Evaluation and selection of manufacturing technologies using the analytic hierarchy process in wing assembly

EVALUATION AND SELECTION OF MANUFACTURING TECHNOLOGIES USING THE ANALYTIC HIERARCHY PROCESS IN WING ASSEMBLY

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ABSTRACT

State of the art technologies are devoted to improving the operational efficiency and subsequent competitiveness of an organisation. The selection process is a tedious, complex and capital intensive task, often based on numerous conflicting factors. Aircraft manufacture requires the selection of potential technologies expected to mature and remain throughout a twenty-five year product lifecycle.

It is common for businesses to have guidelines on how technologies are developed once selected; however, it is unclear how technologies were selected due to a lack of methodology and the reliance of internal know-how policies.

The purpose of this paper is to provide an insight into the application of the analytic hierarchy process for evaluating and selecting the optimum manufacturing technology in a complex aerospace manufacturing environment. A study was applied at a large European aircraft manufacturer to optimise the ranking process of alternative wing component measurement technologies.

Keywords: *Analytic Hierarchy Process, Decision Support, Manufacturing Technology Selection.*

1 INTRODUCTION

Manufacturing organizations are facing intense global competition and consequently an incredible amount of pressure to reduce the overall cost and development time of new products (Akarte et al. 2001). The right manufacturing technology, at the right time, can enable an organization to produce products that are cheaper, better, and faster than those of the competition. Subsequently, the wrong technology, or even the right technology, poorly implemented can be disastrous (Baines et al. 2005). The selection of technology can affect competitive advantage and industry structure, and can worsen as well as improve a firm's competitive position (Porter 1985).

Aircraft manufacture is unique as products have a typical lifespan of 25 years, decision repeatability is low as technologies are expected to mature throughout the product lifecycle. The product and assembly solutions are complex and require high analytical evaluation. Often based on numerous conflicting economic and analytical elements, managers cannot consider all relevant criteria due to bounded rationality and limited capacity for information processing (Deng 1996). As manufacturing solutions become progressively more complex and the number of technologies mature, the process of identifying the optimum solution becomes more complicated. Traditional decision-making relies upon the knowledge and judgment of experienced personnel to pursue nonexistent company know-how policies.

Airbus in the UK, the organization under study, has identified a systematic methodology for deciding on the most appropriate means of evaluating and selecting manufacturing technologies as an area of improvement. There is increased focused on automated systems and management wish to pursue the optimum degree of automation by investing in technology that will secure their long term future and competitive advantage. Improved decision methodologies may contribute to optimum automation levels.

To provide a systematic approach, the Analytic Hierarchy Process (AHP) will be applied to conclude the effectiveness compared with existing practices. AHP is one of the approaches used in determining the relative importance of a set of attributes or criteria, independently to a solution. AHP is designed to solve complex multi-criteria decision problems and is conducted by focusing on individual elements.

Existing quantitative research on manufacturing selection has been typically applied to flexible manufacturing systems (Koltai et al. 2000, Maccarthy and Liu 1993, San and Tabucanon 1994), lean manufacturing systems (Anand and Kodali 2009) and manufacturing automation technologies (Almannai et al 2008, Luong 1998, Baines et al. 2005). There appears to be no report on the selection of manufacturing technologies for wing equipping processes which this research aims to fulfil.

Due to the level of complexity surrounding a highly analytical cross evaluation process, the approaches published cannot be applied to aircraft manufacture. The overall context differs in that change in technology can be costly; therefore it is extremely important to select the right technology at the start of production. There is also a necessity to consider how technologies will mature as they progress through technology readiness levels and remain in production throughout. This report focuses on three alternative technologies capable of measuring key features during the installation and setting of an aircraft wing flap track beam.

2 RESEARCH AIM & METHODOLOGY

The aim of this study is to apply the AHP methodology in an industrial context and to evaluate the effectiveness of the approach with existing decision practices. The intention is to identify the existing limitations, apply AHP and conduct an overall comparison of the applied practices.

