Analytic hierarchy process in determining aircraft basic maintenance training durations

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Abstract

Purpose – Currently, in aircraft basic maintenance training, it is determined that various aircraft basic maintenance training organizations around the world apply different basic maintenance durations for the same modules of the same licence categories. Aircraft basic maintenance training organizations are lacking a common curriculum with standard durations for the basic maintenance training modules. To remedy the problems associated with this issue, the purpose of this study is to develop and demonstrate a quantifiable reference (i.e. theoretical training and evaluation content intensity) based scientific theoretical method to determine the durations of the basic theoretical maintenance trainings held for B1.1 and B2 licence categories in aircraft basic maintenance training organizations.

Design/methodology/approach – The total basic maintenance training duration was first allocated to basic, theoretical and practical maintenance trainings. The obtained basic theoretical maintenance training duration was then allocated to related modules and submodules by using weighted theoretical training content intensity and weighted theoretical evaluation content intensity, which were obtained by applying a multi-criteria decision-making approach using the analytic hierarchy process (AHP).

Findings – In this study, it was found that there is no standardization upon aircraft basic maintenance training organizations for the allocation of the basic maintenance training durations to modules. To remedy this problem, a scientific method, which relies on quantifiable reference bases rather than subjective reasoning, is needed. The reference bases of the proposed theoretical method (i.e. theoretical training and evaluation content intensity) can be tuned with the inclusion of the effect of basic knowledge requirements through multi-criteria decision-making (AHP). The theoretical method proposed in this work is robust in terms of resulting in close proximity values of the basic theoretical maintenance training durations for the common modules of B1.1 and B2 licence categories. The theoretical method is proven to yield greater basic theoretical maintenance training durations for modules having greater theoretical training and evaluation content intensity and lower basic theoretical maintenance training durations for modules having less theoretical training and evaluation content intensity. A distinct similarity in terms of basic theoretical maintenance training durations and the ranking of the modules (in terms of durations) is not present when the average of the training organizations is compared to the results of the theoretical method. A quantifiable reference (i.e. theoretical training and evaluation content intensity) based scientific theoretical method to determine basic theoretical maintenance training durations was developed and demonstrated.

Practical implications – Results of this study would especially be useful in an international effort to standardize the different basic theoretical maintenance training durations applied in various aircraft basic maintenance training organizations.

Originality/value – To the best of the authors' knowledge, this study is the first in providing and demonstrating a scientific theoretical method based on a systematic, multi-criteria decision-making approach to determine the durations of the basic theoretical maintenance trainings.

Keywords Aircraft basic maintenance training, Part-66/147, EASA, Analytic hierarchy process (AHP)

Paper type Research paper

Introduction

Aircraft maintenance can be defined as the process of ensuring that an aircraft perpetually performs its intended function at its designed level of reliability and safety. The aircraft and its components require inspection, maintenance, repair, modifications and parts replacement in accordance with international and national standards issued by the aviation authorities such as the International Civil Aviation Organization, European Union Aviation Safety Agency (EASA), Federal Aviation Administration (FAA), Turkish Directorate General of Civil Aviation (DGCA), etc. The EASA issued regulation, Commission Regulation (EU) No 1321/2014 involves the continuing airworthiness of aircraft and aeronautical products, parts and appliances and the approval of organizations and personnel involved in these tasks. This regulation establishes common technical requirements and administrative procedures for ensuring the continuing airworthiness of aircraft, including any component for installation (EASA, 2022a, 2022b, 2022c). The regulatory view of the aircraft maintenance process can briefly be described as follows:

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- Part-M organizations are responsible for managing the continuing airworthiness of the aircraft.
- Part-145 organizations are responsible for performing the required maintenance planned and stated by the Part-M organizations.
- Certifying staff (authorized aircraft maintenance engineers) who work for the Part-145 organizations and are responsible for performing and certifying maintenance tasks, must hold eligible Part-66 aircraft maintenance license (AML). The AML is issued and approved only if the candidate complies to all knowledge and experience requirements given in Part-66.
- Part-147 aircraft maintenance training organizations are responsible for training the candidates.

In the aircraft maintenance business, as the personnel who can work in base maintenance rather than line maintenance on Group 1, aircraft must have B1.1, B1.2 and B2 licenses, maintenance personnel with a licence in these categories are predominantly used. Most training modules and submodules are common for B1.1 and B1.2 categories. Therefore, only B1.1 and B2 licence categories are under the scope of this paper.

The total duration of basic maintenance training for B1.1 and B2 licence categories given as a requirement to be complied to in Appendix 1 of Annex IV of EASA Part-147 (EASA, 2022a, 2022b, 2022c) is as given in Table 1. The minimum duration of a complete aircraft basic maintenance training course must be as stated in Table 1. However, no information is present on how to allocate these total durations to each module.

Table 1 Aircraft basic maintenance training durations

Licence category	Short description of the licence category	Duration (hours)	Theoretical training ratio (%)
B1.1	Turbine engine aeroplanes maintenance personnel	2,400	50–60
B2	Avionic and electrical systems maintenance personnel	2,400	50–60

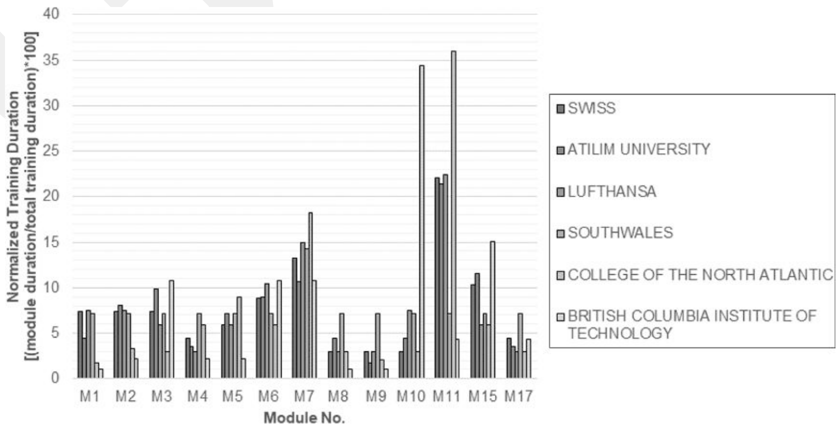
Source(s): Authors' own work

Basic maintenance training durations of corresponding modules of B1.1 and B2 licence categories, as issued by the related approved aircraft maintenance training organizations worldwide, are given in Figures 1 and 2, respectively (Atılım University School of Civil Aviation, 2024; Swiss Aircraft Maintenance Association, 2024; Lufthansa Technical Training, 2024, University of South Wales, 2024; College of the North Atlantic, 2024; British Columbia Institute of Technology, 2024). Note that the values presented in these figures are normalized values as the total training duration of each organization is also different. Significant differences exist between the durations allocated to the same modules by different training organizations. Examining Figures 1 and 2, it can be depicted that an average of 389% difference for B1.1 Licence Category and 265% difference for B2 Licence Category exists between the organizations that have allocated the least and the most durations to each module. The figures show that there is no standardization for the allocation of the basic maintenance training durations to modules.

