An Agile Compliance Framework for the European Cooperation for Space Standardization

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Abstract*— Agile methodologies have become increasingly popular for enhancing quality and customer satisfaction, shortening delivery times, decreasing risk in changing environments, and improving team morale and productivity for a wide variety of complex systems. However, there is limited research regarding how agile attributes and principles can help achieve high European Cooperation for Space Standardization (ECSS) compliance levels, resulting in increased Technology Readiness Levels (TRL) and commercialization potential for the product. Accordingly, the objectives of this research are to identify and prioritize the level of significance of the critical attributes for the successful implementation of agile project management in the space industry and develop an agile framework for ECSS compliance. A multi-phase research methodology was adopted, including a systematic literature review to identify the main attributes of Agile ECSS compliance; surveys to assess the identified attributes; Analytical Hierarchy Process(AHP)-based model to quantify their level of significance; semi-structured interviews with aerospace experts to develop an Agile framework for ECSS compliance; and Lego Serious Play with start-ups decision makers to validate the developed framework. Based on the adopted methodology, the authors identified a total of 43 Agile attributes grouped under seven categories, namely organizational-related, management-related, project-related, process-related, technical-related, team-related, and customer-related attributes. Depending on the AHP analysis of the identified attributes, a five-level agile ECSS compliance framework was developed. Level 1 includes leadership vision and mission attributes. Level 2 includes team commitment and top management support attributes. Level 3 includes joint understanding of uncertainty attribute. Furthermore, level 4 includes technical training and learning, manufacturing system flexibility and customer involvement attributes. Finally, Level 5 includes ECSS compliance and its linkage to the TRL of the product and the process of product commercialization. The results of this study have several implications for researchers and practitioners. First, it provides an in-depth understanding of the AHP method for determining the priorities for the identified agile attributes, which could aid researchers and practitioners working in other space hardware and software engineering domains to implement the AHP method. Second, the 43 identified agile attributes provide a knowledge base classification/taxonomy for practitioners to assist in scaling agile development. Third, the developed compliance framework clarifies the interdependencies among the critical agile attributes, which can assist in identifying the required capabilities necessary to achieve business excellence.

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1. INTRODUCTION

The dynamics of product development processes for space systems differ from those of other domains. The design and development of hardware or software for space applications pose additional challenges because the end products must be highly dependable [1]. In the European space industry, the European Cooperation for Space Standardization (ECSS) standards are commonly required by customers [2]. The ECSS standards were developed jointly by the European Space Agency, national space agencies, and the European space industry; they represent a single set of standards for European space projects [3], [4]. ECSS standard system includes four branches, namely Management (M), Engineering (E), Product Assurance (Q), and Sustainability (S). To ensure completeness and correctness, ECSS standards forces suppliers for different types of review; Preliminary Design Review, Critical Design Review, Detailed Design Review and Site Acceptance Test., etc. Due to factors such as market pressure, globalization, changes in political priorities, increased expectations on hardware and software systems in general, and increased competition, the space industry is pressed to design and develop products with high functionality at lower costs and with shorter delivery times [5]. To address these challenges, it is imperative that the industry must continually evaluate product development methods and determine how to improve them to meet the unique requirements of each product.

Agile methodologies are becoming increasingly popular for a wide variety of complex systems given their demonstrated ability to [6]: (1) enhance quality; (2) enhance prioritization; (3) shorten delivery time; (4) enhance customer satisfaction; (5) decrease risk in changing environments; and (6) improve team morale and productivity. However, there is limited research regarding how agility attributes and principles can help achieve high ECSS compliance levels, which will ultimately increase the product's Technology Readiness Levels (TRL) and commercialization potential.

Previous studies have either focused on the key challenges facing ECSS compliance [7], or ECSS compliance awareness [8], [9]. To the best of our knowledge, no study has examined the significance of key agile attributes and their effect on ECSS compliance. Accordingly, the objectives of this paper are to identify and prioritize the level of significance of the critical attributes for the successful implementation of agile project management in the space industry and develop an agile framework for ECSS compliance.

2. Methodology

As shown in Figure 1, this research follows a multiphase methodology. Each of the phases is described in the following subsections.