To achieve the aim, the project followed a four stage methodology:

1) Model the problem as a hierarchy detailing the decision goal, alternative solutions and evaluation criteria. Experts to agree on all factors.
2) Perform pair-wise comparisons of factors to priority rank the criteria. Experts to agree on comparative ratings using the recommended scale. Similarly, perform pair-wise comparisons between factors and alternatives.
3) Synthesize judgments to yield a set of overall priorities in the hierarchy. Each alternative rated against each criterion summed to determine the ranking.
4) Select the alternative receiving the highest numerical percentage if adequately higher than its predecessor and stable during the sensitivity analysis.

To ensure a fair evaluation is conducted, four experts from different levels in the organisation were involved in the study. Controlled by the first author, it was decided that the best approach of the initial case study would be to generate the factors and pair-wise comparisons within a group creative thinking session. This would enable dynamic and effective discussions to ensure accurate results were concluded. Differences between this approach and alternative methods such as conducting the process individually are discussed.

3 RESEARCH PROBLEM

The organization under study has identified decision methodologies applied to technology selection as an area for improvement. Previous decisions are not being carried out in a methodical fashion, captured and conducted to a level that reflects the overall project value and potential organization impact. The evaluation process is largely based on a two year return on investment that often leads to the disregard of prospective solutions.

Upon the build philosophy being determined, a statement of requirements is set, alternative solutions consisting of baseline technologies and an external tender is conducted. Information such as performance, labour requirements, technology readiness level, process confidence, supplier confidence, *etc.* is collated and relayed to the project manager. Process capability evaluations are conducted to ensure they meet the needs of the manufacturing process. Discussions are held between experts and are validated by effective stakeholders, e.g. health and safety, local production management, to conclude an optimum solution.

The organization has spent considerable time researching into existing technologies to optimise its method of installing and setting wing flap track beams to the bottom skin of a single-aisle aircraft. Situated on the trailing edge, three individual tracks generate a moveable action for an outboard and inboard flap. Flaps are hinged surfaces and extended to reduce the stalling speed of an aircraft during take-off and landing.

The challenge facing the organization is whether to invest in a new technology. The existing process is reliant on a calibrated aluminium beam which allows a manual operator to measure the position of the wing flap track beam to the profile of the top skin. The existing method includes a number of non-value added activities and opportunities to regulate the setting mechanism.

In order to achieve a constant aerodynamic profile between the top skin and flaps, it is important that they are both aligned. This is attained by positioning the track beam relative to the top skin profile during installation. The system has been designed to allow adjustments to take place between the track beam and bottom wing skin. The WZ distance is measured and corrected accordingly. Figure 1 illustrates the alignment of flap track beam to the top skin using the hinge pin centre point. The adjustments are achieved by altering the packers at the FWD and AFT attachment points indicated on the diagram.

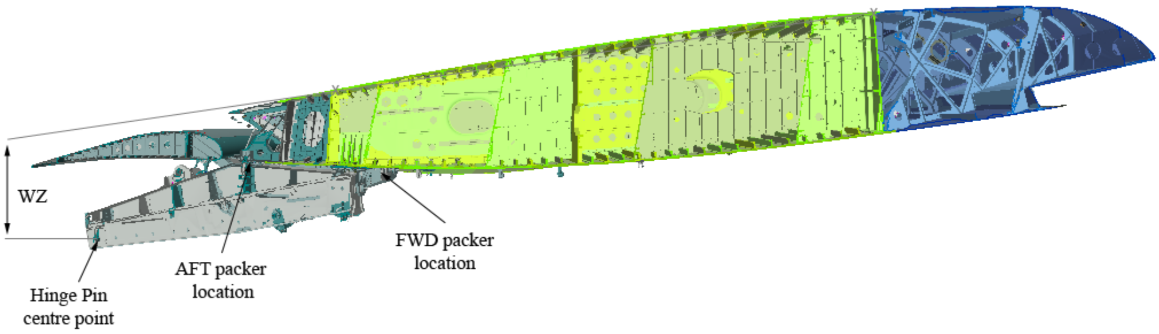

Figure 1 : Wing & track schematic (Airbus 2010)

The current process is carried out in seven stages:

1. Prepare track and temporally install to wing using nominal packer.
2. Set-up measurement equipment, calculate position of track and determine appropriate packer.
3. Remove track and temporally install new packer.
4. Reinstall track to wing.
5. Re-measure and confirm appropriate packer aligns track correctly.
6. Remove track and seal packer.
7. Permanently fit and conduct final measurement.