The incompatibility caused by applying different basic maintenance training durations for the same modules of the same licence categories in different aircraft basic maintenance training organizations may lead to some of the problems listed below:

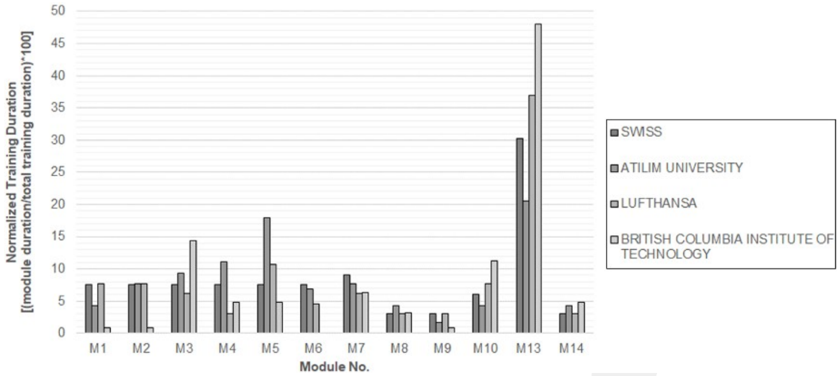
- The module content may not be taught properly if the training duration is set too short for the specific module.
- The module content may be taught properly but with an over-repetition and by eventually causing a shortening of the duration of other modules, if the course duration is set too long for the specific module.
- In the process of undergraduate or graduate student exchange in between formal training institutions like the universities, course exemptions may not be possible.
- In exchange student programs like ERASMUS, the students' registration and enrolment to the module courses in any other institution may not be possible.

Figure 1 Basic maintenance training durations of the B1.1 licence category modules in different training organizations



Source: Authors' own work

Figure 2 Basic maintenance training durations of the B2 licence category modules in different training organizations



Source: Authors' own work

The problems listed above have a potential of adversely affecting the Part-M and Part-145 organizations by causing undetectable differences in the qualification of their trained personnel. It is evident that the qualification of Part-M and Part-145 organizations personnel is crucial when the complexity of the maintenance process is considered. As an example, the Airbus A380 consists of around 4 million individual components with 2.5 million parts, produced by 1,500 companies from 30 countries around the world. A total of 19,000 bolts are inserted inside the fuselage to attach each of the main parts, plus 4,000 to attach both wings (Airbus, 2021).

Because of these problems, there is an obvious need to determine standard durations for each module of the basic theoretical maintenance trainings held for B1.1 and B2 licence categories in aircraft basic maintenance training organizations. In an effort to remedy these problems, a method was developed. In this method, the total basic maintenance training duration to be complied to, was first allocated to basic, theoretical and practical maintenance trainings. The obtained basic theoretical maintenance training duration was then allocated to related modules and submodules. In the latter allocation method, weighted theoretical training content intensity and weighted theoretical evaluation content intensity were used. Weighted theoretical training content intensity and weighted theoretical evaluation content intensity were obtained by applying a multi-criteria decision-making approach in which the analytic hierarchy process (AHP) was used. Through the demonstration of the method a suggestion for the basic theoretical maintenance training durations for each module and submodule comprising the B1.1 and B2 licence categories was obtained.

Theoretical method

To develop and demonstrate the theoretical method, which can be used to determine the durations of the basic theoretical maintenance trainings held for B1.1 and B2 licence categories in aircraft basic maintenance training organizations, a systematic methodology consisting of the following steps was applied in an orderly manner:

- Determining the total duration of basic theoretical maintenance training.
- Determining the related modules and submodules to which the total duration will be allocated to.
- Determining the reference bases for duration allocation to related modules and submodules.
- Application of the AHP to obtain the weight factors to be used in the transformation of the reference bases to weighted reference bases.
- Transformation of the reference bases to weighted reference bases.
- Performing the calculations to obtain the distribution of the basic theoretical maintenance training duration amongst the modules and submodules.

Inputs, intermediate and final outputs of each step of the theoretical method is given in Table 2.

Step 1: determining the total duration of basic theoretical maintenance training

The total duration of basic theoretical maintenance training for B1.1 and B2 licence categories was determined so that this total duration could later be allocated to modules and submodules. According to Table 1, the minimum total duration for basic theoretical maintenance training for both categories should be a value between 1,200 h and 1,440 h. To determine the exact value, a questionnaire was prepared and was answered by 19 Theoretical Trainers of the Atılım University School of Civil Aviation. The filled in questionnaires were processed to obtain the arithmetic average of the 19 answers. The result for the theoretical training ratio returned 55.2%. Thus, the total duration of basic theoretical maintenance training was calculated as 1,324.8 h.

Step 2: determining the related modules and submodules to which the total duration will be allocated to

The related modules and submodules constituting the basic theoretical maintenance training for B1.1 and B2 licence categories were determined so that the total duration of basic theoretical maintenance training (determined in Step 1) could later be allocated to these modules and submodules. The module responsibilities for B1.1 and B2 licence category given in EASA Part 66 (EASA, 2022a, 2022b, 2022c) are given in Table 3.

Table 2 Inputs and outputs of the theoretical method

Step no.	Input	Output
1	• EASA Part 147 (European Union Aviation Safety Agency, 2022a, 2022b, 2022c) requirement clause for total basic maintenance training duration for B1.1 and B2 licence categories • EASA Part 147 (European Union Aviation Safety Agency, 2022a, 2022b, 2022c) requirement clause for basic theoretical maintenance training ratio for B1.1 and B2 licence categories • Questionnaire related to basic theoretical maintenance training ratio	• Filled in questionnaires related to basic theoretical maintenance training ratio • The total duration of basic theoretical maintenance training for B1.1 and B2 licence categories
2	• EASA Part 66 (European Union Aviation Safety Agency, 2022a, 2022b, 2022c) requirement clause for module responsibilities according to licence categories	• Modules and submodules of B1.1 and B2 licence categories to which the total duration of basic theoretical maintenance training will be allocated to
3	• ICAT Distance Learning Modules [Cardiff and Vale College ICAT (International Centre for Aerospace Training), 2011] • TTS Training Manuals (Total Training Support Ltd., 2016) • EASA Part 66 (European Union Aviation Safety Agency, 2022a, 2022b, 2022c) requirement clause for amount of module exam questions • DGCA SHT 66 [Sivil Havacılık Genel Müdürlüğü (Directorate General of Civil Aviation), 2023a, 2023b] requirement clause for amount of module and submodule exam questions	• Reference Bases for allocating the total duration of basic theoretical maintenance training to related modules and submodules of B1.1 and B2 licence categories
4	• AHP questionnaires	• Filled in AHP questionnaires • Weight factors
5	• Reference bases • EASA Part 66 (European Union Aviation Safety Agency, 2022a, 2022b, 2022c) requirement clause for Basic Knowledge Requirements • DGCA SHT 66 [Sivil Havacılık Genel Müdürlüğü (Directorate General of Civil Aviation), 2023a, 2023b] requirement for module exam questions' Basic Knowledge Requirements • Weight factors	• Weighted Reference Bases for allocating the total duration of basic theoretical maintenance training to related modules and submodules of B1.1 and B2 licence categories
6	• Modules and submodules of B1.1 and B2 licence categories to which the total duration of basic theoretical maintenance training will be allocated to • The total duration of basic theoretical maintenance training for B1.1 and B2 licence categories • Weighted reference bases	• Durations of the basic theoretical maintenance trainings for B1.1 and B2 licence categories

