ADAPTATION OF THE MAKE-OR-BUY ANALYSIS FOR AIR TAXI START-UPS USING THE EXAMPLE OF ELECTRIC MACHINES

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Abstract

More power-dense batteries, innovative aircraft concepts, and the demand for faster point-to-point connections open up a new market for advanced air mobility. This market can be segmented by the average mission length into Urban Air Mobility [1] (intra-city-connections, UAM) and Regional Air Mobility [2] (inter-city-connections, RAM). Both market segments are mostly addressed by start-ups, trying to develop new types of small aircraft – so-called air taxis – which answer the demand for faster transportation in an environment-friendly manner [3].

Market forecasts expect air taxis to be produced in – for the aviation industry – large numbers of up to several 1,000 air taxis per year [4]. Consequently, the engaged companies have to realize a commercial series production mirroring the high certification standards of aircraft. Unlike large companies such as Airbus, start-up's often face high financial challenges and have to set-up their entire production from scratch. Hence, they have to understand clearly which components can be provided by suppliers ("buy") and which components should be manufactured in-house ("make"). This strategic decision can be supported by the make-or-buy analysis if appropriately adapted to the aviation sector.

The goal of this paper is to demonstrate the application of a make-or-buy analysis for an air taxi start-up targeting the RAM-market. The analysis is illustrated for the electric machine of a hybrid-electric powertrain. In the first step, specific requirements of the air taxi's electric machine are defined and technical specifications of the drive train's components are discussed. Moreover, it is evaluated, which aspects of the start-up's strategy need to be considered for the analysis. In the next step, the manufacturing processes of the respective drive train components are described and analysed, based on their advantages and disadvantages, suitability for unit quantities, and used materials. In particular, the quality requirements spectra and testing efforts resulting from the different performance requirements for the electric machine are presented in more detail. Based on this analysis, the manufacturing costs of the components are calculated ("make") and compared to supplier prices ("buy"). By analysing the cost functions, a break-even point is determined depending on the number of production units. Finally, the make-or-buy decision is of course also influenced by strategic aspects which have to be reflected in the analysis, e.g. desired production depth of the start-up.

All in all, this paper provides an adaptation of the make-or-buy analysis to the special requirements of start-ups focused on the air taxi market. The process is described here by using the example of the electric propulsion machine but can be applied to all components of the drive train and transferred to further main components of air taxis.

1. INTRODUCTION & OBJECTIVES

Urban and regional transport infrastructure is overloaded due to the high traffic volume [5]. Advanced air mobility aims to answer the growing demand for faster point-to-point transportation with the use of small aircraft – so called air taxis. These air taxis are able to use existing small airfields or can start vertically from dedicated vertiports in the city centers. Since 80 % of the german population live less than 20 km away from these airfields, airtaxis enable more point-to-point connections and shorter travel times can be achieved [6]. Additionaly, innovations in battery technology and air taxi design open up the development of multiple air taxi-concepts [1] and different market segments. These concepts can be segmented by average mission length into Urban Air Mobility (UAM) and Regional Air Mobility (RAM) and are mostly developed by start-ups [3]. With the expected market volume for air taxis being up to several 1,000 units per year and high certification standards regulating the production of air taxis, the set-up of a production line from scratch requires a significant investment in ressources [4]. Therefore, start-ups face an even greater challenge than lange companies due to the limited financial ressources available and have to understand which components can be provided by a supplier ("buy") and which should be manufactured in-house ("make").

To tackle this challenge the European Fonds for Regional Development (EFRE) funds a consortium involving an air taxi start-up focusing on RAM to develop and integrate an electro-hybrid powertrain. The focus of the project "E-SAT – Development and integration of an electro-hybrid powertrain for the Silent Air Taxi" is on the development of the electric machine and the fan. Corresponding to the use case of the air taxi, the aim is to achieve both a lightweight design and the quietest possible operation. A crucial part of this project is the make-or-buy analysis of these components to determine the allocation of ressources from a financial and strategic standpoint. The aim is to identify strategically valuable components to be manufactured in-house and the evaluation of the production of cost-intensive parts to reduce the financial commitment for complex production lines to save the start-up's ressources.

The aim of this paper is the adaption of the make-or-buy analysis with the focus on the special requirements of start-ups in the air taxi market. The analysis is especially conducted on the electric propulsion system as an essential part of all air taxi concepts being developed.

The process is applyable to all components of the drive train of the air taxi and can be transferred to further main components.