There is an amount of non-value added activities that require the track to be installed three times due to the accumulation of build tolerances. It is important that the check is carried out as the packer size can vary due to this accumulation. It can lead to a nominal 200% variation between maximum and minimum packer sizes.

Two alternative measurement technologies have been identified to improve the existing process practices. Firstly, photogrammetry is a technique of taking 3D measurements from 2D photographs captured on a digital camera. Capable of achieving an accuracy of ± 5 microns per meter away from the camera, the technology would enable accurate measurements to be captured post the initial installation of the track and give increased confidence to fully fit the beam during the second installation. Secondly, a laser tracking device would provide additional capability that would enable the wing and track to be actively measured prior and during assembly. By measuring the track before installation, an accurate size packer can be calculated and installed to the track to provide a one-shot installation, reducing the current installation attempts from three to one.

4 APPLICATION & RESULTS

The entire problem of modelling the elements in the hierarchal network, entering the pair-wise comparison values and synthesising the results were conducted using a trial version of *Expert Choice* software. An overview of the methodology is described together with the application.

Saaty (1980) describes the AHP methodology and explains that the effective way to concentrate judgement is to take a pair of elements and compare them on a single property, without concern for other properties of elements, resulting in a sound decision. It facilitates the decision-making process by organizing perceptions, feelings, judgements and memories into a framework that exhibits the forces that influence a decision. It is based on the innate human ability to make sound judgments about small problems.

The aim of this application is to apply an approach to the existing unsystematic decision process in technology selection. The experiment to demonstrate a new approach within the organization wishes to apply a theoretical methodology and compare the approach based on accuracy, decision time and overall confidence. It was decided that the first trial would be applied in a group brainstorming environment to manipulate the group decision-making that currently occurs when more than 2 individuals meet to discuss optimum manufacturing technologies.

Four internal experts involved in the project were selected as part of the activity. The approach was taken to discuss each stage of the methodology and equally decide on the result through active discussions. The criteria and pair-wise comparisons were mutually agreed.

Three steps of the applied AHP methodology suggested by Saaty (1980) are presented together with the application.

Step 1 – Define the criteria to evaluate manufacturing technology for wing equipping processes and establish the hierarchical framework

In line with Saaty's methodology, firstly the criterion to evaluate the alternatives is generated. The problem is represented in a hierarchy including the particulars of the overall goal, decision criteria and alternatives. The hierarchical order reflects functional dependence of one component or a group of components to another.

In this study, two criteria clusters, namely *Aerospace Equipping Elements* and *Common Factors* were agreed to represent the factors of seven and eight sub-criteria dependants respectively. The criteria for identifying the optimum manufacturing technology had been identified after a detailed study of technical literature, discussion with experts and observations of the wing assembly line. The criterion and definition is presented in table 1.

	Code Name	**Definition**
Cluster Criteria		
Equipping Elements	(C_1)	Factors related to the installation of wing systems equipping
Common Factors	(C_2)	General factors not related to manufacturing
Sub-Criteria		
Operator Requirements	(C_1S_1)	Training, skill level, repeatability from operator interference
Process Operation	(C_1S_2)	Tooling, paperwork/software, backup system
Wing Equipping	(C_1S_3)	Specific factors related to the assembly line movement, equipping sequence
Technical	(C_1S_4)	Process capability, adaptability, productivity, testing, mobility, software/hardware
Quality	(C_1S_5)	Required accuracy, repeatability, reliability, number of concessions & calibration
Integration	(C_1S_6)	With existing software/hardware & current process/assembly line
Technology	(C_1S_7)	Future capability, longevity & transfer to future projects
Operation Cost	(C_1S_8)	Installation, operation, tooling, unit & recertification cost. Floor space, man hours
Supply Chain	(C_2S_1)	Supplier agreement & internal supply chain
Risk	(C_2S_2)	Project & production risk
Health & Safety	(C_2S_3)	Machine regulations, work legislation, personal protective equipment
Managing Change	(C_2S_4)	Potential change, required implementation
Economic	(C_2S_5)	Economic justification, payback period, internal rate of return & investment cost
Sociological & People	(C_2S_6)	Work quality, ecological considerations, human considerations, work procedure
Strategy	(C_2S_7)	Short/long term manufacturing objectives & organization vision

