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Towards new educational standards for aircraft maintenance: analysing transversal competencies on industry safety priorities and assessment challenges

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ABSTRACT

The aviation industry is one of the most regulated industries in the world; safety is its overriding objective. In Europe, aviation maintenance training regulations rely on time-based technical experience and theoretical multiple-choice exams for a basic aircraft maintenance licence. The aviation industry and authorities are exploring the incorporation of competency-based training and assessment to keep pace with the rapidly evolving aviation industry. However, the shift from traditional time-based to competency-based education presents challenges for vocational education and training in aircraft maintenance, particularly as the assessment of transversal competencies is a newly introduced element. This study centres on transversal competencies in aircraft maintenance, aiming to uncover priorities and obstacles for training and assessing these competencies in aircraft maintenance education. Survey results from 141 aviation experts revealed that transversal competencies involving communication, teamwork, and work management are viewed as the most important transversal competencies, with communication rated highest χ^2 (2) = 16.2, $p < .001$. In addition, four observable behaviours from these competencies were identified as most important, yet most challenging to assess during education. These findings highlight crucial areas and thus bring focus to developing new, competency-based, educational programmes for aviation maintenance.

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SUBJECTS
Social Sciences; Education; Curriculum Studies; Science Education; Social Sciences; Education; Social Sciences; Education; Higher Education

Introduction

The aviation industry is heavily regulated to ensure global aviation safety. The International Civil Aviation Organization (ICAO) is a United Nations agency that sets the international standards and guidelines for aviation related topics, for instance, the licensing of personnel, aircraft operations, aircraft airworthiness and aircraft accident & incident investigations. Within these standards, the European Union Aviation Safety Agency (EASA) creates aviation regulation for all EU member states on behalf of the European Commission. In Europe, the most common routes to become an aircraft maintenance technician are apprenticeships within airlines or aviation maintenance organisations, or through a Vocational Education and Training (VET) programme for aircraft maintenance at VET schools.

Over the last few decades, numerous technological advances and innovations have made the aviation industry safer, cleaner and more efficient (EASA, 2023; Stamoulis, 2022). This is expected to evolve in the upcoming decades (Prentice et al., 2017). Paradoxically, the educational approach for aviation professionals working in this advanced environment, does not appear to have developed accordingly. For example, current EASA regulations for aircraft maintenance to obtain an Aircraft Maintenance License (AML) are hours-based, focusing on theoretical knowledge, using written multiple-choice assessment

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methods. This educational approach, however, may be less suitable to adequately prepare aircraft technicians to operate in today's complex working environment (EASA, 2023; Gunes et al., 2020; ICAO, 2020; Kearns et al., 2016). The aircraft maintenance industry recognises that education should be more competency-based with a holistic approach to prepare aircraft technicians for working in this complex, constantly changing industry (Airbus, 2022; Boeing, 2022; Kearns et al., 2016; Zylawski & Ma, 2023). In response to this, ICAO has introduced competency frameworks for aviation personnel in safety-critical activities that demand specialised education and licensing (ICAO, 2020, 2021). These frameworks aim to establish new standards, addressing this very challenge. Currently, ICAO is exploring potential amendments to the standards for licensing aircraft maintenance personnel to allow for the future incorporation of Competency-Based Training and Assessment (CBTA). Technical knowledge and skill requirements will be maintained, however, the most impactful amendment of these new standards for CBTA is the replacement of time-based requirements by competencies, creating challenges for the education and assessment of new aviation professionals. Therefore, to facilitate the implementation of CBTA, ICAO has already published several documents for the industry to support the transition. This will be briefly outlined below.

In *ICAO Doc 9868 Procedures for Air Navigation Services-Training* (PANS-TRG 2020) ICAO provides standards, procedures, and guidelines to the aviation industry for the implementation of CBTA in various aviation domains. *ICAO Doc 10098 Manual on Competency-based Training and Assessment for Aircraft Maintenance Personnel* (2021) further assists educational experts to structure a CBTA approach for aircraft maintenance. ICAO's competency framework for Aircraft Maintenance Personnel (AMP) articulates 11 competencies, with, for each competency, several Observable Behaviours (OBs) reflecting the mastery of that particular competency. In total there are 89 OBs articulated in the competency framework for aircraft maintenance.

Despite ICAO's efforts to introduce CBTA, there is little documented experience with CBTA in aviation maintenance education. Already in 2016, Kearns et al. (2016) stated that focusing on hours and multiple-choice questions appears more convenient and easier to manage for the industry and regulators, and little developments appear to have taken place since. Hence, the paradigm shift from traditional education to CBTA challenges the industry in determining qualifying threshold for competencies. Therefore, the main challenge in CBTA is the assessment. From a licensing perspective, the shift to CBTA demands a clear understanding of the evidence needed to determine if candidates meet the required standards based on the OBs. In this light, this study centres on elucidating the focal points and obstacles tied to competency assessment based on ICAO's competency framework for AMP. In the next section, the authors explain the current definitions and use of competencies in aviation to illustrate the need for clear assessment methodologies and why the focus of this study lies on transversal competency assessment.

