ON THE DEFINITION OF DEVELOPMENT OBJECTIVES FOR AIR TAXIS DERIVED FROM A HOLISTIC STAKEHOLDER ANALYSIS

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Abstract

Air Taxis are revolutionary aircraft that are set to create a wide range of new market opportunities. As they are exposed to a high degree of both market and technology uncertainty, it is important to set the right development objectives at the beginning of the development process. Currently, there is no model specifically adapted for Air Taxis to capture requirements and to process them further before starting formal development. To close this gap, the authors suggest a four-step approach to identify requirements and transform them into development objectives for Air Taxis.

First, a literature review is conducted highlighting the theoretical deficit justifying this model. Next, the Air Taxi market is characterised, and associated challenges are outlined. After presenting the general structure of the model, the indicated four steps are detailed. These include the structuring and identification of requirements as well as the formalisation of an objective system and finally the operationalisation of requirements by transforming them into development objectives. Additionally, the single steps are illustrated by conducting a meta-study of 15 papers to define 4 characteristic Air Taxi stakeholders, 6 requirement clusters, and 28 Air Taxi-specific requirements.

1. INTRODUCTION & OBJECTIVES

Globally, more and more people move to cities. The proportion of the global population living in cities is expected to rise from 55 % in 2018 to 68 % in 2050 [1]. The use of private motorised transport already leads to congestion of transport systems and high levels of air and noise pollution [2]. Thus, the current traffic behaviour in cities as such is being questioned and the creation of innovative alternative means of transport is being considered. Restrictions result from very long lead times in the construction and extension of transport infrastructure and, depending on the region of the world, from the respective weather conditions, restricting flying under visual flight rules. [3, 4] Concerning regional transport between cities and the countryside, the situation is often precarious as well. Here, too, the means of transport reach their capacity limits, are inefficient or harmful to the environment. To solve these problems, Air Taxis (ATs) are being developed to enable transport in the third dimension in urban and regional scenarios.

The market for ATs is called Advanced Air Mobility (AAM) and has received a lot of media attention due to the progress made in this field in recent years [5]. New technologies developed in the automotive industry, such as batteries or autonomous driving capabilities, open up possibilities that were previously unthinkable [6–8]. New types of batteries, e.g., not only provide the opportunity for electric flying and the associated sustainability benefits familiar from the automotive industry but also completely new possibilities for aircraft configurations, which in turn allow for a great increase in aircraft efficiency. [9]

As a result, there is a high pressure to innovate, to which the market is reacting to mature ATs for AAM. A McKinsey study puts the investment volume into AAM start-ups in the first five months of 2021 alone at over USD 4.3 billion worldwide, compared to USD 2.3 billion in the entire previous year [10]. The volume is therefore not only very high but also rising sharply at the same time. The industry association Vertical Flight Society (VFS) counts more than 500 different development projects in this field [11]. Current estimates assume an annual sales potential of up to USD 500 billion in 2035 in the United States alone [12]. It is therefore undeniable that AAM is of high relevance. However, as there is no established AAM market yet, market requirements remain unclear, and ATs can be regarded as highly complex and new products associated with significant technological risk.

This makes it all the more important to proceed methodically in this innovative field. Currently, there are no methods that systematize the collection and processing of requirements for ATs. It is therefore unclear on what basis they are determined, which represents a high risk for further development. An AT that is developed for the wrong requirements cannot be successful [13]. The best-known recent example from aviation is the failure of the Airbus A380. The wing was designed for an aircraft version with a higher payload, which was ultimately not built – leading to a heavier wing than necessary [14]. The hoped-for commercial success failed to materialise, therefore Airbus stopped production prematurely and never made a profit on the aircraft type [15]. With that in mind, it is essential to understand the requirements placed on revolutionary aircraft in the form of ATs.

The model in this paper is intended to enable decision-makers to formalise the vision for an AT by translating words into numbers. For example, a decision-maker may be incentivised by current trends to develop a sustainable AT. But sustainability can refer to many different aspects of the AT. It can mean that the climate impact from greenhouse gas (GHG) emissions is low. It can also mean that the cabin of the aircraft is made of sustainable materials. A decision-maker will also consider the ticket price level of the AT. In the past, it has been shown that sustainability and a low price level are difficult to reconcile and the decision-maker therefore has to make trade-offs at the earliest stage of development to conceptualise a feasible AT [16]. Therefore, this paper aims to provide a method to find the optimal requirement basis considering all constraints, which are incorporated into the model in the form of requirements of all relevant stakeholders and are further developed into so-called development objectives.