Table 1 : Criteria and definition

To structure the decision problem and develop the AHP model, the objective, criteria and alternatives were identified:

1. The main objective is to select the optimum manufacturing technology for the assembly of a wing flap track beam. The alternatives considered are:
   - Hard Tooling (existing method)
   - Photogrammetry
   - Laser Tracker
2. The selection of the optimum manufacturing technology is based on competitive priorities; this is referred to as the cluster criteria in the AHP terminology. For which this case study is:
   - Aerospace Equipping Elements
   - Common Factors

3. The AHP terminology terms the cluster criteria and sub criteria acknowledged in table 1 as clusters and elements respectively. The clusters refer to the decision areas, which are affected by the implementation of the alternative manufacturing technologies. The remaining criteria grouped under the clusters represent the elements.

The final phase of the stage one methodology is to represent the problem in the form of a hierarchy. Saaty (1994) explains one of the uses of a hierarchy is that it allows the decision maker to focus judgement separately on each of the several properties, essential for making a sound decision. He describes the most effective way to concentrate judgement is to take a pair of elements and compare them on a single property, without concern for other properties or elements. For this reason, paired comparisons in combination with the hierarchical structure are useful in deriving measurement. The hierarchy is presented in figure 2.

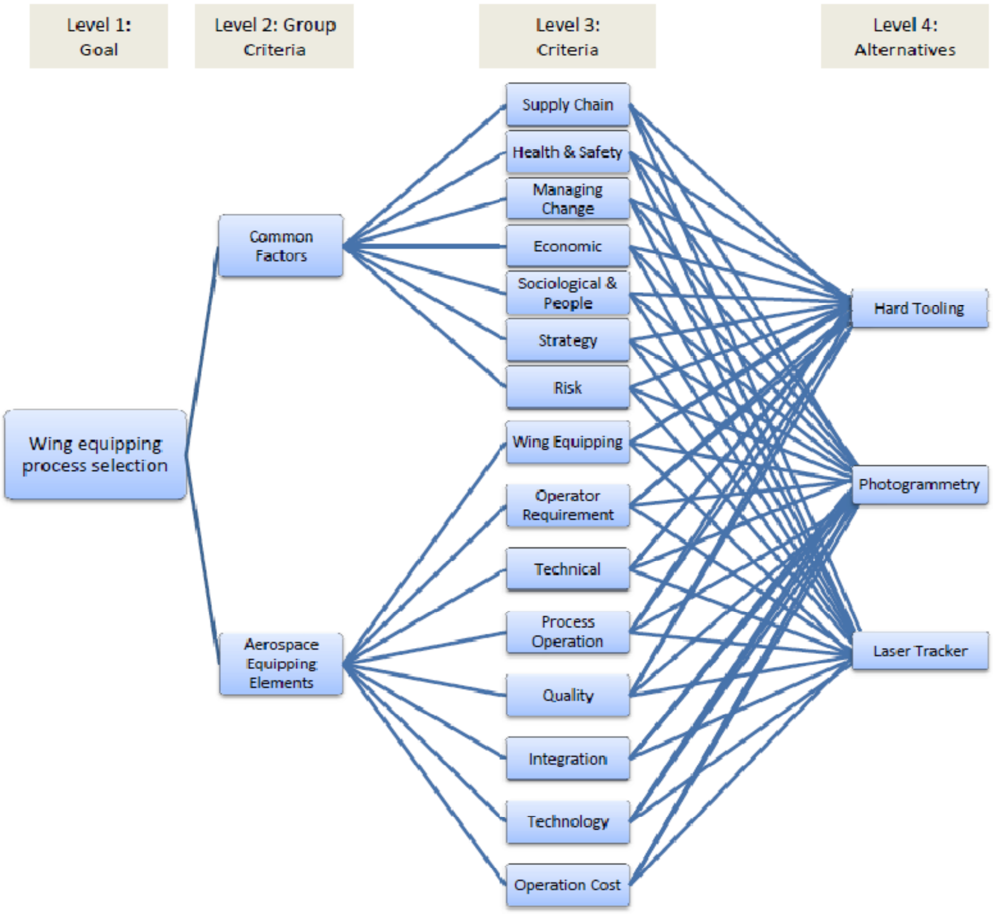

Figure 2 : Hierarchy

The goal is placed at the top of the hierarchy. The hierarchy descends to the cluster criteria in level two and sub criteria in level three, followed by the alternatives at the base or level four.