First of all, the theoretical background of the fields relevant to this paper are analyzed. This includes the general methodology of make-or-buy analyses as well as characteristics of start-ups and air taxi industry. As a result, the requirements for the analysis carried out within this paper can be derived. Factors for strategic decision-making are considered in particular. This is followed by the detailed description of the methodology derived to address the challenges that start-up air taxi companies face when making the make-or-buy decision. The analysis is illustrated for the electric machine of a hybrid-electric powertrain. Electric powertrain components and their production processes are analyzed to enable an evalution of the process complexity and costs. The analysis results are used as input for the make-or-buy analysis. Finally, the paper is concluded and an outlook on further work is given.

2. THEORETICAL BACKGROUND

Air taxis aim to provide faster point-to-point connections either urban or regional [6]. Depending on their purpose, architectures of air taxis differ in five basic technical concepts (see Figure 1) [7]. These concepts differ mainly in the way lift, thrust and flight control are implemented.

Air taxis in the UAM sector are used in cities. They are intended to relieve the existing forms of urban mobility there. Due to the limited space in cities, they mainly have to perform vertical take-offs and landings (VTOL). [8] In contrast, RAM air taxis offer faster connections between regions outside the major cities. This is achieved by using smaller airfields which are located thoughout every region in Germany and accessable in under 20 minutes by 80 % of the population [6].

Both market segments lay down common requirements for air taxi concepts: An environmental friendly operation, minimal noise emissions, a reduction of CO_2 emissions, and a high torque for steep or vertical take-offs. These requirements lead to the usage of electric machine to develop the air taxis' thrust [9]. New air taxi concepts in particular can only be realised with electric machine [7]. This development is made possible by the steady progress in battery technology, which ensures the energy supply for the electric machine.

The estimated market size for UAM and RAM air taxis is estimated at 1.3 trillion € in 2040 [10]. This leads to a broad competitive landscape with a variety of air taxis that differ in terms of the concept of lift generation, passenger capacity, and range. The companies developing these air taxis are mostly start-ups, but also corporations. Regardless of company size, make-or-buy analyses are relevant due to the high production volumes required as companies need to realise commercial series production that simultaneously meets the high certification standards of aviation. On the one hand, the large companies strive for an optimal vertical range and depth of production within their company. Therefore, they have to decide which self-produced components offer potential within the existing products and productions [11]. Start-ups, on the other hand, have to decide which components bring strategic added value if they are manufactured internally. The decision whether to produce in-house and what to buy from suppliers will often determine the business modell of a start-up [12]. Therefore, the make-or-buy analysis is of great importance for start-ups in the aviation market. Due to the high relevance of the methodology for start-ups and their current dominance in the air taxi market, the paper focuses on start-up needs.

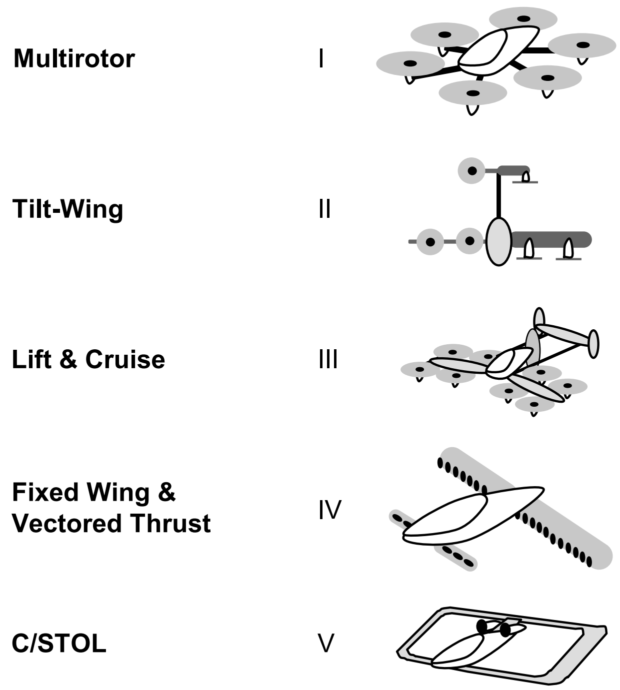


Figure 1: The different air taxi concepts being developed [7]

Start-ups differ in their characteristics from established companies. They focus on their core product with which they aim to exploit a gap in the market and maximise revenues using new business models. Since start-ups are new and often aim at a high-risk business model, they need special funding to support these activities. Furthermore, they have very limited resources, both financially and in terms of access to employees working in the company. Start-ups differentiate themselves from established companies by being highly agile and responsive in their operations rather than rigid in their structures. As the air taxi market is new and not yet established, start-ups target different areas of this market to gain an advantage over competitors and exploit this advantage as the market grows. [13]

In order to adapt the methodology of make-or-buy analysis specifically to the aforementioned requirements of air taxi start-ups, the following section first looks at existing approaches to make-or-buy analysis and explains the strategic facors for decision-making of start-ups and the aviation industry.

