Identify the issue; 5. Use reasoning to solve problems; 6. Compiles data and draws conclusions; 7. Assess the costs and benefits of a proposed activity; 8. Recognize important changes in a system; 9. Focus and avoid distractions when working; 10. Create rules for grouping items.
Self, others, and time management	1. Evaluation of learning or performance; 2. Plan one's and others' time.
Cooperation	1. Adapt ones conduct to others' actions.
Manoeuvres	1. Troubleshoot and fix equipment; 2. Maintain equipment regularly and decide how much maintenance is needed; 3. Identify and resolve technical difficulties; 4. Inspect the machine's gauges, dials, and output for proper operation; 5. Examine and evaluate the product's quality; 6. Identify the necessary tools and equipment.
Judgement and envisagement	1. Visualize how rearranging or moving something will look; 2. Find a pattern in distracting stuff; 3. Quickly compare letters, numbers, objects, photos, and patterns.

Source: Adapted from Baum (2009).

IR4.0 Based Skills in Aircraft Maintenance

It is vital to examine how IR4.0 affects the current organisational structure, what new tasks employees must perform, how they differ from RMAF's, and what additional skills are required to complete them efficiently. The next industrialisation will greatly automate and connect maintenance tasks. Aside from what is already available, external variables impact the equipment, technological advances, and automated systems required. Intelligent systems are linked to maintenance chores, such as intelligent robotics and intelligent transportation. Technology and data handling are required. Job rotation and enrichment are more likely if technology is used more (Liao *et al.* 2017). Skilled technicians can accomplish more. Work that is repetitive and difficult to perform ergonomically is reduced. Technicians must coexist with intelligent machines in the workplace. Although assistant systems will greatly assist, qualified professionals must make final decisions. Teamwork is required not only horizontally and vertically, but also in the actual world using these assistance gadgets. On a daily basis, technicians must process information and data. Humans and machines must collaborate using artificial intelligence, which involves not only button pressing but also speech and gesture. Technology may be controlled using hand phones and tablets. Technicians should be involved in planning, process improvement, and optimization (Lee *et al.* 2018).

In an IR4.0 environment, technicians are expected to perform less manual labour and more process management and monitoring. As the work environment evolves, so do the required abilities and the breadth of the expected tasks (Ra *et al.* 2018). These new skill sets are not meant to be a substitute for existing ones. Rather than that, these additional skills will be required in addition to the existing competencies (Ejsmont 2021).

Maintaining an aircraft, which is a complex piece of equipment, requires proper and thorough training for aviation maintenance workers. The knowledge, skills, behaviours, and attitudes of aircraft maintenance technicians (AMTs) are referred to as competence. Thus, evaluating technicians' abilities is crucial. Topics covered in skill assessments often include subject knowledge, analytical

skill development, decision-making abilities, and overall effectiveness. Aviation human resources often analyse the following conditions: (i) AMT job requirements are outlined in the training syllabus for aircraft maintenance technicians; (ii) the procedures to be employed; (iii) the timing; (iv) the location; and (v) the measures for dynamic that encompass those aspects that will manage judgments based on a person's talents and competency (ICAO 2016).

Nonetheless, many existing frameworks and tools for assessing ability and competence do not explicitly contain all attributes applicable to aircraft maintenance in IR4.0 scenarios. The purpose of this research is to undertake a systematic review of various significant publications on the assessment of aircraft maintenance technician abilities and competency standards and frameworks. This review is expected to discover and determine a set of criteria for skill assessment.

METHODOLOGY

This section details the procedure for conducting the systematic review on how the literature was sourced, which research were deemed relevant, and how the selected papers were reviewed. The process referred to PRISMA approach as a guideline (Page *et al.* 2019). The purpose of this work is to perform a systematic review of the literature in order to address the research objective and research questions listed as follows: Research objective: To identify skill and competency assessment criteria for aircraft maintenance technicians in addressing IR4.0; Research questions: What are the required work skills for aircraft maintenance technicians in addressing IR4.0? What are skills and competency assessment criteria in addressing IR4.0?

Databases Searched

To locate published and acknowledged articles, the most applicable databases and journals were searched. A comprehensive literature search was undertaken in the fields of skills and competencies evaluation, assessment framework development, and aircraft maintenance, utilising peer-reviewed databases, and articles. Scopus, Web of Science, the ACM Digital Library, and Google Scholar were all used as databases. The first two databases are abstract and citation databases that connect to other online resources such as Springer, Emerald, Science Direct, and Wiley Online Library, as well as the IEEE and ACM databases mentioned previously.