Step 2 – Perform pair-wise comparisons between elements and decision alternatives

Pair-wise comparisons are carried out between clusters and elements to calculate the importance with respect to the corresponding criteria. Saaty (1980) describes the pair-wise comparison as the arrangement of elements in the second level into a matrix and elicit judgements from the people who have the problem about the relative importance of the elements with respect to the overall goal. The scale recommended by Saaty (1980) will be used and has been validated for effectiveness, not only in application by a number of people, but also through theoretical comparisons with a large number of other scales. A matrix will be formed and the relative weights of each cluster / element obtained as the eigenvector (eVector) from the matrix.

Pair-wise comparisons were performed systematically to include all combinations of cluster criteria, sub-criteria and sub-criteria / alternative relationships.

Firstly, it was essential to determine the overall importance of the two cluster criteria, *Aerospace Equipping Elements* and *Common Factors*. As per the methodology, a pair-wise comparison was agreed and is illustrated in table 2. All parties involved agreed neither factors were more important than another as each set of elements as a whole should be equally considered.

	Equip.	Comm.	eVector
Equipping.	*x*	1	0.5
Common.	1	*x*	0.5

Table 2 : Comparisons cluster criteria

The pair-wise comparisons resulted in the priority of each cluster at 50%. To determine the priority of criteria within the clusters, a comparison was conducted and is presented in table 3 and 4.

Pair-wise comparison matrix for level 2 (C_1),

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	**eVector**
S_1	*1.0*	4.0	9.0	4.0	4.0	1.0	3.0	0.041
S_2	1/4	*1.0*	4.0	4.0	4.0	3.0	5.0	0.202
S_3	1/9	1/4	*1.0*	9.0	7.0	5.0	9.0	0.469
S_4	1/4	1/4	1/9	*1.0*	5.0	1.0	4.0	0.065
S_5	1/4	1/4	1/7	1/5	*1.0*	5.0	4.0	0.142
S_6	1.0	1/3	1/5	1.0	1/5	*1.0*	4.0	0.057
S_7	1/3	1/5	1/9	1/4	1/4	1/4	*1.0*	0.025

Note: Inconsistency index: 0.12

Table 3 : Common Factors Comparison

Pair-wise comparison matrix for level 2 (C_2),

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	**eVector**
S_1	*1.0*	5.0	5.0	5.0	7.0	1.0	4.0	8.0	0.024
S_2	1/5	*1.0*	1.0	4.0	7.0	1.0	3.0	4.0	0.057
S_3	1/5	1	*1.0*	5.0	7.0	1.0	3.0	4.0	0.056
S_4	1/5	1/4	1/5	*1.0*	7.0	3.0	6.0	3.0	0.133
S_5	1/7	1/7	1/7	1/7	*1.0*	7.0	7.0	7.0	0.461
S_6	1.0	1.0	1.0	1/3	1/7	*1.0*	3.0	5.0	0.047
S_7	1/4	1/3	1/3	1/6	1/7	*1/3*	*1.0*	7.0	0.037
S_8	1/8	1/4	1/4	1/3	1/7	1/5	1/7	*1.0*	0.191

Note: Inconsistency index: 0.12

Table 4 : Equipping Factors Comparison

Comparing health and safety against sociological and people, the group concluded that health and safety, in their view, is six times more important than sociological and people; to the contrary, sociological and people is one sixth as important as health and safety. Within the common factors cluster, health and safety is deemed the most important criteria with a priority of 0.469. By focusing on each factor and comparing it against one another, the overall relevance and importance of each is determined. Economic justification received the highest ranking in the common factors group with a rating of 0.461, or 46.1%. Figure 3 illustrates the results of the comparison in a hierarchical form.