2.1. Existing Approaches to Make-or-Buy Analysis

In general, make-or-buy analyses focus on deciding whether a particular service or product is better sourced from external suppliers or manufactured in-house. This decision is usually influenced by factors such as cost, quality, time, resources availability, and risk [14]. The analysis of relevant factors is different for each use case and industry and must be adapted accordingly. Since companies have been dealing with the make-or-buy decision for a long time, a number of general approaches have been developed to meet this challenge. In the following, the approach of the existing make-or-buy analysis approaches is presented.

Approach	Step 1 Preparation	Step 2 Data acquisition	Step 3 Analysis
Alrammah 2016	Determination of the **scope**	Determination of the **weighting** and **evaluation**	**Cost calculation** based on evaluations and analysis
Padillo 1999	Determination of the **scope** and **evaluation criteria**	**Criteria prioritization** and **time frame** considerations	**Comparison** of the identified options and **decision making**
Platts 2002	**Components** selection	**Data collection** and **weighting** of the evaluation criteria	**Combination** and **evaluation** of the options
Probert 1993	**Competitive landscape** analysis	Internal / external **analysis**	Generation of **strategic options** and **selection**
Serrano 2019	Not described explicitly	Determination of the **weighting** by **paired comparison**	Level of **compliance** of the **options** with the **criteria**

Figure 2: Overview of the existing approaches to make-or-buy analysis [15], [16], [17], [18], [19]

The general structure of the existing methods is a three-step approach. Step one involves the preparation of the analysis, which includes defining the scope of the analysis both internally and externally. This involves defining, for example, the components to be considered or the competitive landscape. Step two is data collection using specific questions according to the use case and market. This data includes possible suppliers, production alternatives and includes the strategic value of the options. Furthermore, evaluation criteria are defined and weighted to create an evaluation basis for the analysis that follows in step three. In the third step, the data obtained is evaluated and the strategic options are compared. This comparison depends on the specifications of the market and the company. An overview of the existing approaches can be found in Figure 2.

In the context of startups, which are the focus here, a practical, easy to use approach is important due to limited resources and the fast-moving nature of the environment and processes. Agile and rapid development means that decisions have to be regularly checked for consistency. Only PROBERT's approach addresses the integration of strategic criteria and options within the framework of manufacturing strategy development, ensuring a practical methodology [18]. This approach is taken up in the following.

2.2. Strategic Factors for Decision-Making

In order to develop a methodology for air taxi start-ups, an understanding of the general strategic factors considered in the make-or-buy analysis is necessary. This requires consideration of both the specific requirements of start-up companies and those of the aviation industry. These are discussed below.

Companies use make-or-buy analysis to identify strategically valuable parts or technologies in order to use their resources optimally and outsource less important parts. The decision is based on a number of strategic factors depending on the company, technology, and component [18], [20], [21]. These include the saving of financial resources, the relation to the company's core competencies, technological advantage and protection of know-how over competitors, the general objective of the product, availability of suppliers or vertical integration into the company's existing production landscape [22], [12].

Start-ups are based on an innovative business idea in a new market with high growth potential.They face challenges such as high uncertainty about their business, their success, limited resources, and little financial security [23]. These factors have an impact on technology development and its production that must be considered in a make-or-buy analysis. On the one hand, start-ups cannot exploit existing supply chains to buy parts. The search for and acquisition of suppliers for collaboration is also more difficult than for a company due to an only small or non-existent supplier network. An additional complication for suppliers is that the cooperation with a start-up company is associated with an increased risk of business failure, as it is not yet established on the market. [24], [25], [26]. On the other hand, the protection of know-how for product manufacturing has a high value for the start-up. This has to be protected to secure competitive advantages in order to be able to manufacture in-house at a later stage of development when more own resources are available. [27]. The decision between make-or-buy of a start-up is characterized by the fact that it has to be made before activities are performed and the company enters a market. This is also referred to as an a-priori make-or-buy decision. [12]

Basically, aviation can be divided into commercial and military aviation industry. The focus of this paper is on the commercial aviation industry, in particular the civil aviation industry. This industry is characterised by high investment costs in individual production facilities and is thus particularly capital-intensive. This is reinforced by the high certification standards in the sector and leads to additional resource requirements for the development and production processes. Furthermore, the production of air taxis requires a high level of technological know-how while at the same time only producing moderate quantities compared to other industries, such as the automotive industry. These factors increase the financial risk in the production of air taxis. [28]

2.3. Interim Summary

Literature review has shown that a make-or-buy analysis usually involves three main steps: preparation, data collection, and data analysis. For each industry, the analysis needs to be adapted to its standards and requirements. Most of the approaches examined lack a streamlined, user-oriented approach to decision-making with a special focus on strategic factors influencing the decision.