Search Terms

The search strings include terms relating to managing and evaluating skill sets and competencies in aircraft maintenance work tasks, such as criteria for skill competency and knowledge management in maintenance, human error in aircraft incidents, and skill assessment and evaluation among aircraft maintenance technicians. The resulting search string was as follows: (skill* OR competenc* OR knowledge OR abilit*) AND (assessment OR evaluation OR appraisal) AND (criteri* OR standard OR component OR design) AND ("Aircraft Maintenance Technician").

These keywords are searched in the abstract, title or keywords of the articles.

Inclusion Criteria and Data Extraction

Several criteria were used to determine which English language publications were relevant. The searches were refined using the four parameters listed below:

- Includes skills and competency (a list of technical talents) as dependent variables, as the focus is on the factors that determine the qualifications of aircraft maintenance technicians;
- Reports on human error situations that need an examination of the aircraft maintenance technicians' skills and competency;
- Consider the influence of determinants of IR4.0-related (digital) skills at the individual worker level;
- Organizational determinants are not discussed (for example, organisational culture and leadership style);
- Are published in a peer-reviewed journal, the most reputable source of scientific information.

Three criteria were used to choose the study. To begin, the titles of all recovered papers were evaluated for eligibility using the aforementioned inclusion criteria. Second, all previously qualifying articles' abstracts were reviewed using the same six identical criteria. Third, the complete texts of all remaining publications were double-checked to ensure they were included. For each article judged significant, data were taken from the full-text article. The authors' names, the date of publication, the journal, the

objectives, the procedure, and the keywords used in the article contexts, as well as the outcomes and conclusion, were all coded for each conceivable manuscript. The papers were coded in order to ensure that only the most vital ones were selected.

Based on the document format and language criteria, the Boolean search activities discovered 161 publications, and three papers were identified as supplementary articles from other sources. These papers are a compilation of database articles and skill-related technical materials. Six from 164 papers in the databases were duplicates, resulting in 158 unique articles being reviewed. After screening the titles and abstracts, the entire texts of 25 papers were thoroughly examined, 15 of which met all inclusion criteria. Figure 1 illustrates the selection flowchart. Since the references in the included articles did not relate to the supplied data, no more records from other sources were discovered. There were five reasons for not conducting a full-text screening on additional sources: (a) there is no dependent variable for skills; (b) there is no entire text; (c) there is no independent variable; (d) there is no quantitative analysis; and (e) there is no directional influence.

The following characteristics were gathered: (1) author and year; (2) study purpose; (3) methodology; (4) data collecting; and (5) criteria for skill assessment. The following technique was used to analyse the extracted data:

- Purpose: This attribute describes the article's or study's objective, which is to educate readers about the skill evaluation framework, professional qualities and standards, engineering and aircraft maintenance skills and competencies related to IR4.0, as well as knowledge and skill training modules;
- Methodology: This attribute denotes the research methodology or techniques used to investigate skills and evaluation in each study, which may include observations, surveys, prioritisation, systematic reviews, ethnography, training mapping, and descriptive analysis;
- Data collection: This property outlines the technique for data collection as well as the categories of respondents;
- Assessment criteria for skills: This attribute elaborates on the articles' sections or components, such as technical knowledge, communication, visual, critical thinking, and information and communications technology (ICT), to mention a few.