Phase One: Data Collection

A. Systematic Literature Review

The literature review is an effective method of gaining insight into a particular research area and evaluating what is currently known on the subject [10]. The review methodology employed in this research has been extensively applied in engineering project management research studies [11]. There were five steps involved in the systematic literature review, including search engines identification, journals selection, keywords identification, articles selection, and factors identification and classification.

Step One: Search Engines Identification

In this research, the authors targeted journals with a strong reputation in project management and engineering. The search for these journals was conducted using Emerald Insight, IEEE Explore, Google Scholar, Science Direct, Pro Quest, Springer, and Taylor and Francis search engines.
These search engines were selected since they cover most publication databases in different research areas and have been extensively used in similar literature review studies in the field of agile project management [12].

Step Two: Journals Selection

Journals were selected based on three criteria: (1) the journals must be published in English language, (2) the journals must be included in Scopus journal and/or Clarivate metrics, and (3) the journals must have an impact factor of at least 1.0.

Step Three: Keywords Identification

The keywords used in the search for published articles included: agility, agile project management, agile for aerospace, agile for manufacturing, agile for software

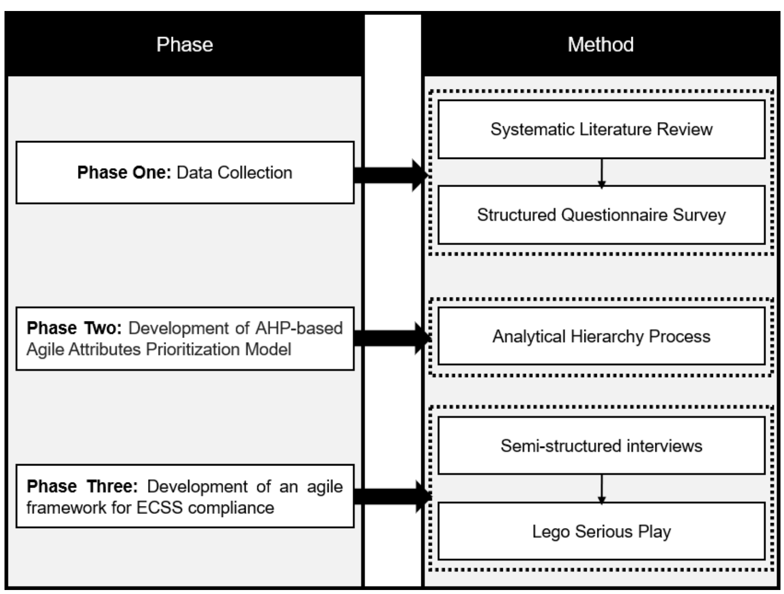

Figure 1. Overall research methodology

development, and critical success factors. The authors chose most of the keywords for this research based on previously published articles that align with this research focus (see e.g., [13], [12], and [14]).

Step Four: Article Selection

After identifying the relevant keywords, the authors selected the relevant research papers based on the following criteria: (1) the articles must address critical success factors for aerospace, manufacturing or software development, and (2) the articles in each journal should be dated within the past 12 years. Furthermore, several conference papers published by reputed bodies like IEEE were selected for this study due to its relevance**.** Ultimately, the database search led to the collection of 127 research papers. However, after screening and taking into consideration the adopted selection criteria, the authors included a total of 48 research articles in the literature review analysis.

Step Five: Content Analysis

Once the relevant articles were identified, the authors performed a detailed qualitative content analysis manually to (1) evaluate the suitability of the articles retrieved from each journal for further analysis; (2) identify the attributes for successful implementation of agile project management for the space industry.

According to [15], content analysis is a method for making replicable and valid inferences about texts based upon the contexts in which they are used. This method provides a powerful aid to organize information and examine patterns and trends in documentary data [15]. There are three distinct approaches to content analysis: conventional, directed, and summative. In the present study, we employed a conventional-type content analysis, which is well-suited to the identification of factors and is frequently utilized in the engineering project management literature (see, e.g., [11]).