A make-or-buy analysis is particularly important for air taxi start-ups, which face challenges such as non-existent supply chains and limited resources to drive their development processes. In the aviation industry, aircraft manufacturing in particular requires high financial investment and commitment. In early development phases, for example, it is essential to produce first prototypes. Make-or-buy analysis is therefore an important method for air taxi start-ups.

In summary, existing methodologies for make-or-buy analysis provide a framework that can be used as a foundation for any industry. According to the requirements and challenges of air taxi start-ups, strategic decision can be supported by the make-or-buy analysis if appropriately adapted to the aviation sector. Therefore the method needs to be specified and adapted.

3. STRUCTURE OF THE METHODOLOGY

The methodology presented in this paper combines the results from existing approaches with the specific requirements of air taxi start-ups into a practical methodology. While the existing approaches follow three steps, an additional fourth step is added in the context of this paper: Definition of scope and preparation of the analysis, definition of evaluation criteria, analysis and evaluation, and the strategic decision making, which is regularly reviewed through iteration cycles. The review in iteration cycles ensures a regular integration of the findings within the further development of the start-up. Figure 3 shows the basic concept of the methodology. The four steps are described in detail below.

3.1.1. Definition of the Scope

The first step involves defining the scope and preparing the analysis [15], [16], [17]. For this purpose, the components and assemblies to be considered are listed. This includes those components that require significant investment to manufacture, special know-how, or which, for example, cause a high degree of dependence on very specialized suppliers. Beyond A and B parts that have a high to moderate relevance to the air taxi, C parts such as screws, washers, and nuts are not considered. In addition, the boundary conditions are defined, such as number of units scenarios from small series to series production, certification, information on the strategic company orientation. Reference process chains with technology alternatives for small series as well as for series production are determined for the focused components.

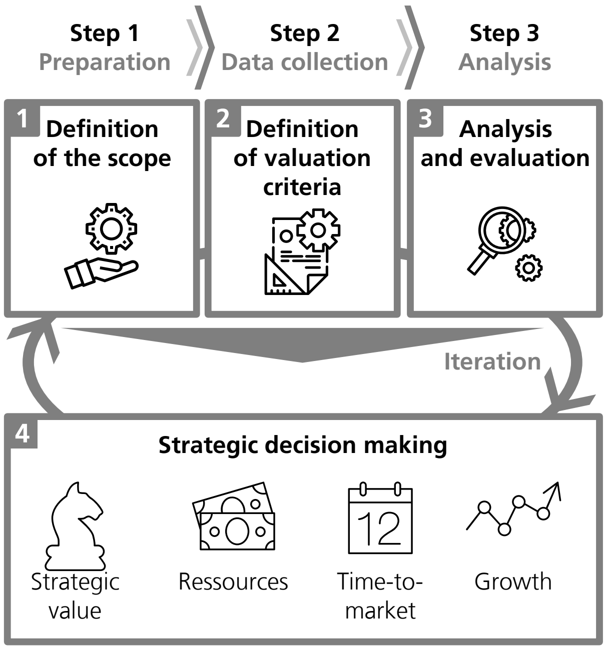


Figure 3: Basic concept of the make-or-buy analysis for air taxi start-ups

3.1.2. Definition of Valuation Criteria

The second step is to define assessment criteria [15], [16], [17] with a view to the orientation of the company. These criteria can be divided into technical and strategic criteria. First, possible criteria are collected in a workshop with all relevant stakeholders and clustered thematically. The most relevant criteria are selected according to the start-ups needs. When selecting the evaluation criteria, the status quo of the start-up as well as internal and external boundary conditions can be included. A systematic determination of the weighting between the evaluation criteria is then carried out through a pairwise comparison [19]. This weighting represents the relative importance of the criteria to each other.

3.1.3. Analysis and Evaluation

In the third step, the data and information generated in step 1 are evaluated and analysed using the criteria from step 2 criteria [15], [16]. For each component, the manufacturing processes along the established process chain are analysed. This includes an analysis of the technology alternatives for the comparison of the "make" options using the evaluation criteria. Based on a selection of technology alternatives for a coherent process chain, the manufacturing costs for in-house production are determined. These costs are compared with the available options for sourcing the parts from an external supplier. A break-even calculation is used to determine the number of units that the start-up needs to produce and sell until in-house production is profitable compared to outsourcing. As described in chapter 2, the limited financial resources of start-ups are the biggest bottleneck. This is considered in the third step of this paper's methodology to provide the options that can be achieved with the available funds.