Competency definitions within the international aircraft maintenance industry

Both inside and outside the international world of aviation, there is no formal agreement on the definitions of 'competence' and 'competency' (Guerrero & De los Ríos, 2012; Kearns et al., 2016; Le Deist & Winterton, 2005; Moore et al., 2002; Mulder et al., 2007; Stoof et al., 2002; Wong, 2020). Also, many languages do not make this distinction and have only one word for this concept. As a result, the terms are used interchangeably in international contexts. Within aviation, ICAO has created a clear definition for 'competency':

> *'A dimension of human performance that is used to reliably predict successful performance on the job. A competency is manifested and observed through behaviours that mobilize the relevant knowledge, skills and attitudes to carry out activities or tasks under specified conditions'* (ICAO, 2020, I-1-2).

The Civil Aviation Authority of the United Kingdom (CAA UK) uses 'competence' and 'competency' interchangeably, defining both as *'a measurable skill or standard of performance, knowledge and understanding, which takes into account attitudes and behaviours'* (CAA, 2019, 3). Nonetheless, the CAA UK recognises the importance of attitudes and behavioural elements in the performance of maintenance, providing guidance to aviation organisations on how to conduct competency assessments (CAA, 2019).

The Federal Aviation Administration (FAA) of the United States of America defines 'competency' as *'a combination of skills, knowledge, and observable behaviours required to perform a task to the prescribed standard'* (FAA, 2019, 15535), but they refer to ICAO's definition as well (FAA, 2019).

Within the European Union (EU), the regulations for Continuing Airworthiness of EASA do not adopt the definition of ICAO, but instead define 'competence' the same as the CAA UK does, and 'competency' as *'a combination of individual skills, practical and theoretical knowledge, attitudes, training and experience'* (EASA, 2022, 986). Initial guidance on CBTA is being developed, this will be explained in the next section.

In this study, the authors chose to use ICAO's definition of 'competency' since ICAO's competency framework for AMP forms the basis of this study.

EU regulations for aircraft maintenance education

For this research, the authors focus on the European educational context. In this section, the current EASA regulations and their limitations with respect to CBTA are discussed.

Although EASA provides acceptable means of compliance and guidance material on competency assessment (EASA, 2022), there are no behavioural or attitudinal standards articulated. Regarding the evaluation of competence, knowledge, skills, attitudes, performance standards, conditions and environmental awareness are mentioned and it is stated that performance during an assessment should cover the learning objectives of the educational programme. For a basic licence, EASA articulates: *'The practical assessment element shall cover the practical training and determine whether the student is competent at using tools and equipment and working in accordance with maintenance manuals'* (EASA, 2022, 841).

The theoretical requirements are extensively prescribed. These requirements mainly cover the technical knowledge aspects. As explained earlier, EASA currently still maintains a time-based approach for practical experience to be deemed competent. Theoretical knowledge is summatively assessed through multiple-choice question formats with a passing threshold of 75% with a limited number of subjects being assessed using one or two essay questions. Currently, CBTA is not explicitly mentioned or defined in EASA's guidance material and regulations regarding theoretical test construction only prescribe the number of questions per module, the number of answer options per multiple-choice question, simplicity of grammar, and avoiding double negatives. The few essay questions aim to assess candidates' clear and concise expression in technical language, with specific guidance on scoring for content and format. With reference to basic knowledge, three knowledge levels are defined, varying by the licence category applied for: Level 1 implies familiarity with fundamental subject elements, Level 2 entails general knowledge of theory and practice, while Level 3 represents the ability to integrate and apply in-depth knowledge of practical and theoretical aspects.

Although the current approach aligns with the time and knowledge-based standards and regulations, when transitioning to CBTA, where behaviour is being assessed, literature shows that this approach is no longer suitable (Carraccio et al., 2016; McClelland, 1973; Miller, 1990; Spencer & Spencer, 1993; Van Berkel et al., 2017). The assessment of performance entails a paradigm-shift in both education and assessment. Already since the early nineties, educational literature is critical of multiple choice assessments for this purpose. Scores on knowledge tests have been shown to be very limited in their ability to predict performance (Spencer & Spencer, 1993), and tend to encourage a surface learning approach by the student (Scouller, 1998). Therefore, they are mostly applied for lower taxonomy levels of understanding (Scouller, 1998; Simkin & Kuechler, 2005; Van der Vleuten, 1996).

Benchmarking EASA regulations against new ICAO procedures reveals that EASA focuses heavily on regulating technical knowledge, skills, and time requirements, while ICAO introduces a holistic approach, balancing knowledge, skills, and attitudes by defining competencies and observable behaviours rather than time requirements.

Because technical requirements are already extensively prescribed, and these will stay relevant in the future, the authors believe that to support an effective shift towards CBTA within the EU, more focus is needed on developing educational methodologies for the non-technical competencies within ICAO's competency framework: the Transversal Competencies (TVCs). In the next section, a more detailed explanation of TVCs will be given.

Transversal competencies

Similar to 'competence' and 'competency', the term holds various interpretations in education and learning, leading to a range of terms in the literature describing this concept (Bray et al., 2020; Caeiro-Rodriguez et al., 2021; Cheetham & Chivers, 1998; Cruz et al., 2020; De Freitas & Almendra, 2021; Devika et al., 2020).