Source(s): Authors' own work

Step 3: determining the reference bases for duration allocation to modules and submodules

The theoretical method was constructed to rely on the theoretical training content intensity and the theoretical evaluation content intensity. That is, the total duration of basic theoretical maintenance training (1,324.8 h) would be allocated to the related modules and submodules given in Table 3 based on these modules' theoretical training content intensity and theoretical evaluation content intensity. It was needed to express the theoretical training content intensity and the theoretical evaluation content intensity in terms of quantifiable reference bases. These quantifiable reference bases were determined through an examination of the training and evaluation resources. It was determined that the ICAT Distance Learning Modules [Cardiff and Vale College ICAT (International Centre for Aerospace Training), 2011] and TTS Training Manuals (Total Training Support Ltd., 2016) are internationally commonly used training resources in aircraft basic maintenance training organizations. Therefore, the amount of pages in ICAT Distance Learning Modules [Cardiff and Vale College ICAT (International Centre for Aerospace Training), 2011] and TTS Training Manuals (Total Training Support Ltd., 2016) were identified as reference bases for theoretical training content intensity. In aircraft basic maintenance training organizations, Module Exams are the method used for the theoretical evaluation of the training. The Turkish Civil Aviation Authority (DGCA) contains a requirement clause in its regulation, namely DGCA SHT 66 (Sivil Havacılık Genel Müdürlüğü [Sivil Havacılık Genel Müdürlüğü (Directorate General of Civil Aviation), 2023a, 2023b] for the amount of questions to be asked in Module Exams per module and submodule. The amount of module and submodule exam questions given in this regulation were identified as reference bases for theoretical evaluation content intensity.

The reference bases (the theoretical training content intensity and the theoretical evaluation content intensity) are given in Table 8 for exemplary purposes for licence category B1.1 Module 6 only.

Step 4: application of the analytic hierarchy process to obtain the weight factors to be used in the transformation of the reference bases to weighted reference bases

At this stage of the study, the total duration of theoretical basic maintenance training (1324.8 h) could have been distributed across the relevant modules and submodules in proportion to the reference bases. However, such an approach would disregard the influence of the Basic Knowledge Requirements,

Table 3 Module responsibilities for B1.1 and B2 licence categories

No.	Module and submodule responsibilities for B1.1 category	Module and submodule responsibilities for B2 category
1	Module 1: Mathematics Submodules: 1.1, 1.2a, 1.2b, 1.3a, 1.3b, 1.3c	Module 1: Mathematics Submodules: 1.1, 1.2a, 1.2b, 1.3a, 1.3b, 1.3c
2	Module 2: Physics Submodules: 2.1, 2.2.1, 2.2.2, 2.2.3a, 2.2.3b, 2.2.4a, 2.2.4b, 2.3a, 2.3b, 2.4, 2.5	Module 2: Physics Submodules: 2.1, 2.2.1, 2.2.2, 2.2.3a, 2.2.3b, 2.2.4a, 2.2.4b, 2.3a, 2.3b, 2.4, 2.5
3	Module 3: Electrical Fundamentals Submodules: 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7a, 3.7b, 3.8, 3.9, 3.10a, 3.10b, 3.11, 3.12, 3.13, 3.14, 3.15, 3.16, 3.17, 3.18	Module 3: Electrical Fundamentals Submodules: 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7a, 3.7b, 3.8, 3.9, 3.10a, 3.10b, 3.11, 3.12, 3.13, 3.14, 3.15, 3.16, 3.17, 3.18
4	Module 4: Electronic Fundamentals Submodules: 4.1.1a, 4.1.2a, 4.1.3a, 4.2, 4.3a	Module 4: Electronic Fundamentals Submodules: 4.1.1a, 4.1.1b, 4.1.2a, 4.1.2b, 4.1.3b, 4.2, 4.3b
5	Module 5: Digital Techniques/Electronic Instrument Systems Submodules: 5.3, 5.4, 5.5a, 5.6a, 5.10, 5.11, 5.12, 5.13, 5.14, 5.15a, 5.15b	Module 5: Digital Techniques/Electronic Instrument Systems Submodules: 5.1, 5.2, 5.3, 5.4, 5.5a, 5.5b, 5.6b, 5.7, 5.8, 5.9, 5.10, 5.11, 5.12, 5.13, 5.14, 5.15a, 5.15b
6	Module 6: Materials and Hardware Submodules: 6.1a, 6.1b, 6.2a, 6.2b, 6.3.1a, 6.3.1b, 6.3.2, 6.3.3, 6.4a, 6.4b, 6.5.1, 6.5.2, 6.5.3, 6.5.4, 6.6a, 6.6b, 6.7, 6.8, 6.9, 6.10, 6.11	Module 6: Materials and Hardware Submodules: 6.1a, 6.1b, 6.2a, 6.2b, 6.3.1a, 6.4a, 6.4b, 6.5.1, 6.5.2, 6.5.3, 6.5.4, 6.6a, 6.6b, 6.7, 6.8, 6.9, 6.10, 6.11
7	Module 7A: Maintenance Practices Submodules: 7.1, 7.2, 7.3, 7.4, 7.5, 7.6, 7.7, 7.8, 7.9, 7.10, 7.11, 7.12, 7.13, 7.14.1, 7.14.2, 7.15a, 7.15b, 7.16a, 7.16b, 7.17, 7.18a, 7.18b, 7.18c, 7.18d, 7.18e, 7.19a, 7.19b, 7.20	Module 7A: Maintenance Practices Submodules: 7.1, 7.2, 7.3, 7.4, 7.5, 7.6, 7.7, 7.15a, 7.16a, 7.17, 7.18a, 7.18c, 7.18d, 7.18e, 7.19a, 7.20
8	Module 8: Basic Aerodynamics Submodules: 8.1, 8.2, 8.3, 8.4	Module 8: Basic Aerodynamics Submodules: 8.1, 8.2, 8.3, 8.4
9	Module 9A: Human Factors Submodules: 9.1, 9.2, 9.3, 9.4, 9.5, 9.6, 9.7, 9.8, 9.9	Module 9A: Human Factors Submodules: 9.1, 9.2, 9.3, 9.4, 9.5, 9.6, 9.7, 9.8, 9.9
10	Module 10: Aviation Legislation Submodules: 10.1, 10.2, 10.3, 10.4, 10.5a, 10.5b, 10.6, 10.7a, 10.7b	Module 10: Aviation Legislation Submodules: 10.1, 10.2, 10.3, 10.4, 10.5a, 10.5b, 10.6, 10.7a, 10.7b
11	Module 11A: Turbine Engine Aircraft Aerodynamics, Structures and Systems Submodules: 11.1.1, 11.1.2, 11.2a, 11.2b, 11.3.1, 11.3.2, 11.3.3, 11.3.4, 11.3.5, 11.4.1, 11.4.2, 11.4.3, 11.4.4, 11.5.1, 11.5.2, 11.6, 11.7a, 11.7b, 11.8a, 11.8b, 11.9, 11.10, 11.11, 11.12, 11.13, 11.14, 11.15, 11.16, 11.17, 11.18, 11.19, 11.20, 11.21	Module 13: Aircraft Aerodynamics, Structures and Systems Submodules: 13.1a, 13.1b, 13.1c, 13.2a, 13.2b, 13.3, 13.4, 13.5, 13.6, 13.7a, 13.7b, 13.8, 13.9, 13.10, 13.11.1, 13.11.2a, 13.11.2b, 13.11.2c, 13.11.3, 13.11.4, 13.12a, 13.12b, 13.13a, 13.13b, 13.13c, 13.14a, 13.14b, 13.15a, 13.15b, 13.15c, 1 3.16a, 13.16b, 13.17, 13.18a, 13.18b, 13.18c, 13.19, 13.20, 13.21, 13.22
12	Module 15: Gas Turbine Engine Submodules: 15.1, 15.2, 15.3, 15.4, 15.5, 15.6, 15.7, 15.8, 15.9, 15.10, 15.11, 15.12, 15.13, 15.14, 15.15, 15.16, 15.17, 15.18, 15.19, 15.20, 15.21, 15.22	Module 14: Propulsion Submodules: 14.1a, 14.1b, 14.2, 14.3
13	Module 17A: Propeller Submodules: 17.1, 17.2, 17.3, 17.4, 17.5, 17.6, 17.7	