3.1.4. Strategic Decision-Making

After the data collection, evaluation and analysis is completed, the information obtained is evaluated from the strategic point of view and a decision is made [18]. The aim is not only to find the most suitable option for each component considered, but also the best solution for the entire process chain for internal production. In close coordination with the technology experts, therefore a coherent process chain is always considered. For each component Depending on the strategic focus the options available for selection are evaluated on the basis of criteria such as strategic value, component utilisation, time-to-market, growth potential, and available resources. The decision initially made for each component is repeatedly checked for convergence and coherence with the other decisions. Likewise, a constant comparison is made with the values and visions of the entire company.

Since both the start-up itself and the further development of the technology are subject to constant evolution, the decisions made are regularly checked for validity. These regular iteration cycles enable the start-up to incorporate learning effects directly. For example, the findings from prototyping are included in the selection of the best possible production technologies for the small series. These insights are also relevant for the number of units scenarios set up in step 1 and the selection of technology alternatives. The fourth step is thus an elementary aspect of continuous improvement and questioning of the decision between in-house production and outsourcing.

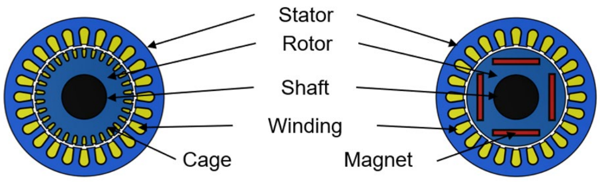
4. RESULTS

The aim of this paper is to demonstrate the application of a make-or-buy analysis for an air taxi start-up targeting the RAM market. As the electric machine is a key component for all air taxi concepts, the analysis is illustrated for the electric machine of a hybrid-electric powertrain. After a general introduction to the technical requirements and specifics of the electric machine, the components as well as the special requirements in aviation, the previously presented step-by-step approach of the methodology is applied and the methodology is validated. Validation focusses on the example of the air taxi concept that is considered in the project “E-SAT – Development and integration of an electro-hybrid powertrain for the Silent Air Taxi”.

4.1. Technical Requirements Electric Machine

The now focussed e.SAT air taxi for RAM is developing and integrating an electro-hybrid powertrain. It leverages advantages of electric drive systems to reduce noise emissions while flying at low altitudes. Especially the start phase of the flight mission profits from low drivetrain noise emissions. Low maintenance requirements, high efficiency, and high reliability compared to internal combustion engines are further advantages of electric machines. Lightweight components are used to meet the requirements of the aircraft design.

For the electric machine two machine topologies are widely used: permanent magnet synchronous machines (PMSM) and induction machines (IM) (see Figure 4). The PMSM topology uses permanent magnets to excite the rotor magnetically. The stator carries a copper winding, which creates a rotating magnetic field. Torque is produced by the interaction of the magnetic fields from the rotor and stator. IMs’ rotors, on the other hand, are excited by currents induced into their short circuited rotor windings by asynchronous rotation of the stator field and the rotor. The currents in the rotor bars lead to undesired ohmic losses, which have a detrimental effect on the machines’ efficiency. [29] In comparison to IMs the PMSM topology enables higher power densities and higher efficiency, both of which play a key role in reducing the overall weight of the drivetrain. Because of its technical advantages, the PMSM is considered below for make-or-buy analysis.



IM		PMSM
+	Efficiency	++
+	High Speed Capability	+
o	Torque Density	++
+	Power Density	++
+	Cost	-
o	Mass Inertia	o
-	Noise	++

Figure 4: Machine profiles and characteristics of different concepts for electric machines

4.2. Make-or-Buy Analysis for the Electric Machine

The developed make-or-buy analysis for air taxi start-ups is applied to the electric machine for the e.SAT air taxi. Each step is executed as proposed in the framework.

4.2.1. Definition of the Scope

In this first step, specific requirements of the air taxi’s electric machine are defined and technical specifications of the drive train’s components are discussed. Moreover, it is evaluated, which aspects of the start-up’s strategy need to be considered for the analysis.

A PMSM, as shown in Figure 5, consists of a rotor assembly, a stator assembly, and a housing, which is used to position stator and rotor relative to each other and to extract heat through a water cooling jacket.