B. Structured Questionnaire Survey

The identified agile attributes for successful implementation of agile project management were used in a structured survey (i.e., AHP based survey) to capture the weights of the identified agile attributes and their categories. The survey included two sections. The first section was concerned with the background information of the targeted research sample (research sample characteristics), for example, the working sector, role and years of experience. In the second section, experts were asked to compare the values of each criteria and sub-criteria with respect to the other criteria and sub-criteria in the pair-wise comparison matrices depending on the analysis criteria values (matrices goals).

Phase Two: Development of AHP-based Agile Attributes Prioritization Model

The purpose of this phase was to quantify and prioritize the level of significance of the identified agile attributes. The assessment model was developed under the AHP environment based on the notions of Saaty [16] and was extensively used by related work [17]. The AHP analysis procedure to rank the priorities of the agile attributes is summarized below:

First, the authors structured the elements of the problem into a hierarchy. For this purpose, the authors developed a hierarchical model consisting of three levels, namely the goal level (i.e., the prioritization of agile attributes), the criteria level (i.e., the categories of the identified attributes); and the sub-criteria level (i.e., the identified attributes).

Second, the authors created a set of (i X j) pair-wise comparison matrices for the criteria and sub-criteria levels with respect to the goal level. Tables 1 shows the values for the pair-wise matrices for the criteria and sub-criteria levels, respectively.

After collecting and computing the overall experts' judgments using the geometrical mean (Equation 1) they were placed into the pair-wise comparison matrix using Equation 2.

$$aij = \sqrt[u]{aij1 \text{ X } aij2 \text{ X} \dots \text{. X } aiju} \qquad (1)$$

where a_{ij} (i, j=1, 2, ..., u) represents the comparison ratios in the pairwise comparison matrix and u is the number of elements.

$$\mathrm{M} = \begin{vmatrix} a_{11} & \cdots & a_{1u} \\ \cdots & \cdots & \cdots \\ a_{u1} & \cdots & a_{uu} \end{vmatrix} \qquad (2)$$

where M refers to the pairwise comparison matrix; and has the following properties: $aij > 0$; $aij = (1/aij)$; $\forall\ i$ where j =1, 2, …, u.

Table 1. AHP pair-wise comparison scale [18]

Numerical scale	Description
1	Equal importance.
3	Moderate importance of one over another.
5	Strong importance.
7	Very strong importance.
9	Extreme importance.
2,4,6	Intermediate values between the two adjacent judgements.
1/3, 1/5, 1/9	Values of inverse comparison (If activity i has one of the above numbers assigned to It when compared with activity j, then j has the reciprocal value when compared with i)

After this, the authors calculated the normalized pair-wise values of the developed matrices (i.e., for the criteria and sub-criteria levels) by finding the summation of the elements (matrix cell's values) in each column using Equation 3 then dividing each element in each column by the summation of that column using Equation 4.

$$S = \sum_{i=1}^{u} aij \qquad (3)$$

$$N = aij / \sum_{i=}^{u} aij \quad (4)$$

Later, the weights of the factors $\{W\}$ (known as local priority), which indicates the relative importance levels of the criteria level were computed by averaging the matrices rows values.

Third, to check the consistency of the criteria level, the authors calculated the maximum or principal eigenvalue (called λmax) of each matrix of pair-wise comparisons. To achieve this, we obtained the weight sums vector $\{Ws\}$ using Equation 5. After this, we calculated the consistency vector $\{Cv\}$ using Equation 6 and computed the λmax value for each matrix by averaging the $\{Cv\}$.

$$\{Ws\} = [A]\,\{W\} \quad (5)$$

$$\{Cv\} = \{Ws\} * 1/\{W\} \quad (6)$$

After obtaining the λmax values for the analysis matrices, the next step was to calculate the consistency rations for all the reciprocal matrices using Equations 7 and 8 to calculate the consistency with respect to their preference weights.

$$\text{Consistency Ratio } (CR) = \frac{CI}{RI} \quad (7)$$

$$\text{Consistency Index } (CI) = \frac{\lambda\text{max} - z}{z-1} \quad (8)$$

where z is the number of criteria; λmax is the maximum eigenvalue; and *RI* is the consistency index of a pair-wise comparison matrix (obtained from Table 2). The matrix outputs are valid and consistent if the *CR* value is less than 10 %. If the *CR* value is equal to or more than 10%, the matrix results are inconsistent and should not be analyzed further [19].