Subsequently, the group moved onto the pair-wise comparisons of the elements in the lowest level. Each alternative is compared pair-by-pair with respect to the covering criterion of the group which is the node directly above in the hierarchy. The elements to be compared are the alternatives with respect to the criteria in level 3. As carried out in the previous pair-wise comparison, all experts discussed appropriate ratings for each alternative and agreed on a figure. Due to the length of data and computation, a single element will be illustrated. The views were computed in *Expert Choice* and can be obtained from the author.

Example 1: comparisons of <u>*risk*</u> against each alternative,
A = *Hard Tooling*, B = *Photogrammetry*, C = *Laser Tracker*

Risk	**A**	**B**	**C**	**eVector**
A	1	6	4	0.082
B	1/6	1	4	0.682
C	1/4	1/4	1	0.236

Note: Inconsistency Index: 0.10

Table 5 : Comparison

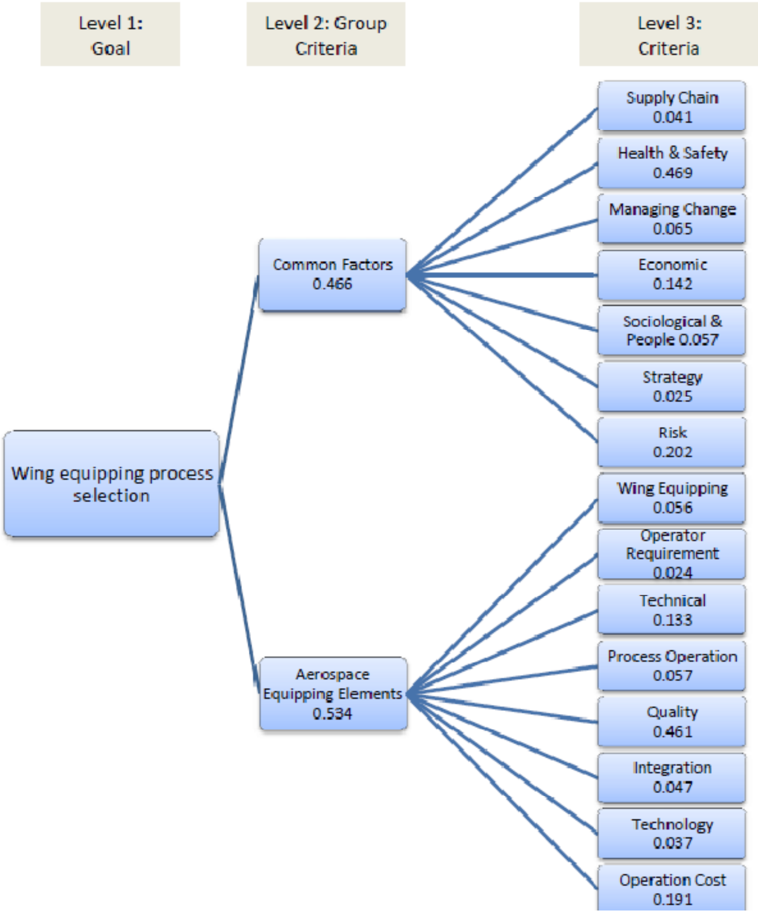

Figure 3 : Hierarchy with priority values

Table 6 illustrates the results of evaluating risk with each alternative. The table suggests that photogrammetry is the safest solution as the decision-makers view was that the overall risk of injury is low. This is a result of the reflective targets placed on the wing within reach of the operator. The laser tracker received the lowest risk rating with 0.236, the group agreed this was due to the risk of injury from the laser, constant movement of the reflective targets and weight of the equipment.