Source(s): Authors' own work

which represent the depth and complexity of knowledge expected for each module and submodule.

These requirements are defined in EASA Part 66 (EASA, 2022a, 2022b, 2022c) and specify the level of knowledge necessary for each licensing category. Table 8 illustrates these requirements for B1.1 Licence Category, Module 6, as an example.

EASA Part 66 outlines three distinct knowledge levels:

1 *Level 1:* A familiarization with the principal elements of the subject.
2 *Level 2:* A general knowledge of the theoretical and practical aspects of the subject. An ability to apply that knowledge.
3 *Level 3:* A detailed knowledge of the theoretical and practical aspects of the subject. A capacity to combine and apply the separate elements of knowledge in a logical and comprehensive manner.

It is evident from these definitions that modules requiring higher knowledge levels demand greater training duration. Consequently, rather than allocating the total training hours solely based on reference bases such as theoretical training content intensity and theoretical evaluation content intensity, it was necessary to adjust the allocation in accordance with weighted reference bases. These weighted values account for the differing training demands imposed by varying knowledge levels.

Weighted theoretical training content intensity and weighted theoretical evaluation content intensity were obtained by applying a multi-criteria decision-making approach in which the AHP was used. By using the AHP, first the weight factors corresponding to each knowledge level were found. Next, the weighted reference bases (weighted theoretical training content intensity and weighted theoretical evaluation content intensity) were calculated for each submodule by multiplying the corresponding weight factors with the corresponding reference bases (theoretical training content intensity and theoretical evaluation content intensity).

The aviation sector constitutes a complex system composed of numerous subsystems, where safety and reliability are paramount. Aircraft Maintenance Training represents one such critical subsystem. Aviation regulations issued by EASA and local aviation authorities strive to standardize this training. In situations where regulations do not provide specific guidance, the application of scientific decision-making methodologies becomes necessary to mitigate subjective biases in the decision-making process.

The AHP is a widely used multi-criteria decision-making method for addressing intricate decision problems. A review of the existing literature reveals a lack of research employing a formal decision-making process for determining the training durations of modules in basic aircraft maintenance training. However, studies using the AHP in relation to aircraft maintenance and training processes are briefly summarized below.

Wang *et al.* (2009) integrated AHP and fuzzy logic methodologies for the analysis and evaluation of human factors in aviation maintenance processes. Their study, grounded in the SHEL and Reason Models, developed a detailed classification of human errors and a causal analysis. Subsequently, an integrated approach combining fuzzy logic and AHP was proposed. Findings from a case study indicated that noise and vibration, professional ethics and responsibility, safety information sharing and software and document integrity held significant weight at the first-level indices. The study concluded that this comprehensive evaluation method could serve as an effective decision support tool for preventing human errors and enhancing safety within maintenance organizations.

In another study, Alharasees and Kale (2023) applied AHP as a multi-criteria decision-making method for supplier selection within the aviation industry. Recognizing the critical role of the supply chain in maintaining the reliability and performance of complex air transport systems amidst increasing demand, the necessity and challenges associated with defining quality performance indicators were emphasized. To this end, a three-level hierarchical model was constructed involving four distinct professional groups: pilots, air traffic controllers, aircraft maintenance personnel and aviation managers. The AHP method was then used to analyze the key components of supply chain quality in air transportation.

Song and Li (2012) used AHP to evaluate student maintenance competencies in a virtual maintenance environment, proposing an evaluation methodology. The research initially presented the mathematical model of AHP, followed by the development of a virtual maintenance environment for aircraft maintenance organizations and the creation of an evaluation index system and model for the provided maintenance training. The study concluded by offering the design of an evaluation system that integrates quantitative and qualitative analysis, thereby enhancing the objectivity and scientific basis of the decision-making process by mitigating the influence of human factors.

The reviewed literature demonstrates the successful application of the AHP method in various decision-making processes within the aviation domain, including the evaluation of human factors, supplier selection and maintenance strategies. These studies underscore AHP's capability to address complex, multi-criteria problems and the structured, analytical approach it brings to decision-making in a critical sector such as aviation.

This research aims to address a notable gap in the literature by applying the AHP method to the calculation and standardization of aircraft maintenance training durations, an area that has not yet been explored. In this context, the principles and approaches of existing AHP applications in the literature can be considered as a foundation and source of inspiration for this study.

The AHP, is also known as the Saaty method (Saaty, 1980). It is a popular method in decision-making and used in a wide range of applications. It is based on constructing a matrix expressing the relative values of a set of attributes. The scale that has been used in this study for relative values in accordance with the Saaty Method is given in Table 4. In the AHP, pairwise comparisons are carried out for all factors, and the matrix is completed. Then, a list of relative weights, importance or value, of the factors (the eigenvector) is calculated. Finally, a consistency ratio (CR) is calculated to measure how consistent the judgments are relative to large samples of purely random judgments. If the CR is much in excess of 0.1, the judgments are untrustworthy because they are too close for comfort to randomness and the exercise is valueless or must be repeated (Saaty, 1980).