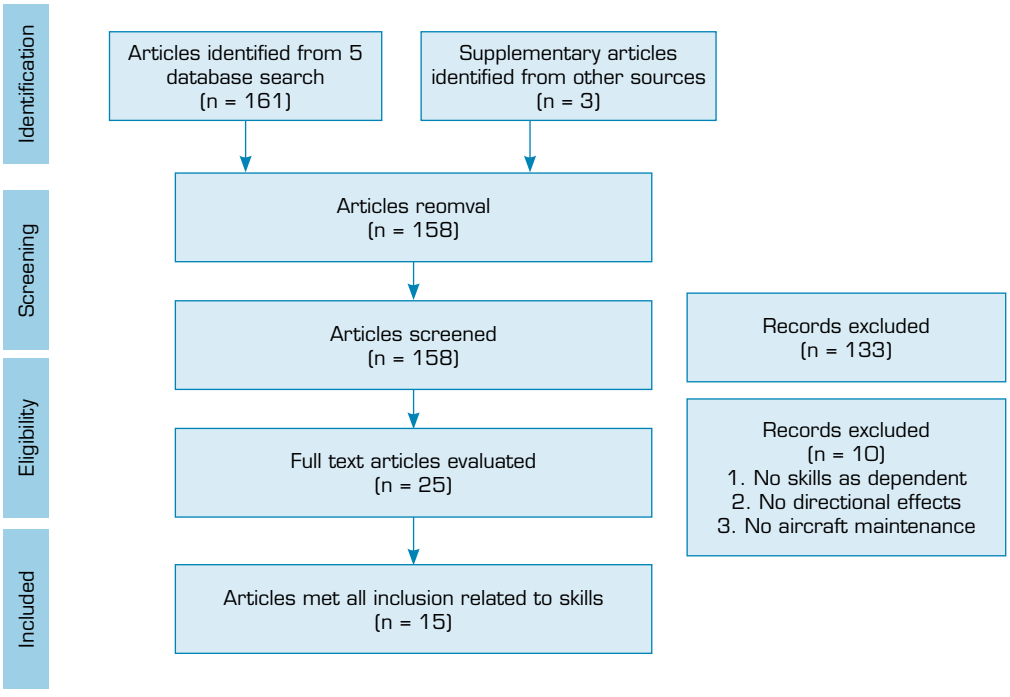

Figure 1. Article Selection flowchart of information through the different phases of the systematic review.

Data Analysis

Manual screening of the selected articles began with reading the title and abstract and using the previously indicated inclusion criteria. The following step was to exclude duplicate articles that were discovered in Scopus but appeared in one of the other three

databases. Finally, each study that had been selected was subjected to an exhaustive examination with three goals in mind. To begin, locate and delete any work that appears to be related but is not included in the title or abstract. Second, duplicate works that are published as distinct articles but contain skills and competency in aircraft maintenance, IR4.0-related aviation skills, and skills assessment difficulties in aircraft maintenance should be identified and eliminated. Finally, all data necessary to accomplish the study's objectives was extracted.

RESULTS AND DISCUSSION

The content analysis of the 15 articles selected is summarized in Table 3. The analysis discusses the purpose of the study, the methods utilized to collect data, and the proposed skill assessment criteria employed in their studies. Most studies evaluate maintenance personnel using standard criteria for skill and competency assessment. These studies address partial skill assessment criteria that place a greater emphasis on the technician's technical abilities and knowledge. Nevertheless, Lappas and Kourousis (2016) and Jasiulewicz-Kaczmarek and Gola (2019) emphasized the critical nature of 21st-century and IR4.0-based abilities for enabling intelligent and sustainable aircraft maintenance work activities.

Table 3. Fifteen papers in-depth analyses.

Author (year)	Purpose	Method	Data Collection	Skills Assessment Criteria
Günes *et al.* (2020)	Develop and apply the assessment processes.	Direct observation, tracking records review and analysis of quality control records, safety management system records review and analysis, comparison of technician performance.	Aircraft maintenance technician.	Systematic observations; Maintenance records; Quality control records; SMS records.
Gorbachev *et al.* (2019)	Develop professionally relevant attributes in future professionals during the training stage.	Survey analysis using probabilistic and statistical methods to identify professionally good attributes of aviation maintenance personnel.	Professional and aviation technician.	Professional indicator.
Shanmugam and Robert (2015a)	Compare maintenance service quality in airline is closely proportional to its fleet size.	Priorities the decision criteria, and using the analytical hierarchy process to priorities important functions and rank the maintenance companies under consideration.	Civil Aviation Authority (CAA) and industry personnel.	The entire performance of the aviation maintenance system is represented by eight decision criteria.
Mohd Kamaruzaman *et al.* (2019)	Compare present engineering skills with the new technologies required for IR4.0.	Systematic review to track, evaluate and synthesis approach for reviewing past studies on engineering skills	Data synthesis from ProQuest; Science Direct; Wiley; Taylor and Francis; IEEE.	Thinking analytically and innovating; Active and learning tactics; Creativity, inventiveness, and initiative Design and programming of technology; critical thinking and analysis; emotional intelligence; System evaluation and analysis
Lappas *et al.* (2016)	Translate and skills to the university classroom for aviation industry personnel.	The assessment and teaching of 21st century capabilities project focuses on identifying such skills and developing methods for teaching them.	Skills for the twenty-first century; pedagogical issues; technology factors; classroom's evaluation; policy frameworks and new assessments.	Creativity and invention; critical thinking; problem solving and decision making; communication; teamwork; content knowledge; and ICT literacy are all important.