Table 2. Consistency Index [18]

n*	2	3	4	5	6	7	8	9	10
RI	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

*n= size of the reciprocal matrix

Fourth, if the *CR* of the criteria matrix is within the accepted limit, then we take the analysis further by normalizing and checking the consistency of experts' decisions for the sub-criteria matrices using the same procedure indicated above.

Fifth, we calculate the global priority of the sub-criteria level, which indicates the overall criteria prioritization by multiplying the local priority matrix of the sub-criteria level with the local priorities of the criteria level.

Phase Three: Development of an agile framework for ECSS compliance

As part of this phase, we developed an ECSS compliance framework using the most significant agile attributes from each of the seven identified attribute categories determined through the AHP priority analysis. The relationship between the key agile attributes were determined by conducting a semi-structured interviews with space experts and Lego Serious Play (LSP) with project and engineering management experts in the UK.

The semi-structured interviews were conducted with nine space experts in the UK to (1) identify the main factors influencing ECSS compliance, and (2) establish the relationships between the identified key agile attributes for ECSS compliance. This method was used because it (1) enables the authors to gather more in-depth opinions and insights from industry experts about the issue beforehand [20]; and (2) is an effective method in explaining or exploring complicated phenomena or situations [21].

The LSP, which involves metaphorical modelling, Lego constructions, and peer discussion to explore complex issues, was conducted with a group of 10 project and engineering management experts (divided into 4 sub-groups) to further validate the relationship between the identified key agile attributes for ECSS compliance. This method was used to increase participants' engagement, imagination, and playfulness [22]. Its techniques heavily rely on story and the use of metaphor through the representation of one thing as another.

3. RESULTS AND ANALYSIS

Agile Attributes

In total, 43 agile attributes were identified following an extensive review and content analysis of the selected articles. Agile attributes identified from the selected articles were categorized into seven categories, namely Organizational-related factors, Management-related factors, Project-related factors, Process-related factors, Technical-related factors, Team-related factors, and Customer-related factors. Such classifications serve to illustrate the diversity of agile attributes and to assist in examining the breadth of exposure to possible attributes so that project parties do not overlook certain attributes while focusing on others. Table 3 presents the identified agile attributes along with the supporting references.

Table 3. The identified agile attributes and their categories.

Category	Agile attributes	Reference
Organizational-related factors	**F01.** Leadership Vision and Mission	[23], [24], [25]
	F02. Effective reward system, incentives and recognitions	[26], [27]
	F03. Continuous knowledge sharing	[28], [29]
	F04. Effective information sharing	[30], [31], [32]
	F05. Continuous information sharing	[29] [33]
	F06. Continual improvement in leadership	[34], [35], [36], [37], [38], [29], [25]

Table 3. ***Continued.***

Category	Agile attributes	Reference
	F07. Organizational culture awareness	[32], [39]
	F08. Cooperative organizational culture instead of hierarchical	[24], [25], [35], [40]
Management-related factors	**F09.** Top management support	[24], [25], [26], [27], [32] [41] [42]
	F10. Management commitment	[29], [38]
	F11. Clearly defined teams' roles and responsibilities.	[43], [44], [46]
	F12. Adaptive management	[35]
	F13. Managers with experience in agile processes	[26], [45], [47]
	F14. Management involvement	[23]
Project-related factors	**F15.** Joint understanding of uncertainty	[35]
	F16. Effective risk mitigation plan	[26], [48]
	F17. Dynamic delivery schedule	[13], [45], [47], [49]
	F18. Detailed and systematic project planning that addresses the varying customer requirements	[12]
Process-related factors	**F19**. Manufacturing system flexibility	[13]
	F20. Process flexibility	[13]
	F21. Priorities establishment	[35]
	F22. Effective requirements analysis	[45], [50]
	F23. Effective processes integration and delivery strategies	[45]
	F24. Effective processes monitoring and controlling	[24]
Technical-related factors	**F25.** Strong technical expertise of the project teams	[47], [51]
	F26. Technical training and learning	[26], [28], [29], [14]
	F27. IT integration	[13], [24], [34], [40], [52]
Team-related factors	**F28.** Team commitment	[24], [38]
	F29. Team size	[25], [28], [33], [53], [54].
	F30. Individual motivation and expertise	[14], [25], [26], [35], [41], [53], [54], [55], [57].
	F31. Strength of relationships with suppliers	[13], [29]
	F32. Highly skilled human resources	[30], [39], [44], [43], [58]
	F33. In time response between teams	[39], [59]
	F34. Strong communication focus with daily face-to-face meetings	[25], [26], [32], [35], [41], [45], [46], [59], [60].
	F35. Staff involvement	[32], [61]
	F36. Team performance	[60]
	F37. Team co-ordination	[29], [41], [55]