The formulization of the AHP is as follows:

$$A = a_{ij} \quad (1)$$

$$i \neq j \quad (2)$$

Table 4 Rating scale for relative values

Intensity	Definition	Explanation
1	Equal time	Their durations are the same
3	Somewhat more time	Experience and judgment allocates a slight amount of more time to one than the other
5	Much more time	Experience and judgment allocates a strong amount of more time to one than the other
7	Very much more time	Experience and judgment allocates a very strong amount of more time to one than the other. Its duration is demonstrated in practice
9	Absolutely more time	The evidence allocating more time to one over the other is of the highest possible validity
2, 4, 6, 8	Intermediate values	When compromise is needed

Source(s): Authors' own work

$$a_{ij} = \frac{1}{a_{ji}} \quad (3)$$

$$a_{ii} = 1 \quad (4)$$

$$a_{ik} = a_{ij}.a_{jk} \quad (5)$$

$$A.\omega = \lambda.\omega \quad (6)$$

$$\lambda = n \quad (7)$$

$$A.\omega = \lambda_{max}.\omega \quad (8)$$

$$\lambda_{max} \geq n \quad (9)$$

$$\lambda_{max} = n \quad (10)$$

$$TE = \frac{(\lambda_{max} - n)}{(n-1)} \quad (11)$$

With n elements to be compared, $C_1 \ldots C_n$ denote the relative weight (or priority or significance) of C_i with respect to C_j by a_{ij} and for a square matrix of order n given in equations (1)–(3) holds and equation (4) holds for all i. Such a matrix is called a reciprocal matrix. The weights are consistent if they are transitive, i.e. Equation (5) holds for all i, j, k. Such a matrix might exist if the a_{ij} are calculated from exactly measured data. Then a vector ω of order n such that equation (6) is satisfied is found. For such a matrix, ω is called the eigenvector and λ is called the eigenvalue.

Table 5 Random index matrix

Order of the random index matrix	Index of consistency for random judgments
1	0.00
2	0.00
3	0.58
4	0.90
5	1.12

Source(s): Authors' own work

For a consistent matrix, equation (7) holds. For matrices involving human judgment, equation (5) does not hold as human judgments are inconsistent to a greater or lesser degree. In such a case, the ω vector satisfies equations (8) and (9). The difference, if any, between λ_{max} and n is an indication of the inconsistency of the judgments. If equation (10) is satisfied, then the judgments have turned out to be consistent. Finally, a consistency index can be calculated from equation (11) that needs to be assessed against judgments made completely at random. Saaty has calculated large samples of random matrices of increasing order and the consistency indices of those matrices. The random matrix index is given in Table 5 (Saaty, 1980). A true CR is calculated by dividing the consistency index for the set of judgments by the index for the corresponding random matrix. If the ratio exceeds 0.1, the set of judgments may be too inconsistent to be reliable. In practice, CRs of more than 0.1 sometimes have to be accepted. If the CR equals zero, then the judgments are perfectly consistent (Saaty, 1980).

With the purpose of obtaining the weight factors corresponding to Knowledge Levels 1, 2 and 3, the AHP questionnaire given in Table 6 was prepared. This questionnaire was answered by 19 Theoretical Trainers of the Atılım University School of Civil Aviation. Although a sample size of 19 is quite small, and will become even smaller after inconsistent results are excluded, it is sufficient for the purpose of this study. The purpose of this study is not to obtain standard basic theoretical maintenance training durations but to demonstrate the suggested theoretical method.

By using the given formulation, an AHP Solver was developed via the Microsoft Excel tool. Values obtained from examples present in literature were input to the AHP Solver and the output of the AHP Solver was compared to the corresponding results in literature. The AHP Solver was validated upon obtaining the same results.

By using the developed AHP tool, 13 out of 19 question sheets returned CRs less than 0.1 (i.e. consistent results). The resulting weight factors of each knowledge level was obtained by calculating the arithmetic average of consistent results. The result is given in Table 7.

Step 5: transformation of the reference bases to weighted reference bases

Weighted reference bases (weighted theoretical training content intensity and weighted theoretical evaluation content intensity) were calculated for each submodule by multiplying the corresponding weight factors given in Table 7 with the

Table 6 AHP questionnaire

Comparison crtieria 1	*9*	*8*	*7*	*6*	*5*	*4*	*3*	*2*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	Comparison criteria 2
Level 1 training																		Level 2 training
Level 1 training																		Level 3 training
Level 2 training																		Level 3 training

Note(s): In each row, please compare the amount of time you would spend for lecturing a theoretical topic and training content in accordance with the knowledge level given in the first column and the time you would spend for lecturing the same theoretical topic and training content in accordance with the knowledge level given in the last column. Place a single "X" mark in only one cell in each row, towards the side (left/right) you would spend more time on. Choose on which cell (1, 2, 3, 4, 5, 6, 7, 8, 9) to place the "X" mark according to the rating scale.
Source(s): Authors' own work

Table 7 Weight factors to be used in the transformation of the reference bases to weighted reference bases

Intensity	Definition
1	0.107
2	0.246
3	0.647

Source(s): Authors' own work

corresponding reference bases (theoretical training content intensity and theoretical evaluation content intensity). The weighted reference bases are given in Table 8 for exemplary purposes for licence category B1.1 Module 6 only.

Step 6: performing the calculations to obtain the distribution of the basic theoretical maintenance training duration amongst the modules and submodules

Having obtained the Weighted Reference Bases for all modules and submodules of B1.1 and B2 licence categories, calculations were done to obtain the distribution of the basic theoretical maintenance training duration amongst the modules and submodules. In this calculation, first of all, the arithmetic average of the weighted theoretical training content intensity and the weighted theoretical evaluation content intensity was calculated since the TTS (Total Training Support Ltd., 2016) content, ICAT [Cardiff and Vale College ICAT (International Centre for Aerospace Training), 2011] content and number of module exam questions are all references of equal importance for the purpose of this study. Next and finally, the total duration of basic theoretical maintenance training (calculated as 1,324.8 h in the first step of the study) was distributed (/allocated) to the modules and submodules directly proportional to the afore calculated arithmetic average.

Results and discussion

As a result of applying the theoretical method, the basic theoretical maintenance training durations for each module and submodule comprising the B1.1 and B2 licence categories were obtained. The results are presented in Figures 3 and 4.

When the resulting basic theoretical maintenance training durations are ordered from highest to lowest, the orders obtained are as given in Table 9. The order given in Table 9 is as expected as it is natural for the module with greater theoretical training content intensity and greater theoretical evaluation content intensity to have greater basic theoretical maintenance training durations. Where Module 11A is found to have the largest duration in the B1.1 licence category, Module 13 is found to have the largest duration in the B2 licence category. The facts that the common modules of both categories such as Modules 7A, 2, 8 and 9A are in the same orders for both licence categories and Modules 6, 10 and 1 are in adjacent orders for both licence categories increases confidence in the theoretical method used in this study.

It is known that the theoretical training and evaluation contents of Modules 1, 3, 8, 9A and 10 are exactly the same for B1.1 and B2 licence categories. These modules are the common modules of B1.1 and B2 licence categories. Therefore, it is expected that these modules should be allocated the same durations for both licence categories. The resulting basic theoretical maintenance training durations are compared in Table 10. It is obtained that the durations differ from each other by only a maximum of 2.1% between the two licence categories. This result demonstrates that the theoretical method used in this study is robust.

Although not presented here for the purpose of simplicity, basic theoretical maintenance training durations of each submodule of licence categories B1.1 and B2 have also been calculated. These durations are the durations that add up to the basic theoretical maintenance training durations of the modules of licence categories B1.1 and B2.