The *rotor assembly* (1) contains the rotor iron core, the magnets and the shaft. The permanent magnets are used for the magnetic excitation of the rotor. An iron core is used to carry the magnetic flux inside the rotor. Since the magnetic flux changes over time, a voltage is induced, which causes eddy currents to flow in the iron core. These currents are undesired, since they lead to ohmic losses inside the iron core without contributing to the torque. To mitigate the effect of eddy currents, the iron cores are usually made of stacked sheets of electric steel. The sheets are insulated on one side to disrupt eddy current paths.

The *stator assembly* (2) includes the slotted stator iron core, which carries a copper *winding*. Concentrated windings facilitate the automatization of the production process. Production methods for the rotor iron core also apply to the stator iron core.

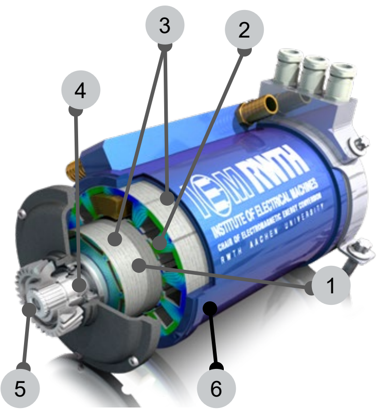
Several methods exist to bond the individual sheets, so that they form a compact *iron core* (3), which can be handled during assembly. Welding the sheets to each other is a cost effective option, which can be automated. Another option is to use bonding varnish to glue the sheets as it is often done in prototypes or small series machines. Interlocking while die cutting the steel sheets is also an option.

Several processes are available for cutting the contour of the steel sheets: Die cutting, laser cutting, waterjet cutting, and electric discharge cutting. While die cutting is a cost effective and fast production method, it comes at comparatively high initial costs for dies, which makes it most suitable for high volume series production. Prototype series often take advantage of other cutting methods like laser or electric discharge cutting, due to the lower initial costs. The processing times are longer compared to die cutting though.

The *steel shaft* (4) carries the rotor iron core, the *bearings* (5), and the balancing discs, all of which are mounted to the shaft by an interference fit. The shaft itself can be produced with a conventional lathe.

Precise positioning between the rotor and the stator assembly are important to ensure constant torque output and to prevent collisions between moving and static parts of the machine. This task is fulfilled by the housing. Cooling channels on the outside of the *housing* (6) provide a way to extract heat from the machine. All parts belonging to the housing can be manufactured by different casting methods and on milling machines.

Afterwards, the components as well as their functions are analzed to identify core components that require crucial technologies or require significant financial investment and considered in the analysis as well as the manufacturing processes and technology alternatives.



1	Rotor assembly
2	Stator assembly
3	Iron cores (Stator, Rotor)
4	Shaft
5	Bearing system
6	Housing

Figure 5: Identification of the main components of the electric machine

Based on the analysis, the components and component groups for which "make" is realistic for the start-up and offers strategic added value were selected during an expert workshop. Housing and shaft are mechanically manufactured components that can be fulfilled more cost-efficiently by specialised suppliers. The *iron cores*, the *rotor* and *stator assembly*, and the *winding* were identified as the relevant machine components for a start-up to manufacture in-house. As key components, these offer strategic added value and are therefore considered in detail as part of the make-or-buy analysis. In the next step, the manufacturing processes of the respective drive train components were described and analysed in detail, based on their advantages and disadvantages, suitability for unit quantities, and used materials. For production of the above-mentioned core components of the electric machine, the consideration of the technology alternatives along the complete production process chain is carried out by means of a morphological box. This morphological box enables the differentiated selection of a suitable manufacturing chain, taking into account all possible technology alternatives and how they fit together [30], [31].

The result of the first step is a fixed area of consideration for the make-or-buy analysis by defining the components and assemblies including the determination of suitable manufacturing processes for further consideration.

4.2.2. Definition of Valuation Criteria

After identifying and defining the critical components, step two is taken to establish evaluation criteria that are used to select the technologies in the established manufacturing process chains. For this purpose, a workshop is held with all stakeholders for the joint collection and selection of evaluation criteria that are used for the decision between alternatives within the make-or-buy analysis. First, relevant criteria are collected for each stakeholder in the workshop. These are then jointly clustered and summarised in categories according to economic and technical criteria. From the collection of criteria, the experts select the most important factors for the production of the electric machine of the e.SAT. Evaluation criteria are, for example, influence on product quality, process and product flexibility, automatability or fixed and variable costs. After setting up a common definition for the criteria in order to ensure a uniform understanding, the weighting is carried out among each other. For weighting, a pairwise comparison is carried out to determine the relevance of the criteria to and among each other. The process for determining the evaluation criteria and the weightings is summarised in Figure 6.

Result of the second step are jointly defined evaluation criteria for the make-or-buy analysis and their weighting in order to further evaluate the technology alternatives from step 1.