Table 3. ***Continued.***

Category	Agile attributes	Reference
Customer-related factors	**F38.** Customer training and education	[14], [24]
	F39. Customer involvement	[14], [24], [38], [45], [56]
	F40. Customer commitment	[26], [38]
	F41. Customer experience	[24]
	F42. Good customer bond	[26],[29]
	F43. Customer support	[24]

Survey Sample Characteristics

A total of seven survey forms were distributed to project management academics in the UK. Of the seven distributed surveys, five were returned and completed. The respondents to the survey were project management academics working in the higher education sector in the UK. The analysis of the survey respondents' characteristics indicated that 100% are employed in the public sector (i.e., public research universities). Additionally, the respondents held a variety of academic positions, including lecturers (80%) and associate professors (20%). Moreover, 60% of the respondents had 10 or more years of experience, while 40% had 1-5 years of experience.

Survey Sample Size Sufficiency

The key advantage of AHP over other multi-criteria decision making and prioritization methods is that it does not require a large sample size to produce sound and statistically robust results [62], [63]. In fact, the literature on AHP applications in engineering management studies indicates that there are no strict requirements regarding the sample size for AHP analysis. Several studies have used sample sizes ranging from four to nine [64]. To this end, the AHP survey was answered by five project management academics in the UK with knowledge of agile principles and methodologies. Accordingly, the obtained survey responses are deemed sufficient for the AHP analysis.

Agile Attributes Priorities

In total, nine reciprocal matrices were created to assist the respondents in performing pair-wise comparisons of the hierarchy's criteria and sub-criteria levels. Consistency ratios were computed to confirm the consistency of the experts' assessments throughout all reciprocal matrices. For the Organizational-related factors (CR=0.089<0.1), the most significant agile attribute was F01: vision and mission (Weight=36.2; Group Rank=1; Overall Rank= 6). For Management-related factors (CR=0.096<0.1), the most significant agile attribute was F09: top management support (Weight=58.8; Group Rank=1; Overall Rank= 2). For Project-related factors (CR = 0.011<0.1), the most significant agile attribute was F15: joint understanding of uncertainty (Weight=66.6; Group Rank=1; Overall Rank=1). For Process-related factors (CR = 0.054<0.1), the most significant agile attribute was F19: manufacturing system flexibility (Weight=49.1; Group Rank=1; Overall Rank=4). For Technical-related factors (CR = 0.056<0.1), the most significant agile attribute was F25: technical training and learning (Weight=55.9; Group Rank=1; Overall Rank=3). For Team-related factors (CR = 0.093<0.1), the most significant agile attribute was F26: team commitment (Weight=35.2; Group Rank=1; Overall Rank=7).

Finally, for Customer-related factors (CR = 0.088<0.1), the most significant agile attribute was F40: customer training and education (Weight=45.3; Group Rank=1; Overall Rank=5).