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Table 3. Continuation.

Author (year)	Purpose	Method	Data Collection	Skills Assessment Criteria
Wahbi (2015)	Investigate the importance of human skills on aviation maintenance workers' performance.	The survey, used to collect the relevant data. Used of quantitative strategy.	Employees of (JALCo), a company located in Amman.	Behavioural competencies; functional competencies; managerial competencies; performance level.
Manjunath *et al.* (2019)	Examine the skill gap as well as the link between skills and performance.	A structured questionnaire was carried out at Sanria Engineering and Consulting Pvt Ltd., Mysuru based on simple random sampling technique.	Questionnaires five-point Likert scale.	Communication, technical, problems solving, interpersonal, decision-making skills.
Tsagkas *et al.* (2014)	Analyse 12 incidents of departures from approved procedures during scheduled/ unscheduled maintenance checks performed by a Greek aircraft major sector.	Using an ethnographic method, we were able to uncover deviant behaviour during maintenance inspections and examine the reasons that contributed to these deviations.	12 individual cases.	The discovered criteria varied from the most normative (manuals) to the most contextual (personal comfort, schedule pressures).
Stadnicka *et al.* (2017)	Create a strategy for and schedule for aircraft maintenance tasks.	A mathematical model created to reduce the lead time of maintenance procedures while taking into consideration operator competence requirements.	54 groups of activities in an aircraft maintenance.	Hall's marriage theorem is used to define complicated limits on multiskilled operator assignment.
Lin *et al.* (2018)	Develop competency mapping method based on conceptual maps for training in the aviation industry.	Developed training modules using concept maps based on existing approaches and procedures.	100 clients, many of them were heavy industry engineers, managers, and directors of operations.	Visual representation of the task and proposed solution interpretation.
Shanmugam and Robert (2015b)	Present a survey of the literature on human aspects in aircraft maintenance, as well as interpret and synthesize the findings.	Broad areas of aircraft maintenance rules have been recognized, and each area has been investigated in order to determine the level of scientific advancement and publications.	Scientific journal articles, research reports, books, and conference proceedings; on the regulatory framework.	In aircraft design, manufacture, operations, and maintenance, human factors principles are used extensively.
Jasiulewicz-Kaczmarek and Gola (2019)	Describe the most recent developments in maintenance management, starting with the IR4.0 challenges and the economic, environmental, and social problems of sustainable development.	Intelligent and sustainable maintenance was considered in three perspectives. Historical, development and maintenance perspective.	Based on literature review of journals.	Technical knowledge intelligent and sustainable maintenance was considered in three perspectives.
Puspita *et al.* (2020)	Provide learning outcomes for the Avionics programme in the aircraft maintenance training organization's curriculum application as aviation maintenance professionals.	Descriptive analysis method in describing problems.	New graduates of the Diploma 3 Avionics study programme University of Nurtanio Bandung.	Attitude; general skills; special skills; knowledge.

Continue...

Table 3. Continuation.

Author (year)	Purpose	Method	Data Collection	Skills Assessment Criteria
Watkins *et al.* (2016)	Examine how professionals in the aviation sector see the link between Education, Certification and Experience (ECE) and the development of their knowledge skill and ability (KSA).	The link between aviation industry experts is investigated using mixed methods concurrent triangulation. In the aviation industry, ECEs and KSAs are necessary.	404 professionals worked in the aviation industry.	Knowledge, skills, and abilities in relation to education, certification, and experience.
Rifai *et al.* (2021)	Mapping to strengthen human factor training material AMT with HFACS.	Data from online surveys will be analysed using the HFACS in this descriptive research.	Surabaya Aviation Polytechnic graduated 410 aircraft maintenance technicians.	Human Factors Analysis and Classification System (HFACS).

The findings indicate that skills and determinant categories should be explored for the purpose of identifying research gaps that will aid in maintaining a focus on improving and tracking the required skills assessment components or criteria for aircraft maintenance workforce in the era of IR4.0.