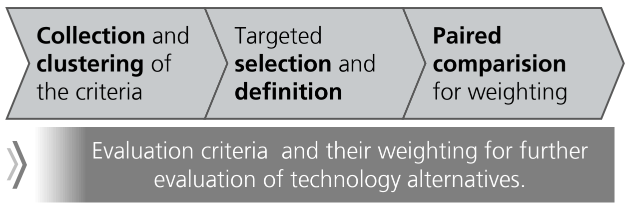


Figure 6: Definition of valuation criteria

4.2.3. Analysis and Evaluation

Once the evaluation criteria have been defined and weighted, the analysis can be carried out per core component. For this purpose, the process chains are analysed with the technology alternatives from step 2. For each technology, the analysis is carried out using a technology profile. These technology profiles represent a collection of the relevant information for each technology such as a general process description, process/ technology specifications like accuracies or materials. In addition they show advantages and disadvantages of the technology as well as an estimation of the required investment volume. In addition, the technologies are classified on the basis of the evaluation criteria from step 2 using qualitative scales. In this way, an assessment of the technology alternatives for the comparison of the "make" options is made on basis of the evaluation criteria and their weighting.

Regarding the preselected components considered for in-house production (see chapter 4.2.1) in this chapter the *stator winding* is chosen exemplarily to demonstrate the technology analysis. An expert workshop collects and clusters criteria, which enable the rating of different manufacturing process solutions. The identified criteria are then condensed further to take specific requirements of the e.SAT into account in a targeted selection process. Impact on product quality, product flexibility, process flexibility, potential for automation and technology availability were identified as technological key criteria, while economic criteria are composed of fixed costs and variable costs. A conclusive paired comparison provides a ranking of those criteria according to their relative importance to the e.SAT project. These are taken into account in the following discussion

The achievable *copper fill* factor represents an important technical parameter for the product quality. It specifies the amount of copper per unit of slot area, which can be placed in the stator slots. Increasing this parameter is crucial to reduce the machine size and weight. Reproducible process quality is a further important factor to ensure predictable machine lifetimes. Therefore, different winding methods must be considered to meet the requirements and achieve highest possible cooper fill factor.

The winding to be produced is a concentrated tooth winding in inwardly facing stator slots. *Manual-*, *needle-*, *flyer* and *linear winding* processes are suited to manufacture this winding topology. While manual and needle winding processes enable the winding of unsegmented stators, a linear winding process depends on free access to all sides of the coil. In an unsegmented stator iron core of the e.SAT machine this access is not available. Thus, a segmentation of the stator iron core is necessary if a linear winding process is chosen. [32]

A *manual winding* process usually consists of manufacturing air coils with machine assistance, which are then inserted into the stator slots by hand. The process itself is flexible since it can be used to produce concentrated tooth windings as well as distributed windings on inwardly and outwardly facing slots. While only small investments are required to implement this process, the expenses for wages and the low manufacturing throughput contraindicate the utilization of manual winding within large volume productions. Reproducible quality is difficult to achieve due to the low degree of automatization. Thus manual winding is only suitable for machine prototyping in the context of the e.SAT project. [32] In order to realize a commercial series production it is necessary to consider other technologies.

A *needle winding* process on the other hand offers a highly automatable process with good reproducibility. A hollow needle, which guides the copper wire, is used to lay the winding into the slots. As with manual winding, the flexibility of the process allows to manufacture concentrated tooth windings as well as distributed windings on inwardly and outwardly facing slots. However a certain part of the slot area can not be filled with copper since the needle occupies space inside the slot. Therefore, the achievable copper fill factor is significantly reduced with inwardly and outwardly facing slots. This restriction does not apply to the winding of segmented stators, where the teeth can be accessed from all sides before they are inserted into the stator yoke. [32]

Linear winding and *flyer winding* offer the advantages of high automatability and enable higher throughput rates than needle winding at the expense of process flexibility. The linear winding process requires segmented iron cores, which can be accessed from all tangential wire directions. This enables a wire guide to control the wire position on the iron core, while the iron core rotates. The process offers precise control of the wire orientation. The flyerwinding inverts the aforementioned process by having a static iron core and a rotating wire guide, which uses a fixture to guide the windings into the slots of the iron core. This eliminates the need to segment the iron core. All three processes require initial investments but are able to produce windings with high copper fill factors and reproducible results. [32]

The advantageous combination of comparatively low investment cost, high process throughput, good copper fill factor and high automatability favor the use of a *linear winding* process in combination with a *segmented machine stator* within the scope of the e.SAT project.