In their report about 'key-competencies', the Organisation for Economic Co-operation and Development (OECD, 2005) labels TVCs as competencies that affect labour market, private relationships and societal and political engagement. In their competency framework for key TVCs, they centralise both reflection and autonomy and how they are related; reflection on one's actions and values is an important prerequisite to act autonomously.

TVCs are generally characterised as higher-order, not subject-specific, and multi-dimensional (Bray et al., 2020; Fahrenbach et al., 2020). TVCs involve a high degree of attention and gravity of knowledge and skill application (Winch, 2013). They are related to self-management, autonomy, teamwork, problem-solving and communication (Winch, 2013; Winch & Addis, 2022). Although these competencies are not automatically transferable (Winch & Addis, 2022), it is argued that TVCs make employees more flexible and adaptable to changing working circumstances (Calero López & Rodríguez-López, 2020; European Centre for the Development of Vocational Training, 2020; Fahrenbach et al., 2020; McMasters & Komerath, 2005; Villardón-Gallego et al., 2020; Winch & Addis, 2022). Similar to the OECD, Villardón-Gallego et al. (2020) refer to TVCs as life competencies, essential for personal development, social inclusion, and employment. Others also associate the concept of TVCs with features such as creativity, innovation, learning to learn, initiative, reflection, responsibility, perseverance, self-direction, critical thinking and goal-oriented behaviour (Bray et al., 2020; Calero López & Rodríguez-López, 2020; Cheetham & Chivers, 1998; Craps et al., 2022; Eizagirre Sagardia et al., 2018; Guerrero & De los Ríos, 2012). Unlike Winch and Addis (2022), Telha et al. (2016), Moldovan (2020) and Villardón-Gallego et al. (2020) state that TVCs can be developed in one context and transferred to another context as they are relevant in many professional, social and life settings.

To illustrate TVCs within an aviation context, Telha et al. (2016) identified 45 different TVCs for the Portuguese Airforce, grouped into six different categories: Individual Excellence, Military Skills, Operational Skills, Strategic Skills, Results and Courage. There are more authors dividing TVCs into different categories, for example, metacognitive, intrapersonal, interpersonal, intellectual, cognitive, functional, ethical, behavioural, global and critical competencies (Caeiro-Rodriguez et al., 2021; Care & Luo, 2016; De Freitas & Almendra, 2021; Moldovan, 2020).

Although the concept of TVCs takes on different guises within the literature, certain elements seem consistent. Therefore, the authors constructed the following definition as their guiding interpretation throughout this study, excluding less commonly employed interpretations and thus ensuring consistency: *Transversal Competencies are holistic, generic dimensions of human performance, tacit and almost intangible in nature. They are associated with attitudinal, autonomous, self-directive behaviour to flexibly adapt to changing circumstances both at work and in life. Underlying aspects are reflection, self-evaluation and a constructive affiliation with other people and the environment.*

Purpose of this study

From an aviation regulation standpoint, the industry's adherence to traditional education methods is understandable. However, with ICAO's introduction of CBTA, assessing competencies pose new challenges in terms of developing objective educational methods compared to the existing methods for technical knowledge, skills and time requirements. This study represents a first step towards these new methods, by conducting research amongst expert aviation industry professionals to understand the industry's priorities and challenges regarding learning and assessing TVCs. This is needed to set priorities and bring focus when shifting to CBTA, given the extensive array of competencies and observable behaviours in ICAO's competency framework for AMP. Because of the international nature of aviation, with a strong interdependence among the different professional roles, these priorities and challenges

extend beyond national and cultural aviation contexts. Therefore, input from aviation professionals worldwide – representing a range of roles – is essential.

Research objective

This study aims to generate clear insight into the aviation industry's priorities and necessities by exploring which TVCs of ICAO's competency framework are considered crucial yet complex to assess. This is a relatively new area of research within aviation, and little information is available on this topic.

Research questions

The main research question is: ***which TVCs from ICAO's competency framework for AMP are considered crucial, yet difficult, to objectively assess?***

From this main question, the following sub research questions were developed:

1. Which competencies and OBs from ICAO's competency framework for AMP can be objectively labelled as 'transversal'?
2. Which TVCs from ICAO's competency framework for AMP are prioritised as the highest by the aviation industry?
3. Which underlying OBs of the highest prioritised TVCs are considered most important by the aviation industry?
4. Which underlying OBs of the highest prioritised TVCs are considered hardest to assess by the aviation industry?

The next part of this article explains the research design in detail.

Methods

As the main research question is exploratory, a qualitative research approach is suitable (Borrego et al., 2009; Cohen et al., 2018; Creswell, 2012; Kelly & Bowe, 2011). However, sub-questions two, three and four hold ordinal elements ('highest', 'most important' and 'hardest') and therefore qualitative data can be quantified (Harpe, 2015; Joshi et al., 2015; Sirkin, 2006). To generate a complete understanding of the struggles and priorities of the aviation industry regarding the assessment of TVCs in aircraft maintenance, a mixed methods approach has been applied using an exploratory design where the quantitative phase succeeds the qualitative one. Consequently, the sequencing of the study follows a deliberate order due to the interdependence of the questions. Specifically, the outcome of sub-question one shapes the content used to investigate sub-questions two, three and four. This logical connection results in the arrangement of the study in the order mentioned.