After discussing the theoretical foundation in chapter 2 by conducting a literature review and characterising the AAM market, the general structure of the model is presented at the beginning of chapter 3. The model itself is detailed afterwards. This paper closes with a conclusion and outlook.

2. THEORETICAL FOUNDATION

This chapter gives an overview of the theoretical basis. To do so, the impact of early development phases is presented (cf. section 2.1) and a literature review is conducted (cf. section 2.2). Lastly, the AAM market is introduced, and its challenges are discussed (cf. section 2.3).

2.1. Impact of early development phases

The scope of this paper is to provide a model for the derivation of development objectives for ATs. Hence, it needs to be executed before formal aircraft development starts. According to the development process by GUDMUNDSSON, this is a four-phase process that starts with the requirements phase [17].

The result of that phase is the definition of Top-Level Aircraft Requirements (TLARs). This paper provides development objectives for the entire aircraft. TLARs are often focused on aircraft performance and do not set cost or comfort requirements [18]. In the context of this paper, the development objectives are used to consider the entire range of requirements to derive TLARs at a later stage.

The early development phases of an AT are of disproportionally high importance for its development. In FIG 1 it is shown that decisions taken in the early development process determine a large amount of the product's lifecycle costs [18].

This is supported by ROSKAM who reports that 85 % of costs are determined in the 'project-phase' of development and only 15 % in the 'detail-phase' [19]. An investigation by ROLLS-ROYCE of 2,000 components supports this further by establishing that 80 % of product lifecycle costs are determined before the first design review [20]. Regardless of how much of the costs are exactly determined at which point, it is clear that early development has a major impact on the product's success and it is of the utmost importance to start with specific development objectives [21].

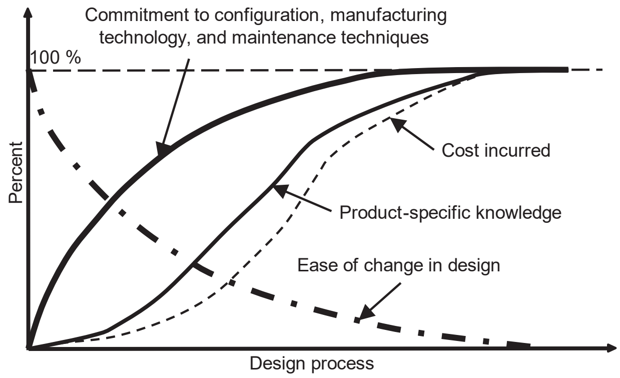

FIG 1: Early determination of lifecycle costs [18]

2.2. Literature Review

Based on the motivation and objective of this paper six specific objectives are formulated for the scope of the model and reflected in the literature review. First, ATs should be considered and an application under high technology and market uncertainty should be ensured. Moreover, stakeholders of complex technological products should be identified, and their requirements should be derived. Next, operationalised development objectives should be determined based on the requirements and lastly, it should be possible to verify the fulfilment of requirements to allow for an agile approach.

A literature review is conducted to investigate how existing work achieves the defined objectives. The sources are works on product development that demonstrate the relevance of requirements [22–27]. Additionally, several requirements engineering processes are analysed which show how requirements are applied in the product development process [28–37]. Results of this review are directly adopted by the model and discussed thereinafter. Finally, aircraft development processes by GUDMUNDDSON and ZHANG AND ZHANG are examined to understand how traditional aircraft development is conducted and requirements influence the design process [17, 38].

During the literature review, four areas of deficits can be identified which are to be addressed by the model. The first area is that ATs are not specifically considered in most of the sources [22–37]. Secondly, there is a low sensibility for stakeholders as they are not analysed in detail [17, 22–28, 34–38]. The third identified area does not specify development objectives but rather identifies requirements without processing them further [31–36]. The last area is that no clear structure of requirements is implemented preventing rapid verifiability of the fulfilment of requirements [17, 24, 28, 37, 38]. Based on the identified deficits, the model is created accordingly (cf. chapter 3).