Calculated basic theoretical maintenance training durations of the modules of licence categories B1.1 and B2 resulting from the theoretical method were compared to those durations of different aircraft basic maintenance training organizations. The results are presented in Figures 5 and 6. Next, calculated basic theoretical maintenance training durations of the modules of licence categories B1.1 and B2 resulting from the theoretical method were compared to the average of all training organizations' basic theoretical maintenance training durations and the results are presented in Tables 11 and 12. When these results are analyzed, it is noticed that in both licence categories:

- The largest positive percent differences are obtained in the first two modules that yielded the largest durations according to the theoretical method. This result demonstrates that the approach of allocating greater theoretical maintenance training durations to modules having greater theoretical training and evaluation content intensity has not been generally adapted by the subject aircraft basic maintenance training organizations.
- Vice versa, negative percent differences are obtained for the modules that yielded lower durations according to the theoretical method. This result demonstrates that the approach of allocating lower theoretical maintenance training durations to modules having less theoretical training and evaluation content intensity has not been generally adapted by the subject aircraft basic maintenance training organizations.

Next, the ranking of the modules according to their basic theoretical maintenance training durations was compared for that calculated with the theoretical method and that obtained from the average of the different basic maintenance training organizations. The results are presented in Table 13. Analyzing these results, it is found that, a similarity does not exist in the modules' ranking in terms of basic theoretical maintenance training durations.

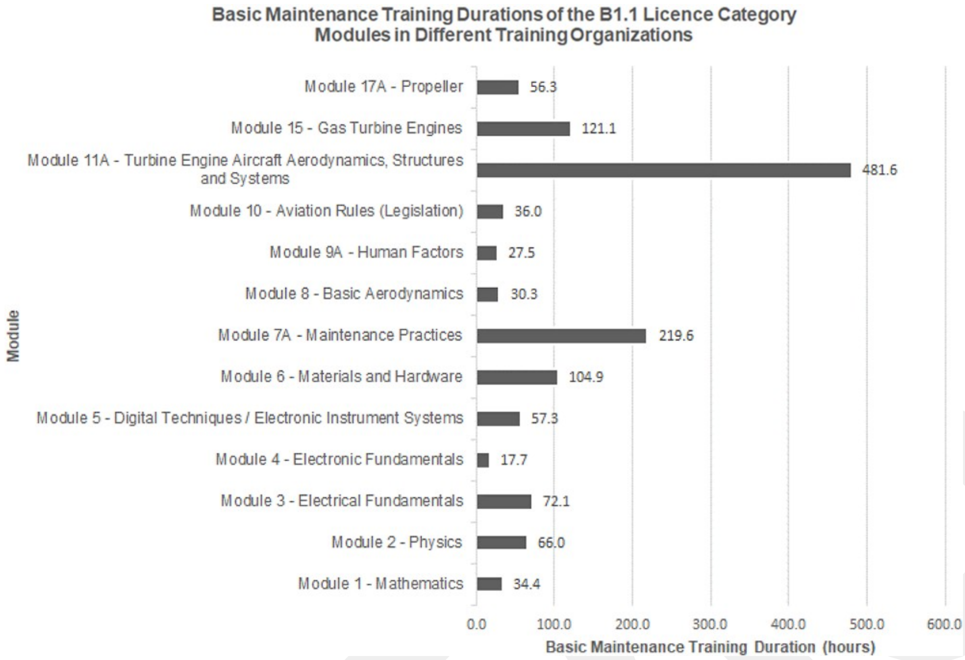
In this study, a scientific theoretical method to determine the durations of the basic theoretical maintenance trainings was developed and demonstrated with a small sample consisting of 19 Theoretical Trainers of the Atılım University School of Civil Aviation and 13 consistent answers. The obtained basic theoretical maintenance training durations for each module of licence category B1.1 and B2 are solely demonstrations of the developed method and not suggestions for worldwide use in different aircraft basic maintenance training organizations. Nevertheless, for a global application and to obtain a standardization in the durations of the basic theoretical maintenance trainings among different aircraft basic maintenance training organizations, the following steps can be applied:

Table 8 Weighted reference bases for Category B1.1 Module 6

Submodule no.	Required knowledge level	Module exam question level	Weight factor	Theoretical training content intensity: No. of pages in ICAT	Theoretical training content intensity: No. of pages in TTS	Theoretical evaluation content intensity: No. of module exam questions	Weighted theoretical training content intensity: Weighted number of pages in ICAT	Weighted theoretical training content intensity: Weighted number of pages in TTS	Weighted theoretical evaluation content intensity: Weighted number of module exam questions
6.1a	2	2	0.246	39	30	4	9.594	7.38	0.984
6.1b	1	1	0.107	19	32	3	2.033	3.424	0.321
6.2a	2	2	0.246	41	46	5	10.086	11.316	1.23
6.2b	1	1	0.107	4	2	2	0.428	0.214	0.214
6.3.1a	2	2	0.246	47	26	5	11.562	6.396	1.23
6.3.1b	2	2	0.246	27	44	3	6.642	10.824	0.738
6.3.2	2	2	0.246	42	38	3	10.332	9.348	0.738
6.3.3	2	2	0.246	31	42	3	7.626	10.332	0.738
6.4a	1	1	0.107	7	19	3	0.749	2.033	0.321
6.4b	3	3	0.647	30	12	5	19.41	7.764	3.235
6.5.1	2	2	0.246	33	14	3	8.118	3.444	0.738
6.5.2	2	2	0.246	69	30	4	16.974	7.38	0.984
6.5.3	2	2	0.246	29	18	2	7.134	4.428	0.492
6.5.4	2	2	0.246	29	32	3	7.134	7.872	0.738
6.6a	2	2	0.246	27	10	2	6.642	2.46	0.492
6.6b	2	2	0.246	5	4	2	1.23	0.984	0.492
6.7	2	2	0.246	25	14	2	6.15	3.444	0.492
6.8	2	2	0.246	24	10	3	5.904	2.46	0.738
6.9	2	2	0.246	31	20	4	7.626	4.92	0.984
6.10	2	2	0.246	30	22	5	7.38	5.412	1.23
6.11	2	2	0.246	29	42	6	7.134	10.332	1.476