Table 4. The results of the AHP analysis

Code	Global Priorities (%)	Group Ranking	Overall Ranking
F01	36.2	1	6
F02	22.7	2	10
F03	20.5	3	13
F04	7.3	4	25
F05	5.2	5	31
F06	3.5	6	35
F07	2.0	8	40
F08	2.6	7	37
F09	58.8	1	2
F10	13.2	2	18
F11	7.9	4	23
F12	11.4	3	20
F13	6.5	5	27
F14	2.1	6	39
F15	66.6	1	1
F16	17.8	2	15
F17	9.6	3	21
F18	6.0	4	28
F19	49.1	1	4
F20	21.9	2	11
F21	18.0	3	14
F22	4.0	5	33
F23	4.2	4	32
F24	2.8	6	36
F25	55.9	1	3
F26	35.2	1	7
F27	8.9	3	22
F28	28.5	2	8
F29	21.8	2	12
F30	14.0	3	16
F31	13.2	4	18
F32	5.6	6	29
F33	6.8	5	26
F34	5.5	7	30
F35	1.4	10	43
F36	1.8	8	41
F37	1.5	9	42
F38	13.9	3	17
F39	26.9	2	9
F40	45.3	1	5
F41	7.8	4	24
F42	3.7	5	34
F43	2.4	6	38

Agile ECSS Compliance Framework

As mentioned in Stage Three of the research methodology, the ECSS compliance framework was developed using the most significant agile attributes from each of the seven identified attribute categories determined through the AHP priority analysis, and experts input via semi-structured interviews and LSP.

The developed framework presented in Figure 2 shows the key agile attributes influencing ECSS compliance. The framework components were organized into hierarchical levels depending on the attributes' level of influence observed from the LSP and the expert interviews. Level 1 includes leadership vision and mission attribute. Level 2 includes team commitment and top management support attributes. Level 3 includes joint understanding of uncertainty attribute. Furthermore, level 4 includes technical training and learning, manufacturing system flexibility and customer involvement attributes. Finally, Level 5 includes ECSS compliance and its linkage to the Technology Readiness Level (TRL) of the product and the process of product commercialization. The following sub-sections provide a detailed description of each level of the developed framework.

Level 1: Leadership Vision and Mission

The leadership vision and mission attribute is a foundational element which defines the ECSS compliance level. The clarity of the vision, its communication in appropriate written and oral forms, and the way it is translated into objectives and goals by project teams all play a significant role in their planning and execution. Leadership influences top management support, team commitment, and the level of technical training and learning through its comprehensiveness and quality of vision.

Level 2: Top Management Support and Team Commitment

In this context, top management support attribute is defined as the degree to which top management understands the importance ECSS compliance and are personally involved in the compliance planning and procedures. In fact, research has shown that agile methodologies were spontaneously adopted by teams as support for agile initiatives increased at the top management/corporate level [65]. Top management support directly influences team commitment, the joint understanding of uncertainty, customer involvement, and manufacturing flexibility.

Team commitment attribute on the other hand, is critical for developing an Agile culture. The commitment of Agile teams allows them to share responsibility together and build mutual trust. It also facilitates the identification of skills among team members. In addition, it fosters an environment of trust, which encourages higher team standards, synergy, and productive problem-solving [66]. Moreover, it provides a focus for continuous improvement, which facilitates adaptability and making changes based on empirical evidence. Further, it facilitates the development of a culture of transparency that allows an organization to experience the benefits of inspection and adaptation [67]. A team's commitment directly influences top management support and the understanding of the project's uncertainties.

Level 3: Joint Understanding of Uncertainty

Uncertainty refers to an absence of complete certainty; that is, the outcomes of any event are not known, and therefore cannot be predicted or measured [68]. In other words, uncertainty refers to events about which there is insufficient information to determine their probabilities of occurrence. Understanding project uncertainties by project teams and the support of upper management (e.g., by allocating a budget for risk management training and activities) facilitates the identification and quantification of project uncertainties and, ultimately, enables the identification of risks and exploitation of opportunities, creating a flexible and more controlled production process.

Level 4: Technical Training and Learning, Customer Involvement, and Manufacturing System Flexibility

Technical training and learning refer to information sharing and continuous learning capabilities that increase the success probability of effective agile practices [69]. Continual technical training and learning are driven by the leadership vision and mission and have an impact on manufacturing system flexibility and the level of ECSS compliance. Another key attribute at this level is customer involvement. Customer involvement refers to the interaction between customers and company representatives throughout the project lifecycle [70]. The degree of customer involvement is closely correlated with the success of a project and the flexibility of its processes [24]. In other words, projects tend to be more successful when the customer is actively involved. Involving customers in the project can also enhance customer satisfaction, which is advocated by the agile manifesto's first principle [71].