2.3. Market characteristics and challenges

The AAM market is divided into the Urban Air Mobility (UAM) and Regional Air Mobility (RAM) markets. To avoid confusion these markets are defined by their mission profile as shown in TAB 1. [39] It should be added that the split between the two markets is not as clear cut as the fixed numbers might suggest. If an AT has a range of 130 km but largely operates within urban areas and is a VTOL, it would be classed within the UAM. Concerning other literature, it is added that the designation of AAM, UAM and RAM in the understanding of this paper, is not yet well established. This terminology has only been established since 2020 [5]. It is therefore not uncommon to find works that do not use the same framework.

TAB 1: Classification according to mission profile [39]

	UAM	RAM
Number of seats	1 – 4	4 – 9
Take-off / Landing requirement	Vertiport	Airport
Cruise speed	100 – 200 kph	200 – 400 kph
Range	< 100 km	100 – 500 km

Within the AAM, five different use cases can be postulated. They start at the shortest travel distances for Airport-Shuttles and range up to an Inter-City use case as exemplified by FIG 2. [40] Of those use cases, the Inter-City use case can be attributed to the RAM market. While the Sub-Urban-Commuter use case can be part of either RAM or UAM, the remaining three use cases are addressing UAM. In both urban and regional environments, ATs can help alleviate traffic constraints. While urban areas are congested by an ever-increasing urban population, regional modes of transport like cars, trains, or CS-25 aircraft are limited as they are either constrained by a high number of trucks moving goods or long lead times [39, 41] In both environments, ATs promise to drastically reduce travel time and provide a sustainable alternative to traditional modes of transport. While COHEN ET AL. argue that ATs will solely be operated on-demand [42], this is disputed by LILIUM, which will operate its ATs, at least initially, on scheduled routes [43].

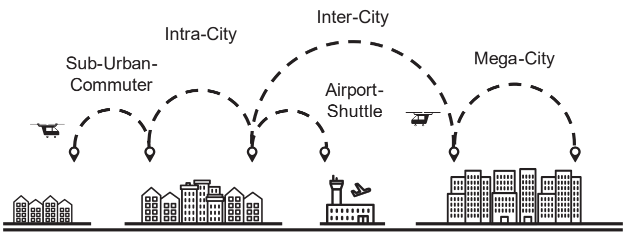

FIG 2: Generic AAM use cases [40]

Within the AAM different technological highlights can be identified, of which a selection is presented in this paper. The first highlight is electrical flight. This enables clean and climate-friendly flying, as no GHG emissions are created during flight [44] and additionally quiet or near-silent flight. Purely electric flying is possible for ranges up to 80 km with battery densities which are available today [45]. At greater ranges, the battery mass becomes a limiting factor for the AT and therefore hybrid powertrain architectures are used [46]. These offer unprecedented configuration options nonetheless. Especially in the field of hybrid-electric flying, there is still very much research required to understand the best possible powertrain architectures. It is not yet clear whether it is best to link the electric and combustion part of the power train in parallel or series. Regardless of that, it is clear that these new design opportunities allow new configurations with highly improved efficiency. [47]

Another technological highlight is autonomous flight. This has great advantages for operators. First and foremost, the cost of pilot salaries is cut, which is a significant expense. In the current aviation market, there is already a shortage of pilots, which would only be worsened by additional pilot demand for ATs. Since ATs have a lower number of passengers, a higher number of pilots on a per-passenger basis is required. This also means pilot costs for ATs are disproportionally high. [48] Finally, the absence of a pilot opens the space and mass for another passenger. In the case of a 2-seater AT the exclusion of a pilot could double the passenger capacity without any further development. The downside to autonomous flight is its feasibility, however. It has not been certified yet and it is unclear what challenges would need to be overcome to achieve it. [49] This is the reason why both UAM- and RAM-AT-developers are developing viable business models using a pilot. They aim to avoid betting their development on the success of autonomous flight but do include systems for future autonomous operations. [41, 50]

A large challenge for ATs is certification as a whole. As previously stated no autonomous ATs are certified thus far, but this is also the case for VTOLs. They face special challenges for certification as they will operate in densely populated urban areas. In case of a catastrophic engine failure, an AT needs to perform an emergency landing. Little or no place for that exists in cities. It, therefore, needs to be ensured that the risk of failure is low enough to be deemed acceptable by certification bodies. [51] The previously described challenges are mainly applicable to UAM-ATs, while RAM-ATs face little challenge to be certified. In the European Union, the first electric aircraft, the Pipistrel Velis Electro is certified [52]. It is therefore determined that electric flying itself does not pose a great challenge for ATs.