The seven criteria for evaluating aircraft maintenance technician skills and competency based on IR4.0 that were identified in this study through systematic evaluations are depicted in Fig. 2. These criteria are believed to provide valuable scopes and boundaries for implementing methods, instruments, or mechanisms for evaluating an individual's technical capabilities and proficiency acquisition, transfer, and development develop (Güneş *et al.* 2020). As a result, management may evaluate the effectiveness and efficiency of training and certification programmes within the RMAF talent management framework.

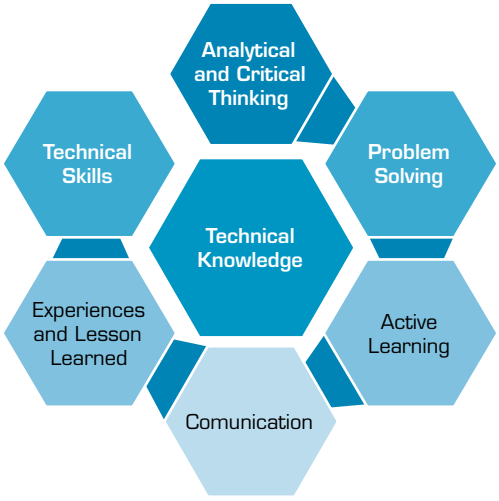

Figure 2. Aircraft maintenance technician skills and competency assessment criteria based on IR4.0.

Technical Knowledge

Knowledge labour includes information processing and knowledge development, putting the knowledge worker, in this case aircraft maintenance personnel, front and centre. Expertise and information are the most significant resources for knowledge workers in an ever-changing society. The working climate of an aircraft maintenance technician is evaluated. It shows the benefits of obtaining certifications to exhibit proficiency in a certain field. The importance of establishing integrity on a curriculum vitae cannot be emphasised. Certifications can be used to build an organised training curriculum and improve workers' skills (Watkins *et al.* 2016). According to Puspita *et al.* (2020), one of the dimensions and representations of learning

results is awareness. To invent or combine aviation science and technology, employees must be logical, critical, meticulous, and imaginative (Stadnicka *et al.* 2017).

Analytical and Critical Thinking

Many individuals confuse analytical and critical thinking; however, this is not true. Analytical thinking is the process of reducing difficult knowledge down into smaller, more accessible components or concepts. Improving knowledge or providing evidence-based judgments requires modifying data. For example, to make sensible decisions, critical thinking requires analysing and assessing information or points of view. Recurring process in which one goes back and forth between information to form an opinion, foster a belief, or simply decide what is true or logical. The IR4.0 has a large gap in the demand for ability mastery, according to Mohd Kamaruzaman *et al.* (2019), technicians' competencies should improve in the years ahead. It was evident that prior knowledge was required. Table 3 shows early exposure to the need to learn new skills so that their talents are still useful to IR4.0 concerns. The third stage involves selecting specific aircraft maintenance task basic criteria using either a multi-criteria decision model or a heuristic decision model, as stated by Shanmugam and Robert (2015a) personnel in the future aircraft sector is expected to work in more diverse contexts (multidisciplinary, multi-site and multi-cultural). These soft talents will likely be important success factors throughout their prolonged careers (Lappas *et al.,* 2016; Lin *et al.,* 2018).

Active learning

Active learning is a style of training where participants debate course content to solve difficulties. Even if active learning places more responsibility on technicians than passive learning methods like lectures, instructor training is still vital. Thus, when evaluating the technicians, it is necessary to consider for ongoing learning progress. Aspects of active learning were also noted by Kamaruzaman *et al.* (2019).

Problem solving

Problem solving skills help aircraft maintenance technicians solve issues rapidly. Problem-solving is a personal strength, not a skill acquired through work or life experiences. Problem-solving skills will improve as workers become more familiar with workplace upkeep and repairs. As stated by Shanmugam and Robert (2015b), the evaluation and training of 21st century skills project is used as a baseline for identifying the developing *problem-solving* capacity set. Effective organisations, according to Manjunath *et al.* (2019) strengthen problem-solving skills. The ability of employees to deal with challenging events is crucial to the organization's success. As a result, many companies use leadership programs to help employees solve problems. While technology has constrained workers' problem-solving abilities, new skills have emerged.

Communication

Communication is the act of transmitting information from one place to another. It can be expressed orally, visually, or nonverbally. In practise, it is usually a mix of all three. To communicate effectively with a broad group of people, you must actively listen, express your views correctly, write clearly and concisely, and work well in a group. Because every action requires communication, communication research is vital for both employers and employees. Thus, communication affects individual and organisational effectiveness. Effective communication improves efficiency and fosters good working relationships at all levels of an organisation. A good communication system fosters positive relationships among employees, leading to increased productivity. In the future, the aircraft sector will need people who can communicate effectively. The significant transformation in the aviation sector today. One example is cross-border outsourcing of services. Team members can even work from home on the same project (Manjunath *et al.* 2019).