Manufacturing system flexibility is the ability to cope with the growing product variety to ensure better system performance [72]. Top management support, customer involvement, a joint understanding of uncertainty, and teams' technical training and learning are all factors that influence manufacturing system flexibility, which in turn affects ECSS compliance level.

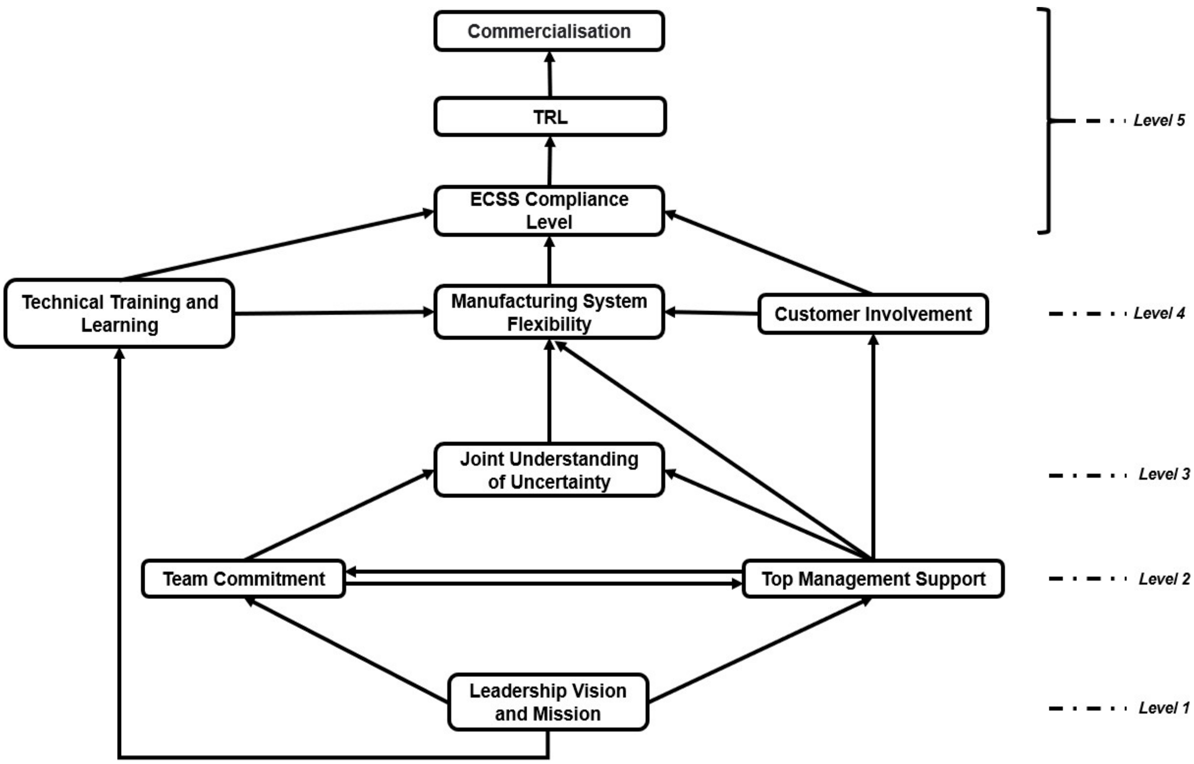

Figure 2. Agile ECSS compliance framework

Level 5: ECSS Compliance Level, TRL, and Product Commercialization

TRLs are different points on a scale used to measure the progress or maturity level of a technology [73]. In the space industry, TRL is used to measure the maturity of software, electrical, electronic, and electromechanical components, materials and manufacturing processes. The scale ranges from 1 to 9, where TRL 1 is the lowest and TRL 9 is the highest. As an input to the project implementation decision process, the TRL scale is useful for the following purposes [74]: (1) early monitoring of basic or specific technology developments serving a given future mission; (2) providing information on the technical readiness of a future project; (3) tracking the progress of the technology development process.