The particular relevance of financial resources for a start-up to build up its own production capacities was already presented in chapter 3. For a comprehensive comparison of each technology alternative, the manufacturing costs for in-house production are thus determined. In addition to initial fixed costs, these also take into account production framework conditions (e.g. desired shift system, processing time per unit, degree of utilization of the machine) and other costs that arise in in-house production (e.g. depreciation, interest, space costs, maintenance, energy costs). Based on this analysis, the manufacturing costs of the components are calculated ("make") and compared to supplier prices ("buy"). By analysing the cost functions, a break-even point is determined depending on the number of production units.

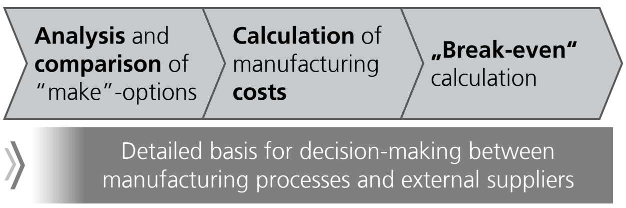


Figure 7: Analysis and evalulation of the strategic options

The result of the third step provides the detailed decision-making basis within the make-or-buy decision for manufacturing alternatives in-house "make" and outsourcing to suppliers "buy". The process for the analysis and evaluation is displayed in Figure 7.

4.2.4. Strategic Decision Making

Once the analysis from step 3 has been completed, a basis for decision-making is available to support the make-or-buy decision. Finally, the make-or-buy decision is also influenced by strategic aspects which have to be reflected in the analysis. These include desired production depth, strategic added value as a competence advantage over competitors, a possibly broad internal utilisation of a technology, time-to-market of the product, future market growth, as well as considerations of whether the overall portfolio is compliant with internal resources. As the information content increases due to further technical development, it is important to regularly check, question, and validate the results under the aforementioned strategic aspects for long-term orientation in an iterative process in order to adjust them if necessary. This is particularly relevant against the background of the start-up's development cycles. The start-up is not only supported by the method in the make-or-buy decision, but also implements a continuous learning process for future decisions and products. The summary of the steps is shown in Figure 8.

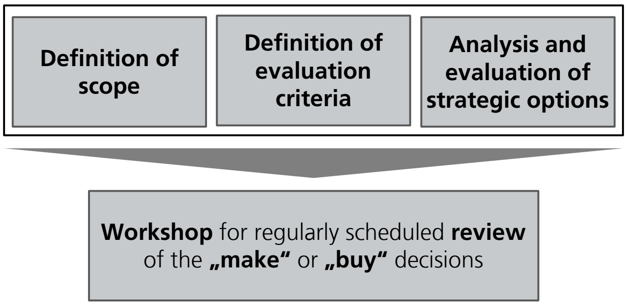


Figure 8: Strategic decision making on the basis of the results of steps 1, 2 and 3

5. CONLUSION & OUTLOOK

All in all, this paper provides an adaptation of the make-or-buy analysis to the special requirements of start-ups focused on the air taxi market. The process is described by using the example of the electric propulsion machine but can be applied to all components of the drive train and transferred to further main components of air taxis. While existing literature offers a variety of general approaches for a make-or-buy analysis, it does not offer an approach that explicitly considers the specific requirements for start-ups and the air taxi industry. These requirements, especially the usually limited availability of financial resources to build up production capacities, represent a challenge that is addressed in the elaborated methodology. The methodology's four steps take into account technical aspects of individual components, a variation of possible production technologies as well as company's environment. In addition, an iterative learning process is implemented that enables continuous improvement of the decisions made.

The validation of the methodology using the example of the electric machine for the drive train of the Air Taxi showed that a systematic approach to the make-or-buy decision supports the identification of a systematic comprehensive manufacturing strategy and ensures a justified use of limited resources. For this purpose, both technical and economic criteria are taken into account. In order to establish comparability between the different technological alternatives, qualitative evaluation is usually needed and used. A quantitative comparison is not implemented in the process of using the method described. The method can be applied to all other components of the powertrain.

The current technical development focus within the project EFRE E-SAT is on the production of the electric machine for small series. Nevertheless, early decision-making for long-term development is already highly relevant and depends on many parameters within the early development. The findings from the small series are also decisive for the next steps and must be continuously developed. Thus, within the next steps of the project as a whole, the goal of series production is being pursued.

Future work should focus primarily on implementing a continuous learning process for series production by using and detailing the methodology. For example, by taking a detailed look at guaranteeing quality for large quantities, the potential for automating entire process chains or identifying general technical problems that need to be taken into account at an early stage when selecting technologies for series production.

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