Next to being certified ATs, also require the necessary infrastructure to take-off and land. Again, UAM faces greater challenges than RAM. RAM can use exiting airport infrastructure that is ready to be used [53]. It is shown for example that in Germany 85 % of the population live within 20 km of a potential RAM-airport and in the United States, this figure stands at 99.7 % and 30 miles (48 km) [39, 54]. These airports are currently used by General Aviation (GA). On the other hand, vertiports for UAM first need to be constructed as existing helicopter infrastructure does not suffice. This objective cannot be achieved singlehandedly but requires general social acceptance wherever UAM-ATs are to be operated so that vertiports can be constructed. [8, 55, 56]

The above points lead to the last major challenge for ATs. A significant unknown in the market introduction of ATs is their social acceptance. The disparity between UAM and RAM holds true again. ATs in urban environments could be annoying to the population both due to noise and as a visual nuisance if they fly in high succession overhead [55]. Even though electric flying allows for drastically reduced noise emissions it is shown that this does not necessarily equate to less annoyance as the sound profile of low-noise electric flying is different and can have a lot of high-frequency tones [57]. On the other hand, residents living close to airfields used for RAM services are used to the noise produced by aircraft with combustion engines and lower noise aircraft will not pose a challenge. Additionally, RAM-ATs will have higher cruising altitudes which means they will disappear shortly after take-off. On the passenger side, it is not clear what the reaction to the high degree of technological advance of ATs is and whether it will be seen as a safe mode of transport [56].

All in all, AAM has to face certain market and technological challenges that need to be reflected during the design phase of ATs.

3. DEFINITION OF DEVELOPMENT OBJECTIVES FOR AIR TAXIS

In this chapter, a model is designed to derive operationalised development objectives for ATs from corresponding stakeholders. The model first describes how requirements can be structured (cf. section 3.1), before demonstrating how they are identified (cf. section 3.2). As an intermediate step the objective system of the developer is formalised (cf. section 3.3) before the requirements are finally operationalised into development objectives (cf. section 3.4). If the requirements cannot be successfully operationalised, an iteration is used and the requirements are either rephrased or the objective system is adapted. The general structure of the model is depicted in FIG 3.

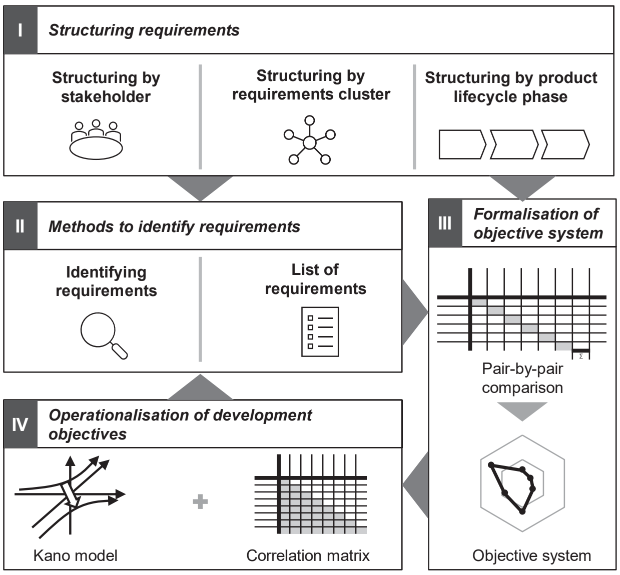

FIG 3: General structure of the model

Throughout the model, a meta-study of 15 different sources is used to understand stakeholders and requirements better. Within its requirements, its corresponding stakeholder and product lifecycle phase (PLP) are identified. Market studies are analysed to understand under what conditions an AT can be successful [6, 53, 58–64]. Additionally, studies on the societal acceptance of ATs are investigated as they help to widen the requirement space [8, 55, 56]. Lastly, three aircraft development processes are studied to define a base of requirements [17, 65, 66].