Qualitative phase

To answer sub-question one, each OB from ICAO's competency framework was evaluated and categorised as either transversal or technical, with all raters using the stated definition. The evaluation was conducted by a team of four raters, meeting the standards for qualitative research (Cole, 2024). The raters included the three authors of this article, as each brings a unique expertise: Aviation Maintenance Education, Aviation and Aerospace Engineering, and Education & Learning Design. The fourth rater was an industry expert with over 30 years of experience in Continuing Airworthiness, Safety, and Compliance within aviation maintenance. The authors believe these four raters provide a complementary combination that covers all relevant perspectives. A consensus on the nature of each OB was reached when three or more reviewers agree. TVCs were defined as such when at least half of the OBs were labelled as 'transversal'. Based on the evaluation of these four independent raters, seven out of the 11 competencies from ICAO's competency framework were labelled as 'Transversal'. Fleiss' Kappa for interrater reliability $= 0.712$ ($p < 0.001$), which is substantial (Landis & Koch, 1977).

The seven competencies labelled as TVCs and their ICAO (2020) definitions are listed below:

- Competency 2: Work Management – Manage available resources efficiently to prioritise and perform tasks in a safe and efficient manner.
- Competency 5: System Thinking – Understand and determine how the various components of systems management interact and affect the overall system safety performance.
- Competency 6: Coordination and Handover – Manage coordination and handover between personnel.
- Competency 8: Teamwork – Operate safely and efficiently as a team member.
- Competency 9: Problem-Solving and Decision Making – Accurately identify and resolve problems using the appropriate decision-making process.
- Competency 10: Self-Management and Continuous Learning – Demonstrate personal attributes that improve performance and maintain an active involvement in self-learning and self-development.
- Competency 11: Communication – Communicate effectively in all situations and ensure clear and common understanding.

Quantitative phase

To answer the other sub-questions, an online Likert scale survey was designed and conducted among aviation experts to explore which TVCs from ICAO's competency framework are considered most crucial to be mastered by AMP to ensure the continuation of a safe aviation industry. Ranking by experts is a suitable method to achieve group consensus about the importance of certain issues and identify priorities (Okoli & Pawlowski, 2004; Schmidt, 1997). In addition to ranking the competencies, the experts were asked to rate the importance of each OB of their top three selected competencies, and their view on the complexity to assess these OBs. This way, both the priorities and obstacles regarding TVC assessment are exposed. To minimise respondent fatigue, the survey was limited to explore these priorities and challenges. The TVCs and OBs used for this survey were derived from the qualitative phase of this research.

First, the survey was piloted with a group of aircraft maintenance instructors familiar with CBTA ($N = 10$) to assess its readability and estimated completion time. The responses from the pilot survey were not included in the research data. The survey was subsequently distributed among aviation experts at three different international aviation conferences in 2023 – two held in Europe and one in the United States – attended by professionals from around the world. All participants attended a session about TVC's in aviation maintenance provided by the first author. As CBTA is a new concept in aviation, the session included an explanation of competencies – distinguishing them from technical knowledge and skills, and covering transversal competencies – to ensure participants understood the concept before completing the survey. The session was carefully designed to avoid the potential of bias. The participants could access the survey through a QR Code or URL link that was shared on a screen after the presentation or workshop at the conferences. Although the three international conferences served different target groups of aviation experts, at the second and third conferences people were asked to refrain from filling in the survey if they had already done so. In the survey, participants were asked about professional aspects like aviation domain, organisation type and years of professional working experience. No other personal data was collected, to ensure maximum anonymity and reduce potential bias (Kang & Hwang, 2023). Each participant was extensively informed about participation in this study by means of an informed consent included in the opening statement of the online survey. This statement explained that by clicking through the survey and submitting their responses, participants were providing their informed consent to take part in the study. Ethical permission for this study was granted by the Human Research Ethics Committee of the Delft University of Technology (reference 2845).

Results

The survey ran from April to July 2023. A total of 230 responses were received. After screening and cleaning the data for completeness on both the demographic questions and the importance of TVCs,

Table 1. Spread of respondents within the different fields of the aviation domain (n = 137).

Domain	*n*	%
Airworthiness of Aircraft including Maintenance	87	63.5
Other[a]	21	15.3
Flight Operations / Air Crew / Cabin Crew	18	13.1
Aviation Psychology / Human Factors Experts	9	6.6
Air Navigation Services / Air Traffic Control	2	1.5

[a]Most participants who answered 'other' stated that they work in Aviation (Technical) Training, which is placed as a category under the organisation type they work for in Table 2.

Table 2. Spread of respondents by organisation type (n = 138).

Organisation type	*n*	%
Airline	52	37.7
Training Organisation / Education	30	21.7
Government / Regulator	17	12.3
MRO[a] Organisation	12	8.7
Other	11	8.0
Manufacturer (OEM[b] & part suppliers)	10	7.2
Military / Law enforcement	3	2.2
General Aviation	3	2.2

[a]Maintenance, Repair & Overhaul.
[b]Original Equipment Manufacturer.

141 usable responses remained for analysis, with only a few experts omitting an occasional question. This sample size is adequate, given the number of variables and statistical analyses employed within this study (Cohen et al., 2018).