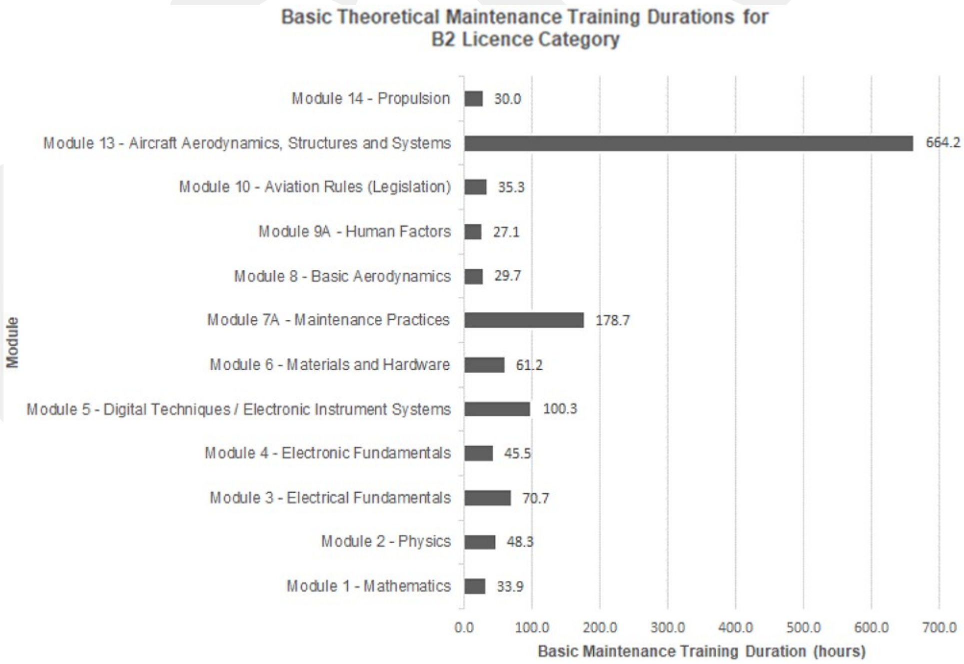
Source(s): Authors' own work

Figure 3 Obtained basic theoretical maintenance training durations for B1.1 licence category modules



Source: Authors' own work

Figure 4 Obtained basic theoretical maintenance training durations for B2 licence category modules



Source: Authors' own work

- Within an international effort, the developed method can be applied in all relevant countries.
- During this effort, different training and evaluation resources (books, training notes, number of exam question requirements regulated by other local civil aviation authorities etc.) can be found and added to the method.
- During this effort, it would be possible to significantly expand the sample size of the AHP. The AHP questionnaires could

Table 9 Obtained basic theoretical maintenance training durations in descending order for licence categories B1.1 and B2

	Licence category B1.1		Licence category B2	
Order (from highest to lowest)	Module	Ratio of module duration to total duration (%)	Module	Ratio of module duration to total duration (%)
1	Module 11A – Turbine Engine Aircraft Aerodynamics, Structures and Systems	36.3	Module 13 – Aircraft Aerodynamics, Structures and Systems	50.1
2	Module 7A – Maintenance Practices	16.6	Module 7A – Maintenance Practices	13.5
3	Module 15 – Gas Turbine Engines	9.1	Module 5 – Digital Techniques / Electronic Instrument Systems	7.6
4	Module 6 – Materials and Hardware	7.9	Module 3 – Electrical Fundamentals	5.3
5	Module 3 – Electrical Fundamentals	5.4	Module 6 – Materials and Hardware	4.6
6	Module 2 – Physics	5.0	Module 2 – Physics	3.6
7	Module 5 – Digital Techniques / Electronic Instrument Systems	4.3	Module 4 – Electronic Fundamentals	3.4
8	Module 17A – Propeller	4.2	Module 10 – Aviation Rules (Legislation)	2.7
9	Module 10 – Aviation Rules (Legislation)	2.7	Module 1 – Mathematics	2.6
10	Module 1 – Mathematics	2.6	Module 14 – Propulsion	2.3
11	Module 8 – Basic Aerodynamics	2.3	Module 8 – Basic Aerodynamics	2.2
12	Module 9A – Human Factors	2.1	Module 9A – Human Factors	2.0
13	Module 4 – Electronic Fundamentals	1.3		

Source(s): Authors' own work

Table 10 Basic theoretical maintenance training durations of the common modules of licence categories B1.1 and B2

Module	Basic theoretical maintenance training duration of licence category B1.1	Basic theoretical maintenance training duration of licence category B2	Percent difference (%)
Module 1 – Mathematics	34.4	33.9	1.5
Module 3 – Electrical Fundamentals	72.1	70.7	2.0
Module 8 – Basic Aerodynamics	30.3	29.7	1.8
Module 9A – Human Factors	27.5	27.1	1.8
Module 10 – Aviation Rules (Legislation)	36.0	35.3	2.1

Source(s): Authors' own work

be answered by theoretical trainers of different aircraft basic maintenance training organizations worldwide.

- During this effort the applicability of different multi-criteria decision-making approaches can be evaluated, if applicable different approaches (such as Analytic Network Process, Aggregated Indices Randomization Method, etc.) can be implemented in the theoretical method.
- By using the worldwide collected data as an input to the theoretical method, the results can be obtained. These obtained results would be the candidate international standard basic theoretical maintenance training durations.
- Participation of international aviation authorities, especially the participation of EASA and FAA to this international effort would be crucially important for the dissemination of the results. For the successful standardization of the obtained basic theoretical maintenance training durations, these durations should be issued as requirements in the relevant regulations of the international civil aviation authorities.
- Only after this step, if the local civil aviation authorities also issue the same requirements in their relevant regulations, the standardization can be achieved.
- Finally, all aircraft basic maintenance training organizations worldwide can develop their curriculums to comply to these requirements for international standard basic theoretical maintenance training durations. Since developing standard curriculum is viewed as a broad subject related to, course/training content, evaluation content, academic/national regulations, etc., it has the potential of being future work.

Conclusion

Overall results of this study demonstrate that there is no standardization upon aircraft basic maintenance training organizations for the allocation of the basic maintenance training durations to modules. To remedy this problem, a scientific method which relies on quantifiable reference bases rather than subjective reasoning is needed. The reference bases of the proposed theoretical method (i.e. theoretical training and evaluation content intensity) can be tuned with the inclusion of the effect of basic knowledge requirements through multi-criteria decision-making (AHP). The theoretical method proposed in this work is robust in terms of resulting in close

Figure 5 Comparison of basic theoretical maintenance training durations of licence category B1.1 obtained from the theoretical method with those of different training organizations