Experiences and Lesson Learned

People with extensive expertise in the aviation sector have a distinct advantage over those who do not. Use technicians' skills to troubleshoot difficulties on all linked systems on the aircraft. Moreover, working experiences and lessons learnt generate a strong individual tacit knowledge. Context influences the aviation maintenance technician's overall behavioural competence. The technicians concluded that there was a strong connected and strong linkage between the three behavioural, functional, and management competencies and employee productivity. Wahbi (2015) highlights the importance of behavioural competence was a strong interrelated and strong connection between the three behavioural, functional, and managerial competencies and the employee productivity.

Technical Skills

Competence in using specialised knowledge or skills to perform a task. Technical skills are defined as the ability of one unit of labour to convert data into output, and that handling complicated problems takes technical experience. Management should encourage employees to develop their technical capabilities. However, technology alone cannot increase staff productivity. Many studies have emphasised the importance of technical skills, but workers must have both technical and soft skills to succeed (Al Asefer and Abidin 2021; Manjunath *et al.* 2019; Patacsil and Tablatin, 2017). Preparation or acquiring aircraft maintenance training at a college or credential body can help a person become a qualified technician. Aircraft maintenance professionals are trained in fundamental and specific technical skills (Puspita *et al.* 2020).

In summary, the above criteria are crucial for evaluating aircraft maintenance technicians' skills. Gorbachev *et al.* (2019) stressed the importance of the technicians' demands and impacts during their training. Throughout the research procedure, the circumstances and characteristics of their origin, development, and assessment were determined.

CONCLUSION

An aircraft maintenance technician completes a difficult job. Technicians execute aircraft maintenance must have a varied set of skills and competencies. This study reviewed 15 journal articles and technical reports on aircraft maintenance technicians' skill and competency assessment. The authors used PRISMA methodology to perform the systematic review which was intended to answers two research questions: (i) What are the required work skills for aircraft maintenance technicians in addressing IR4.0? and (ii) What are skills and competency assessment criteria in addressing IR4.0?

Seven skill assessment criteria, namely technical knowledge, analytical and critical thinking, active learning, problem solving, communication, and experiences and lessons learned, were identified in order to create a comprehensive skill assessment framework based on the formal qualifications of aircraft maintenance technicians when it comes to addressing IR4.0. These criteria were analysed methodically in order to determine the inclusive scopes of each.

The research will continue to emphasize the importance of developing a competency-based skill assessment and training mapping model for aviation maintenance personnel in order to address IR4.0 and skill mismatch or gap challenges in aircraft maintenance personnel.

AUTHORS' CONTRIBUTION

Conceptualization: Thulasy N, Nohuddin PNE, Nusyirwan IF, Abd Rahim N and Amrin A; **Methodology:** Thulasy N, Nohuddin PNE and Nusyirwan IF; **Software:** Thulasy N and Nohuddin PNE; **Validation:** Nusyirwan IF; **Formal analysis:** Thulasy N and Nohuddin PNE; **Investigation:** Thulasy N and Nohuddin PNE; **Resources:** Thulasy N, Nohuddin PNE, Nusyirwan IF, Abd Rahim N and Amrin A; **Data Curation:** Thulasy N and Nohuddin PNE; **Writing – Original Draft:** Thulasy N and Nohuddin PNE; **Writing – Review & Editing:** Nusyirwan IF, Nohuddin PNE and Chua S; **Visualization:** Chua S; **Supervision:** Nusyirwan IF, Abd Rahim N and Amrin A; **Project administration:** Thulasy N, Nohuddin PNE, Nusyirwan IF, Abd Rahim N and Amrin A.

DATA AVAILABILITY STATEMENT

All data sets were generated or analysed in the current study.

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REFERENCES

Al Asefer M, Abidin NSZ (2021) Soft skills and graduates' employability in the 21st century from employers' perspectives: A review of literature. International Journal of Infrastructure Research and Management 9(2):44-59.