Expert panel composition

In terms of professional background, the Airworthiness & Maintenance domain emerges as the most prevalent (see Table 1). Around 37% of participants represent various other critical roles within aviation. Predominantly, respondents are affiliated with airlines, followed by education and training organisations and regulatory bodies (see Table 2). Nearly 64% of all participants declare over two decades of aviation experience (see Table 3). Not more than 4% had maximally 5 years of working experience in aviation. Given their extensive experience in aviation, the participants can be considered experts. Moreover, a large portion of respondents represents the maintenance domain, which aligns with the study's focal point. In addition, it is considered advantageous to have a level of heterogeneity among the experts to cover multiple perspectives on a problem which leads to better results (Powell, 2003; Rowe et al., 1991). By having a diverse representation of relevant interacting domains in this expert group, a comprehensive view of TVC assessment priorities and challenges in aviation maintenance is offered.

Rating of importance of transversal competencies

The participants ranked all seven TVCs from most important (1) to least important (7). Table 4 shows how these rankings have been distributed. Based on the descriptives, it appears that Communication and Work Management were both ranked as most important, and Teamwork and Problem-Solving & Decision Making both as second most important. Almost 70% of all respondents ranked Communication in their top three most important TVCs, while more than 53% did this for Work Management. The ranking of importance of Problem-Solving and Decision Making is nearly evenly distributed across all levels, which explains the multiple modes found. Almost 47% of all respondents placed this competency in their top three most important TVCs. Teamwork, on the other hand, appears to follow a more normal distribution, with over 50% of respondents ranking this competency in their top three most important competencies. Figure 1 presents a heatmap to further illustrate the distribution of importance rankings across the seven TVCs.

Based on these results, it is evident that Communication, Work Management, and Teamwork are regarded as the three most crucial TVCs for AMP. To test for significant differences between the ranking of these competencies by the participants, Friedman's ANOVA was applied, a non-parametric test

Table 3. Spread of respondents by years of work experience (n = 138).

Years of work experience	*n*	%
0–5	6	4.3
5–10	11	8.0
10–20	33	23.9
20–30	49	35.5
30–40	30	21.7
More than 40	9	6.5

Table 4. Descriptive statistics of ranking the importance of the seven TVCs.

TVC	*N*	*Mean*	*Median*	*Mode*
Work Management	141	3.47	3	1.00
System Thinking	141	4.67	5	7.00
Coordination and Handover	141	4.93	5	5.00
Teamwork	141	3.49	3	2.00
Problem Solving and Decision Making	141	3.79	4	1.00[a]
Self-Management and Continuous Learning	141	4.74	5	7.00
Communication	141	2.91	3	1.00

[a]More than one mode exists, only the first is reported.

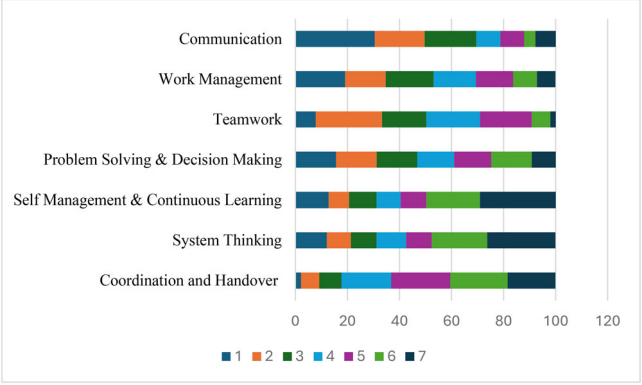

Figure 1. Heatmap of the importance rankings of the seven TVCs. *Note: 1 = most important, 7 = least important.*

suitable for comparing different rankings and ratings within the same group (Field et al., 2012), which shows that there is a significant difference χ^2 (2) = 16.2, $p < 0.001$.

A Durbin – Conover post hoc test (Field et al., 2012) was employed for pairwise comparisons which indicates that Communication is rated significantly more important than both Teamwork and Work Management. Teamwork and Work Management can be considered equally important.

Importance and assessment complexity of the associated observable behaviours

As described earlier, each competency has several OBs. For each OB the participants ranked on a 5-point Likert-scale the importance of that particular OB for the performance of the competency it is related to, where 1 = very unimportant and 5 = very important. Similarly, for the difficulty to assess, participants were asked to rate each OB from 1 = very easy to 5 = very difficult.

Communication

The Transversal OBs of Communication are listed in Table 5, together with rating descriptives in the survey regarding the importance and difficulty to assess of each OB. It should be noted that OB 11.5 is missing, as this OB was labelled as technical.

Importance. Friedman's ANOVA reveals significant differences between the importance rating of these OBs: χ^2 (7) = 62.3, $p < .001$. Post hoc Durbin-Conover pairwise comparisons were employed to identify specific locations where significant differences exist. To manage the extensive number of comparisons, a Bonferroni correction was applied to adjust the *p*-value, reducing the risk of a Type I error. The adjusted *p*-value was set at 0.002.

Table 5. Transversal OBs of Communication from ICAO's competency framework (ICAO, 2021) with descriptives of the rating of importance and difficulty to assess.