The commercialization of the product, which is the end goal of the developed compliance framework, depends highly on TRL, which is dependent on the level of ECSS compliance. This direct relationships between ECSS compliance and TRL, and TRL and product commercialization were emphasized by the majority of the interviewees. The following quotes reflect the impression of a senior aerospace engineer:

> *"Following the book (i.e., ECSS standards) will ensure a 99.9% success rate. This means achieving high TRL during the development process […]. The higher TRL of a specific product, the greater the scope of its commercialization […]. There is much to be stressed regarding the importance of having a high TRL during product development. This will require more budget, more training, and an understanding of the ECSS standards themselves on the part of developers and end-users".*

4. CONCLUSIONS

In this paper, the authors investigated and analyzed the significant factors that contribute to the successful implementation of agile project management within the European aerospace industry, as well as developed an agile framework for complying with ECSS. The authors (1) identified the key attributes for successful implementation of agile project management in the space industry; (2) quantified and prioritized the identified agile attributes; and (3) Developed a framework for ECSS compliance.

The authors used a multi-phase research methodology. First, a systematic literature review was conducted to identify and classify the key attributes for the successful implementation of agile project management in the space industry. Second, a structured questionnaire survey was distributed to 7 agile project management experts in the UK to determine the weights of the identified agile attributes and their categories. Third, an AHP model was developed to determine the level of significance of the identified agile attributes. Fourth, a set of semi-structured interviews was conducted with nine space experts in the UK to (1) identify the main factors influencing ECSS compliance; and (2) establish the relationships between the identified key agile attributes for ECSS compliance. Fifth, a Lego Serious Play was conducted with a group of 10 project and engineering management experts to further validate the relationship between the identified key agile attributes for ECSS compliance.

Based on the adopted research methodology, the authors identified a total of 43 agile attributes grouped under seven categories (i.e., organizational-related, management-related, project-related, process-related, technical-related, team-related, and customer-related factors). In addition, the most significant agile attributes in each category based on the AHP analysis were as follows: joint understanding of uncertainty (in the Project-related factors), followed by top management support, technical training and learning, manufacturing system flexibility, customer training and education, vision and mission, and team commitment. Furthermore, the authors developed and validated a five-level agile ECSS compliance framework. Level 1 includes leadership vision and mission attributes. Level 2 includes team commitment and top management support attributes. Level 3 includes joint understanding of uncertainty attribute. Furthermore, level 4 includes technical training and learning, manufacturing system flexibility and customer involvement attributes. Finally, Level 5 includes ECSS compliance and its linkage to the TRL of the product and the process of product commercialization.

4.1 Theoretical and Practical Implications

This study has several implications for researchers and practitioners. First, it provides a deep understanding of the AHP method used to assign priorities to the identified agile attributes, which could aid researchers and practitioners working in other Space hardware and software engineering domains to implement the AHP method. Second, the 43 identified agile attributes provide a knowledge base classification/taxonomy for practitioners to assist in scaling agile development. Third, the developed compliance framework clarifies the interdependencies among the critical agile attributes, which can assist in identifying the required capabilities necessary to achieve business excellence. This knowledge can assist practitioners in implementing agile principles and methodologies in their organizations, and in developing appropriate plans and solutions to achieve a higher degree of ECSS compliance.

4.2 Research Limitations

This study, while valuable, has certain limitations. The primary limitation is associated with the use of the AHP technique. Despite the numerous advantages of AHP as a decision-making and problem-solving tool, it is important to recognize its limitations. A potential disadvantage of AHP is that it is heavily reliant on subjective judgment and personal preference, which may introduce bias into the decision-making process. Additionally, AHP can be a complex and time-consuming process, particularly when there are a large number of factors or criteria to consider. Furthermore, the AHP can be challenging to explain to others due to its reliance on subjective judgment and complex calculations, making it difficult to effectively communicate the reasoning behind a decision.

Another limitation of this research is that it primarily relies on expert judgment through questionnaire surveys, semi-structured interviews, and a Lego Serious Play. To complement the results, alternative methods such as project-based case studies should also be considered.

Lastly, the study identified only 43 agile attributes that were classified under seven groups (i.e., organizational-related, management-related, project-related, process-related, technical-related, team-related, and customer-related factors). To enhance the study, further agile attributes should be identified and classified under the existing groups or new groups.

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