Aziz A (2018) Sixty and beyond — RMAF plans more upgrades. The Malaysian Reserve. [accessed Jul 15 2021]. https://themalaysianreserve.com/2018/06/04/sixty-and-beyond-rmaf-plans-more-upgrades/

Balaraman P, Kamalakannan P (2016) Skill gap analysis and training needs in Indian aerospace industry. J Airl Airpt Manag 6(2):115-132. https://doi.org/10.3926/jairm.56

Baum MS (2009) Aviation maintenance technicians model code of conduct. Aviators Code Initiative. [accessed Jul 29 2021]. https://www.secureav.com/AMTMCC-v1.0.htm

Ejsmont, K (2021) The impact of Industry 4.0 on employees — Insights from Australia. Sustainability 13(6):3095. https://doi.org/10.3390/su13063095

Farrar CR, Worden K (2007) An introduction to structural health monitoring. Phil Trans R Soc A 365:303-315. https://doi.org/10.1098/rsta.2006.1928

Gehrke L, Kühn A, Rule D, Moore P, Bellmann C, Siemes and Standley M (2015) A discussion of qualifications and skills in the factory of the future: A German and American Perspective. Düsseldorf, Washington (DC): Association of German Engineers, American Society of Mechanical Engineers.

Gorbachev O, Shestakov V, Stefański K (2019) Assessment of professionally important qualities aviation technical staff. AIP Conf Proc 2077(1):020022. https://doi.org/10.1063/1.5091883

Güneş T, Turhan U, Açıkel B (2020) An assessment of aircraft maintenance technician competency. Int J Aviat Sci Tecnol 1(1):22-29.

Guyon I, Amine R, Tamayo S, Fontane F (2019) Analysis of the opportunities of Industry 4.0 in the aeronautical sector. Paper presented 10th International Multi-Conference on Complexity, Informatics and Cybernetics. Hall Science Ouverte; Paris France.

[ICAO] International Civil Aviation Organization (2016) Doc 9868, Procedures for Air Navigation Services — Training. 2nd edition. Quebec: ICAO. [accessed 18 Sept 2021]. https://www.icao.int/sam/documents/2016-cbt/module%204-3%20doc%209868.alltext.incl%20amdt%204.pdf

Jasiulewicz-Kaczmarek M, Gola A (2020) Maintenance 4.0 technologies for sustainable manufacturing – An overview. IFAC PapersOnLine 52(10):91-96. https://doi.org/10.1016/j.ifacol.2019.10.005

Kamaruzaman FM, Hamid R, Mutalib AA, Rasul MS (2019) Conceptual framework for the development of 4IR skills for engineering graduates. Glob J Eng Educ 21(1):54-61.

Lappas I, Kourousis KI (2016) Anticipating the need for new skills for the future aerospace and aviation professionals. J Aerosp Technol Manag 8(2):232-241. https://doi.org/10.5028/jatm.v8i2.616

Lee M, Yun JJ, Pyka A, Won D, Kodama F, Schiuma G, Park H, Jeon J, Park K, Jung K, Yan M-R, Lee S, Zhao X. How to respond to the Fourth Industrial Revolution, or the Second Information Technology Revolution? Dynamic new combinations between technology, market, and society through open innovation. J Open Innov Technol Mark Complex 2018; 4(3):21. https://doi.org/10.3390/joitmc4030021

Liao Y, Loures ER, Deschamps F, Brezinski G, Venâncio A (2017) The impact of the Fourth Industrial Revolution: A cross-country/region comparison. International Journal of Production Research 28:e20180061. https://doi.org/10.1590/0103-6513.20180061

Lin Y, Shahhosseini AM, Jankex C (2018) Board 58: Concept map-based aviation competency mapping and training. Paper presented 2018 ASEE Annual Conference and Exposition. American Society for Engineering Education; Salt Lake City, Utah. http://doi.org/10.18260/1-2--30063

Manjunath S, MB Shravan, Dechakka BB (2019) A study on assessment of skill gap to enhance workforce performance. International Journal of Management, Technology and Engineering 21(4):3561-3576.

Olaganathan R, Miller M, Mrusek BM (2020) Managing safety risks in airline maintenance outsourcing. Int J Aviat Aeronaut Aerosp 7(1):7. https://doi.org/10.15394/ijaaa.2020.1435

Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, Shamseer L, Tetzlaff JM, Akl EA, Brennan SE *et al.* (2021) The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. Syst Rev 10:89. https://doi.org/10.1186/s13643-021-01626-4

Patacsil F, Tablatin C (2017) Exploring the importance of soft and hard skills as perceived by IT internship students and industry: A gap analysis. Journal of Technology and Science Education. 7. 347. 10.3926/jotse.271.