OB	Description	Importance			Difficulty to assess		
		n	*Mean*	*Median*	*n*	*Mean*	*Median*
11.1	Selects appropriate method of communication	87	4.15	5	86	2.92	3
11.2	Uses effective verbal communication	87	4.40	5	87	2.83	3
11.3	Uses effective written and other non-verbal communication	87	4.24	4	86	2.75	3
11.4	Maintains situational awareness when selecting method of communication, speaks clearly, accurately and concisely	86	4.35	5	87	3.05	3
11.6	Demonstrates active listening by asking relevant questions and providing feedback	86	4.30	5	87	2.69	2
11.7	Verifies comprehension of counterparts and corrects as necessary	86	4.15	4	87	3.15	3
11.8	Uses eye contact, body movements and gestures that are consistent with verbal messages where applicable	86	3.89	4	87	2.90	3
11.9	Interprets non-verbal communication accurately	85	4.10	4	87	3.44	4

The results indicate that OBs 11.1, 11.2, 11.3, 11.4 and 11.6 are all considered significantly more important than OB 11.8. The OBs 11.2. and 11.4 are also significantly more important than OB. 11.7 and 11.9. OB 11.6 was also ranked as more important than 11.9. The Bonferroni correction is known for its conservative nature (Field et al., 2012; Sedgwick, 2012). Despite being just beyond the adjusted critical *p*-value, OB 11.1 could be considered more important than OB 11.9, evidenced by a *p*-value of 0.003. Generally, these findings indicate that the OBs related to verbal communication are considered significantly more important than OBs related to non-verbal communication.

Difficulty to assess. Next, the OBs related to verbal communication were compared for significance in difficulty to assess: OBs 11.1, 11.2, 11.4 and 11.6. Friedman's ANOVA shows that significant differences can be found: χ^2 (3) = 11.4, $p = 0.010$. As only four OBs are compared there was no Bonferroni correction applied for the Durbin – Conover Pairwise Comparison tests. The results indicate that OBs 11.1 and 11.4 are both considered significantly more difficult to assess than OB 11.6. Both OBs 11.1 and 11.4. describe the selection of communication methods, while 11.6 concerns active listening and asking questions. This suggests that the selection of appropriate communication based on the situation is considered more difficult to assess than the demonstration of active listening, asking relevant questions and providing feedback.

Work management

Also, for this TVC, the individual OBs have been rated on importance and difficulty to assess. Table 6 shows the transversal OBs of Work Management that were included in the survey, and the rating descriptives from the survey regarding the importance and difficulty to assess of each OB.

Importance. All OBs scored high to very high on importance, no significant differences of importance were found using Friedman's ANOVA: χ^2 (4) = 6,27, $p = 0.180$.

Difficulty to assess. The ratings of difficulty to assess show more variance, where OB 2.10 stands out from the other OBs. Here, Friedman's ANOVA does show a significant difference; χ^2 (4) = 23,4, $p < .001$. A Durbin-Conover pairwise comparison post-hoc test detects significant differences in assessment difficulty, with a Bonferroni correction of the *p*-value 0.05/10 = 0.005, resulting in OB 2.10 as significantly more difficult to assess than all the other transversal OBs of Work Management with $p < 0.001$.

Teamwork

This competency has the most OBs of all competencies in ICAO's competency framework for AMP. Moreover, all OBs were labelled as transversal, which means that they were all included in the survey. Table 7 shows the description of the OBs of Teamwork and the rating descriptives from the survey regarding the importance and assessment complexity of each OB.

Importance. There are significant differences in how these OBs were rated for importance, using Friedman's ANOVA; χ^2 (13) = 67.3, $p < .001$. Due to the large number of tests, the Bonferroni correction

Table 6. Transversal OBs of Work Management from ICAO's competency framework (ICAO, 2021) with descriptives of the rating of importance and difficulty to assess.

		Importance			Difficulty to assess		
OB	Description	*n*	*Mean*	*Median*	*n*	*Mean*	*Median*
2.1	Plans, prioritizes and schedules tasks effectively	49	4.46	5	51	2.67	3
2.3	Requests assistance when and where required	49	4.42	4	51	2.86	3
2.4	Manages time effectively	50	4.17	4	51	2.82	3
2.7	Offers and accepts assistance, when necessary, and asks for help	49	4.31	4	51	2.73	2
2.10	Manages environmental stress, interruptions, distractions, variations and failures effectively	50	4.21	4	51	3.33	4

results in a very small adjusted p value for statistical significance: $0.05/91 = 0.00055$. Consequently, only $p < 0.001$ is considered as significant. Post hoc Durbin-Conover pairwise comparisons test results indicate that OB 8.1 is significantly more important than the OBs 8.7, 8.8, 8.11, 8.12 and 8.14. If the p-value were less conservative, OB 8.6 could be added to the list of significantly more important OBs, evidenced by $p = 0.001$.

The findings suggest that OBs describing more concrete (verbal) actions hold greater importance compared to more generic ones, which focus on integrity, honesty, and soundness. With a less conservative p-value, OB 8.10 would be considered more important than OB 8.13, with $p = 0.001$. Moreover, it is worth noting that the OB demonstration of soundness (OB 8.14) is considered more important than feedback-related OBs (OBs 8.3 and 8.4).