Step 3 – Synthesizing results to select optimal manufacturing technology

The final stage is to establish the composite or global priorities of each manufacturing technology, the priorities of the criteria are synthesized to calculate the overall priorities of the decision alternatives. The local priorities are lay out with respect to each criterion in a matrix and multiplied by each column of vectors by the priority of the corresponding criterion (1), adding across each row results in the desired vector of manufacturing technology (table 6).

$$Total\ x = C_1 [\ x\ (\ C_1S_1 \ldots\ldots\ldots C_1S_7\ )] + C_2 [\ x\ (\ C_2S_1 \ldots\ldots\ldots C_1S_8\ )\ ] \qquad (1)$$

	C_1S_1 (0.041)	C_1S_2 (0.202)	C_1S_3 (0.469)	C_1S_4 (0.065)	C_1S_5 (0.142)	C_1S_6 (0.057)	C_1S_7 (0.025)
A	0.202	0.082	0.048	0.709	0.149	0.122	0.054
B	0.701	0.682	0.682	0.212	0.691	0.558	0.218
C	0.097	0.236	0.271	0.079	0.160	0.320	0.728

	C_2S_1 (0.024)	C_2S_2 (0.057)	C_2S_3 (0.056)	C_2S_4 (0.133)	C_2S_5 (0.461)	C_2S_6 (0.047)	C_2S_7 (0.037)	C_2S_8 (0.191)	**Total**
A	0.517	0.113	0.078	0.056	0.072	0.235	0.100	0.258	**0.126**
B	0.359	0.652	0.635	0.243	0.301	0.652	0.433	0.637	**0.516**
C	0.124	0.235	0.287	0.701	0.626	0.113	0.466	0.105	**0.359**

Table 6 : Local and global priorities of manufacturing technologies

Photogrammetry received the highest ranking with 0.516 (51.6%) and provides a foundation that it is the optimum solution. The laser tracker was ranked second with 0.359, followed by the existing hard tooling method with a score of 0.126.

A series of sensitivity analyses were conducted to investigate the impact of changing in priority of criteria against the alternative ranking. Using the Expert Choice software, a dynamic sensitivity was performed to understand how realistic the final outcome was. Saaty (1980) explains that it is desirable that the priorities do not fluctuate widely with small changes in judgment. The analysis indicated that when the importance of the cluster criteria was changed up and down by 5 percent in all possible combinations, the ranks of the alternatives remained stable. In this respect, the organization can have confidence in the highest ranked technology.

5 CONCLUSION

It had been identified that there is a lack of theoretic decision methodologies in the existing literature applied to technology selection in aircraft manufacture. Aircraft manufacture is unique in that parts and manufacturing systems often remain in place throughout a lengthy product lifecycle of typically 25 years. Any change in technology will require large investment in time and cost. Ideally, the optimum technology will be implemented at the start of production and mature throughout the product lifecycle. The aim of this study was to conclude the use of a systematic decision process compared to the existing know-how policies.

This application has validated the optimum solution in a timely and less costly manner; it required less effort and provided additional confidence to the decision makers. The overall time to agree on the factors during the creative thinking session was 90 minutes compared with the existing four hour practices. The feedback was that the approach benefited from being methodological and timely to conduct. All experts agreed that the process was accurate and felt an improvement compared with existing practices. It was evident that the analytic hierarchy process can apply a systematic decision methodology to a complex and conflicting problem. In this case, the maximum criteria within a single matrix were eight; this ensured full concentration for each comparison. Larger factors can cause the process to become tedious resulting in the loss of quality in the decision. Although the approach was carried out as a group, it is clear an individual approach may result in a different outcome. As the author wished to replicate the existing group decision process, it was felt that this was the most appropriate format.

The constraints of applying AHP to this study are that the decision makers must convert their knowledge and technical specifications to the ranking scale recommended by Saaty. Specifications such as quality, often stated in mm, are converted to a relative scale. Conversely, applying judgments for relative element meanings, it provides a logical and reliable form of measuring incommensurable elements. The group believed the importance of elements accurately represented the views of the decision makers. They felt that during the final stages part of the accuracy was lost due to the 1 – 9 scale for comparing elements to alternatives. To conclude, the results dictate the outcome achieved using the existing process, thus giving confidence in the AHP approach. The use of the scaling for alternative evaluation, lack of technical specification reasoning and capture of historical data, dynamic adaptability and individual opinion required, suggests that AHP may not provide the optimum decision-making methodology for aircraft technology selection and requires further development.

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