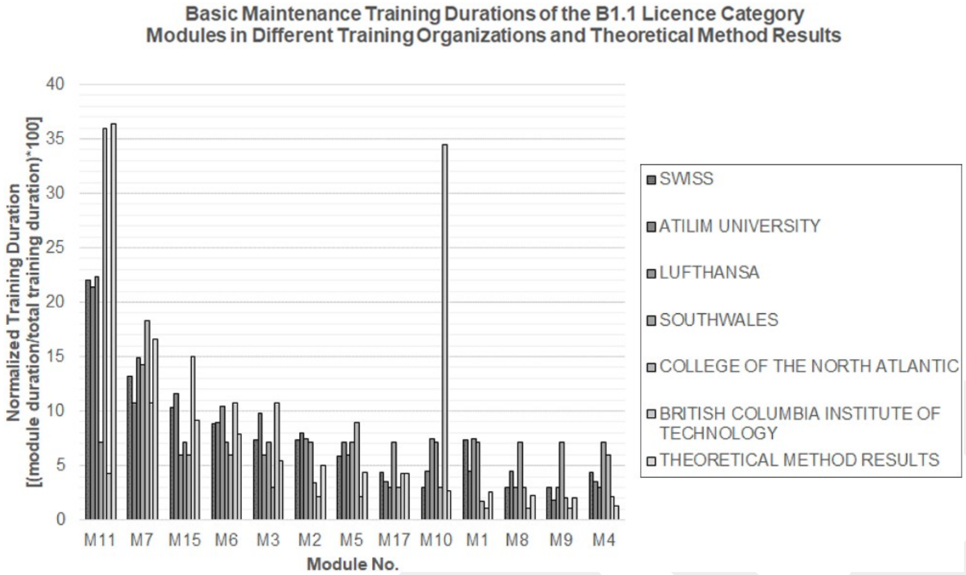


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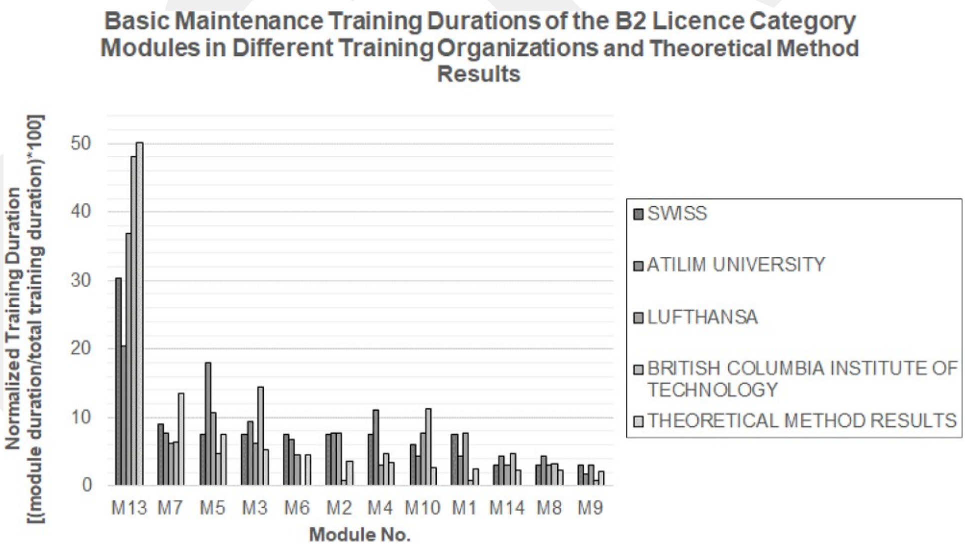
Figure 6 Comparison of basic theoretical maintenance training durations of licence category B2 obtained from the theoretical method with those of different training organizations



Source: Authors' own work

proximity values of the basic theoretical maintenance training durations for the common modules of B1.1 and B2 licence categories. The theoretical method is proven to yield greater basic theoretical maintenance training durations for modules having greater theoretical training and evaluation content intensity, and lower basic theoretical maintenance training durations for modules having less theoretical training and evaluation content intensity. A distinct similarity in terms of basic theoretical maintenance training durations and the ranking of the modules (in terms of durations) is not present when the average of the training organizations is compared to the results of the theoretical method. Therefore, it can be concluded that this study fills the existing gap in training standardization by suggesting a scientific theoretical method

Table 11 Comparison of basic theoretical maintenance training durations of licence Category B1.1 obtained from the theoretical method with the average training durations of different training organizations

Module	Durations obtained from the theoretical method (normalized values)	Average training durations of different training organizations (normalized values)	Percent difference (%)
Module 11A	36.4	18.9	92.6
Module 7A	16.6	13.7	21.0
Module 15	9.1	9.3	−2.1
Module 6	7.9	8.7	−8.7
Module 3	5.4	7.3	−25.8
Module 2	5.0	5.9	−15.8
Module 5	4.3	6.2	−30.3
Module 17A	4.2	4.2	0.4
Module 10	2.7	9.9	−72.6
Module 1	2.6	4.9	−46.6
Module 8	2.3	3.6	−36.4
Module 9A	2.1	3.0	−30.6
Module 4	1.3	4.4	−69.4

Source(s): Authors' own work

Table 12 Comparison of basic theoretical maintenance training durations of licence Category B2 obtained from the theoretical method with the average training durations of different training organizations

Module	Durations obtained from the theoretical method (normalized values)	Average training durations of different training organizations (normalized values)	Percent difference (%)
Module 13	50.1	33.9	47.7
Module 7A	13.5	7.3	83.9
Module 5	7.6	10.3	−26.3
Module 3	5.3	9.4	−43.1
Module 6	4.6	4.8	−2.9
Module 2	3.6	5.9	−38.6
Module 4	3.4	6.6	−48.3
Module 10	2.7	7.3	−63.5
Module 1	2.6	5.1	−49.7
Module 14	2.3	3.8	−40.3
Module 8	2.2	3.4	−34.0
Module 9A	2.0	2.2	−5.0

Source(s): Authors' own work

based on a systematic, multi-criteria decision-making approach to determine the durations of the basic theoretical maintenance trainings.

In this study, a scientific theoretical method to determine the durations of the basic theoretical maintenance trainings was developed and demonstrated. The steps that can be followed to obtain a standardization among different aircraft basic maintenance training organizations for the basic theoretical maintenance training durations was also introduced. The end result of this study, which is the developed and demonstrated theoretical method would especially be useful in an international effort to standardize the different basic theoretical maintenance training durations applied in various aircraft basic maintenance training organizations. Such a standardization would eventually result in the basic maintenance training programs or curriculums of different aircraft basic maintenance training organizations to be commensurate. Therefore, it is assessed that the results of this study would be beneficial in; determining course exemptions in the case of student transfers from one aircraft basic maintenance training organization to another or in the case of a student participating to the ERASMUS program. It is assessed that use of the results of this study will provide efficacious basic theoretical maintenance training durations, which will ensure effective learning. By means of this standardization the maintenance personnel can be trained to common qualification levels. Increased qualification levels of maintenance personnel have a strong possibility of increasing the quality of the crucially important

Table 13 Comparison of the ranking of modules in terms of basic theoretical maintenance training durations

Ranking (from largest duration to smallest duration)	B1.1 Licence Category		B2 Licence Category	
	Theoretical method	Average of different training organizations	Theoretical method	Average of different training organizations
1	Module 11A	Module 11A	Module 13	Module 13
2	Module 7A	Module 7A	Module 7A	Module 5
3	Module 15	Module 10	Module 5	Module 3
4	Module 6	Module 15	Module 3	Module 7A
5	Module 3	Module 6	Module 6	Module 10
6	Module 2	Module 3	Module 2	Module 4
7	Module 5	Module 5	Module 4	Module 2
8	Module 17A	Module 2	Module 10	Module 1
9	Module 10	Module 1	Module 1	Module 6
10	Module 1	Module 4	Module 14	Module 14
11	Module 8	Module 17A	Module 8	Module 8
12	Module 9A	Module 8	Module 9A	Module 9A
13	Module 4	Module 9A		

Source(s): Authors' own work

and complex maintenance processes performed in Part-M and Part-145 organizations.

Further work

With the aim of obtaining an international standard for the aircraft basic theoretical maintenance training durations, planned future work contains, initiation and conduct of work to apply the developed and demonstrated scientific theoretical method in an international effort following the related steps suggested in this study. The planned future work can be followed by development of standard curriculum for aircraft basic maintenance training organizations. Other planned future work consists of developing and demonstrating a scientific theoretical method to determine basic practical maintenance training durations.

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