Difficulty to assess. Looking at the difficulty to assess, the ratings show significant differences through Friedman's ANOVA: χ^2 (13) = 62.5, $p < .001$. Pairwise Comparisons are applied to find where these differences are, using again a p-value of $p < 0.001$ for statistical significance due to the Bonferroni correction for the large number of tests. The post-hoc test shows that OB 8.12 is considered significantly more difficult to assess than the five other OBs (8.2, 8.5, 8.6, 8.10 and 8.13). Also OBs 8.13 and 8.6 are considered more difficult to assess than OBs 8.7, 8.8 and 8.11.

Results summary

This study aimed to answer the following research question: ***Which TVCs from ICAO's competency framework for AMP are considered crucial, yet difficult, to objectively assess?***

The following sub-questions (SQs) were developed:

1. Which competencies and OBs from ICAO's competency framework for AMP can be objectively labelled as 'transversal'?
2. Which TVCs from ICAO's competency framework for AMP are prioritised as the highest by the aviation industry?
3. Which underlying OBs of the highest prioritised TVCs are considered most important by the aviation industry?
4. Which underlying OBs of the highest prioritised TVCs are considered hardest to assess by the aviation industry?

In answer to SQ 1, the TVCs identified are Work Management, System Thinking, Coordination and Handover, Teamwork, Problem-Solving & Decision Making, Self-Management & Continuous Learning, and Communication.

In answer to SQ2, the following top three TVCs were selected by the aviation experts as the most important in ICAO's competency framework: Communication, Teamwork, and Work Management. Further investigation reveals interesting insights concerning *SQ3* and *SQ4*.

For Communication, it is evident that the OBs associated with verbal communication hold more importance than those with non-verbal communication. OB 11.4, encompassing maintaining situational awareness during communication and speaking clearly, accurately, and concisely, was rated as the most challenging to assess among all the verbal communication OBs. Given its comprehensive nature, OB 11.4 likely embodies the importance of the other verbal OBs, except for OB 11.6, which focuses on active

Table 7. Transversal OBs of Teamwork from ICAO's competency framework (ICAO, 2021) with descriptives of the rating of importance and difficulty to assess.

		Importance			Difficulty to assess		
OB	Description	*n*	*Mean*	*Median*	*n*	*Mean*	*Median*
8.1	Fosters an atmosphere of open communication	51	4.55	5	51	2.86	3
8.2	Encourages team participation and cooperation	51	4.31	4	52	2.27	2
8.3	Uses feedback to improve overall team performance	51	4.18	4	52	2.92	3
8.4	Provides feedback constructively	51	4.18	4	51	3.02	3
8.5	Shows respect and tolerance for other people	51	4.69	5	52	2.47	2
8.6	Carries out duties in support of a team	51	4.10	4	50	2.73	3
8.7	Uses negotiating and problem-solving techniques to manage unavoidable conflict when encountered	51	4.39	5	52	2.45	2
8.8	Raises relevant concerns in an appropriate manner and good judgement	51	4.47	5	51	2.55	2
8.9	Accepts feedback constructively	51	4.51	5	52	2.71	3
8.10	Shares experiences with the aim of continuous improvement	51	4.47	5	51	2.43	2
8.11	Manages interpersonal conflicts to maintain an effective team environment	51	4.27	4	52	2.37	2
8.12	Anticipates and responds appropriately to the needs of others	51	4.20	4	52	3.08	3
8.13	Demonstrates integrity and honesty	51	4.22	4	52	2.90	3
8.14	Demonstrates soundness	51	4.33	4	52	2.69	3

listening, asking questions, and feedback. Overall, OB 11.4 emerges as the most critical and difficult-to-assess OB for Communication.

For Work Management, no significant differences in importance were found among the individual OBs. However, OB 2.10, addressing effective management of environmental stress, interruptions, distractions, variations, and failures, stood out as most challenging to assess compared to other OBs within this competency.

In the context of the competency Teamwork, OB 8.1, emphasising fostering an atmosphere of open communication, appeared to be of particular importance compared to the other OBs. Concerning the difficulty of assessing OBs in this area, OB 8.12, focusing on anticipating and responding appropriately to the needs of others, proved to be the most challenging for the aviation industry.

To answer the main research question, the transversal OBs from ICAO's competency framework that are highlighted as most important *and* most difficult to assess are:

- OB 2.10 Manages environmental stress, interruptions, distractions, variations and failures effectively.
- OB 8.1 Fosters an atmosphere of open communication.
- OB 8.12 Anticipates and responds appropriately to the needs of others.
- OB 11.4 Maintains situational awareness when selecting method of communication, speaks clearly, accurately and concisely.

Discussion

The survey respondents ranked Communication as the most important TVC, followed by Work Management and Teamwork being equally important. This is in line with Boeing's Maintenance Error Decision Aid (MEDA), where both Communication and Teamwork are identified as level 2 contributing factors to Maintenance Error. While Work Management is not explicitly mentioned in MEDA, it is referred to through factors like environmental stress management, time management, planning, and prioritising (Boeing, 2016). This shows alignment between the survey results and Boeing's established critical elements for aviation maintenance. Additionally, more recent studies have highlighted the crucial role of effective communication in ensuring safe operations within the complex aviation maintenance industry (Korba et al., 2023; Newman & Scott, 2023) however, these studies do not reference ICAO's competency framework for aircraft maintenance. As ICAO defines global standards for aviation and its competency framework underpins this study, the findings have worldwide relevance and are not limited to the European aviation context.