Puspita H, Ana A, Wulandari IY, Andriana D (2020) The evaluation of the learning curriculum of the aircraft maintenance training organization 147 for avionic study program as a basis in meeting the need of the aviation industry. J Eng Educ Transform 34(Special Issue):26-31. https://doi.org/10.16920/jeet/2020/v34i0/157848

Ra S, Shrestha U, Khatiwada S, Seung WY, Kwon K (2019) The rise of technology and impact on skills. Int J Train Res 17:sup1, 26-40, https://doi.org/10.1080/14480220.2019.1629727

Rifai M, Setyio A, Suprapto Y, Harianto BB, Irfansyah A (2021) HFACS for mapping strengthening human factor training material on prospective aircraft technicians. J Phys: Conf Ser 1845:012076

Roach D, Rice T (2018) Addressing technical and regulatory requirements to deploy structural health monitoring systems on commercial aircraft. Paper presented ICAS 2018. International Council of the Aeronautical Sciences. Belo Horizonte, Brazil. [Aug 21 2021]. https://www.osti.gov/servlets/purl/1806775

Saltoğlu R, Humaira N, İnalhan G (2016) Aircraft scheduled airframe maintenance and downtime integrated cost model. Adv Oper Res 2016:2576825. https://doi.org/10.1155/2016/2576825

Schumacher A, Erol S, Sihn W (2016) A maturity model for assessing Industry 4.0 readiness and maturity of manufacturing enterprises. Procedia CIRP 52:161-166. https://doi.org/10.1016/j.procir.2016.07.040

Schwab K, Samans R (2016) The future of jobs employment, skills and workforce strategy for the fourth industrial revolution. World Economic Forum. [accessed Feb 01 2022]. http://www3.weforum.org/docs/WEF_Future_of_Jobs.pdf

Shanmugam A, Robert TP (2015a) Ranking of aircraft maintenance organization based on human factor performance. Comput Ind Eng 88(C):410-416.https://doi.org/10.1016/j.cie.2015.07.017

Shanmugam A, Robert TP (2015b) Human factors engineering in aircraft maintenance: A review. J Qual Maint Eng 21(4):478-505. https://doi.org/10.1108/JQME-05-2013-0030

Stadnicka D, Arkhipov D, Battaïa O, Ratnayake RMC (2017) Skills management in the optimization of aircraft maintenance processes. IFAC-PapersOnLine 50(1):6912-6917. https://doi.org/10.1016/j.ifacol.2017.08.1216

Thulasy TN, Nohuddin P, Abd Rahim N, Amrin A (2021) Skill set issues in aircraft maintenance from Industrial Revolution 4.0 context: A document analytics survey. Hum Syst Manag 41(4):503-516. https://doi.org/10.3233/HSM-210013

Tsagkas V, Nathanael D, Marmaras N (2014) A pragmatic mapping of factors behind deviating acts in aircraft maintenance. Reliab Eng Syst 130:106-114. https://doi.org/10.1016/j.ress.2014.05.011

Valdés RA, Comendador VFG, Sanz A, Castán JP (2018) Aviation 4.0: More safety through automation and digitization. In: Kuşhan MC, editor. Aircraft Technology. London: IntechOpen. https://doi.org/10.5772/intechopen.73688

Wahbi YI (2015) Impact of human competencies on aviation maintenance employees' performance. (A case study at JALCo) (master's thesis). Amman, Jordan: The Middle East University. [accessed Jul 15 2021]. https://meu.edu.jo/libraryTheses/5873692c5fbf0_1.pdf

Watkins D, Newcomer JM, Earnhardt MP, Marion JW, Opengart RA, Glassman AM (2016) A cross-sectional investigation of the relationships education, certification, and experience have with knowledge, skills, and abilities among aviation professionals. Int J Aviat Aeronaut 3(1):6. https://doi.org/10.15394/ijaaa.2016.1101

Yusof I, Rahim ARA (2017) Aircraft acquisition conceptual framework. Asian Social Science 13(4):37-64. https://doi.org/10.5539/ass.v13n4p37

Zainal K, Abu Talib AR, Hack I (2015) Malaysian Aerospace Industry Blueprint 2030: Cruising into a complete Aero-systems life cycle. Cyberjaya: Malaysian Industry Government Group for High Technology.