During the qualitative phase of the study, sub-question one was answered. Seven out of the 11 competencies outlined in ICAO's competency framework for AMP were labelled as 'Transversal'. Notably, 'Situational Awareness' *(Recognise and understand the maintenance environment and relevant information; anticipate future events)* and 'Risk Management' *(Demonstrate an effective safety approach to the work*

environment considering its risk profile and the availability of recourses) were excluded. Despite the transversal overarching definition of these competencies, numerous individual OBs linked to them demonstrated a complex interplay between technical and transversal aspects, resulting in a hybrid status that fell beyond the scope of this study. Given that a substantial number of OBs related to Situational Awareness and Risk Management did not meet the threshold for classification as 'transversal' (requiring agreement from three or more raters), these competencies were not designated as TVCs. However, this does not imply that these two competencies are unimportant. On the contrary, Situational Awareness and Risk Management are crucial in the aviation industry. As mentioned, though, the individual OBs were seen as too intertwined with technical elements that excluded them from the TVC selection for this study. Nevertheless, hybrid competencies like Situational Awareness and Risk Management should be included in all educational programs for aircraft maintenance and their assessment needs careful designing, for which future research is essential.

Limitations

This study consists of two distinct phases: a qualitative phase and a quantitative phase. In the qualitative phase, a panel of four assessors engaged in the classification of OBs as either transversal or technical competencies, achieving a noteworthy level of interrater reliability. Nonetheless, a larger number of raters could potentially yield alternative designations for certain competencies, thereby influencing the subsequent quantitative phase. In this latter phase, the survey could have displayed a different spectrum of TVCs and OBs. Furthermore, an alternative labelling approach, wherein a 'hybrid' category is introduced instead of a strict dichotomy between 'technical' and 'transversal', could have conferred a higher degree of complexity to both phases of the study. This approach might have offered a more nuanced depiction of the complex nature of CBTA in aviation maintenance. The current study, however, aimed at TVC assessment in contrast with technical competencies as the latter are already regulated into detail. The inclusion of a hybrid category would have entailed complexities in ascertaining whether the designation of a particular competency as crucial or difficult to assess, places emphasis on the transversal or the technical aspect. Since this study focuses on TVCs in distinction to the technical elements, the authors chose to distinguish between these two competency types. Finally, applying the Bonferroni correction resulted in a more stringent outcome, which may have blurred subtle differences. A less conservative statistical approach might have affected the number of OBs identified as important and difficult to assess.

Conclusion

With a proposed global shift from traditional, time-based educational requirements to competency-based education on the horizon, educators in the aviation maintenance industry need to look at developing reliable assessment methods for behavioural standards. The introduction of TVCs in ICAO's competency framework, pose new challenges for aviation maintenance educators. As a first step, this study focused on identifying the key priorities and challenges in assessing TVCs within aviation maintenance training and education.

Of the 11 competencies formulated by ICAO, 7 have been labelled as 'transversal' based on the assessments of four different raters using the following definition: *Transversal Competencies are holistic, generic dimensions of human performance, tacit and almost intangible in nature. They are associated with attitudinal, autonomous, self-directive behaviour to flexibly adapt to changing circumstances both at work and in life. Underlying aspects are reflection, self-evaluation and a constructive affiliation with other people and the environment.*

The competencies labelled as 'transversal' are: 'Work Management', 'System Thinking', 'Coordination and Handover', 'Teamwork', 'Problem-Solving and Decision Making', 'Self Management and Continuous Learning', and 'Communication'.

- From these TVCs, aviation experts selected Communication, Teamwork, and Work Management as the most important. These competencies were further elaborated by analysing the importance and

assessment difficulty of each OB, as rated by the aviation experts. The results indicate that the industry needs support in developing assessment methodologies for evaluating the following OBs:

- OB 2.10 Manages environmental stress, interruptions, distractions, variations and failures effectively.
- OB 8.1 Fosters an atmosphere of open communication.
- OB 8.12 Anticipates and responds appropriately to the needs of others.
- OB 11.4 Maintains situational awareness when selecting method of communication, speaks clearly, accurately and concisely.

The findings of this study support ICAO's efforts to promote the implementation of CBTA and have implications for both educational organisations and aviation regulators, such as EASA, to integrate TVC assessments more thoroughly into their regulations.

Now that the industry's key priorities and challenges in assessing TVCs in aircraft maintenance have been uncovered in this study, the subsequent steps in this research will involve identifying performance levels for these TVCs and developing effective educational methods for training and assessment of these competencies and observable behaviours. This will include further research to develop these methods in close collaboration with the aviation maintenance industry. The intended creation of valid and reliable assessment methodologies for these TVCs will represent an advancement in supporting CBTA within the aviation maintenance sector.

Author contributions

Lydia Kes conceptualised the study, designed the methodology, collected and analysed the data and prepared the original draft. Gillian Saunders-Smits conceptualised the study, supervised the methodology design, reviewed and edited the manuscript. Marcus Specht conceptualised the study, supervised the methodology design, reviewed and edited the manuscript. All authors read and approved the final manuscript.

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Data availability statement

The data that support the findings of this study are available in 4TU Research Data at https://doi.org/10.4121/6078fecf-116f-4541-b8c1-a1341ad762c1 Data will be made available on reasonable request.

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