3.1. Structuring requirements

Before identifying requirements, it is necessary to create a structuring method. A simple list of requirements without any underlying structure limits its use as it is very complex to work with. To reduce complexity and to support later updating of the requirements a set of structuring possibilities is proposed by this paper: by stakeholder, PLP or requirement cluster.

3.1.1. Structuring by stakeholder

The first structuring possibility is to document the stakeholder who demands a requirement. A wide variety of different stakeholders can be identified for such a complex product when conducting a holistic stakeholder analysis. First, this paper identifies different sets of generic stakeholders from three different stakeholder models. These are then aggregated into a smaller list of relevant stakeholders for the design of an AT to ultimately determine four characteristic stakeholders for ATs. Each of those characteristic stakeholders represents a group of different stakeholders and combined they represent the entirety of AT-stakeholders. Characteristic stakeholders are introduced to reduce the model's complexity.

To identify generic stakeholders, the new St. Gallen Management Modell (NSGMM) by RÜEGG-STURM, the framework for production and management by SCHUH and the value chain by PORTER [67–69] are used. The NSGMM is based on six central management dimensions and allows to identify stakeholders in the surrounding environment of a company. The framework production and management is based on the NSGMM and is adapted for companies that manufacture products. The value chain by PORTER identifies the value-adding activities within a company. Based on the different frameworks different generic stakeholders can be identified which are compared in TAB 2.

Only the stakeholders marked in **bold** are considered further as only these are considered to have a significant impact on the AT development and its success. This judgement is based on the meta-study of AT requirements. To reduce complexity these stakeholders can be reduced further to four characteristic stakeholders.

The first characteristic stakeholder is the **manufacturer** of the AT. This stakeholder not only considers the company that produces and sells the assembled AT but any development partners or suppliers, which are involved in the development and production process.

The next characteristic stakeholder is the **operator** of an AT. This stakeholder represents any entity that operates the AT like airlines or private individuals who could buy the AT as a private aircraft. The competition is also considered indirectly as operators compare different ATs. The AT developer can take this into account using benchmarking techniques.

The third characteristic stakeholder is the **customer** of an AT, meaning the paying customer flying with an AT. Here different modes of transport can be considered as competitors as well, as customers will choose the mode of transport with the best cost-benefit ratio.

The last characteristic stakeholder is the **public**. This stakeholder not just considers the general population as residents of airports and vertiports are impacted by AT-flights but also lawmakers and regulators, as they represent the interest of the public.

TAB 2: Comparison of generic stakeholders

NSGMM [67]	Framework for production and management [68]	Value chain [69]
Suppliers	**Suppliers**	**Suppliers**
Business processes	Purchase management	Inbound logistics
	Factory planning	Operations (production)
	Production and logistics management	
	Quality management	
		Outbound logistics
	Management industrial services	Customer support
	Technical sales	Marketing & sales
Support processes		Sales channels
	Procurement management	Purchase (procurement)
	Technology management	**Technology development**
		Human Resources
	Innovation management	
Employees	Employees	
Management processes		Business structure
Competitors	**Competitors**	
Customers	**Customers**	**Buyers**
Public / NGOs	**Public/ NGOs**	
State	**State**	
Investors	Investors	

3.1.2. Structuring by requirement cluster

Another method to structure requirements is to group them into requirement clusters. To do so, clusters need to be identified. First, the STEEP factors are considered. STEEP is an acronym for society, technology, economy, environment, and policies. These factors allow describing the business environment in terms of specific market conditions. [70] Another well-known acronym is PESTEL, which is closely related and additionally considers legal aspects. [71] It is evaluated whether the STEEP-factors can be used as requirements clusters by evaluating three different sources from the meta-study representing each of the introduced sub-groups [17, 55, 60].

The result of this initial analysis is that the societal and environmental factors show significant intersections. The noise emissions impact both society and the environment as well. As the requirement clusters are used in a later model step to prioritise requirements however they should have as little overlap as possible [72]. The STEEP-factors are therefore adapted, and requirement clusters are defined which do not overlap. To limit complexity the number of clusters is kept as low as possible.

In total, six requirement clusters are identified. The first cluster is **operations & performance**, which considers any requirements that have an impact on the operations of an AT. Their fulfilment ensures a smooth operation at a high technical performance. The next requirement cluster **comfort & appeal** considers subjective aspects of the passenger's well-being during the flight. **Ecological sustainability** includes any aspects that have a climate impact while **economic sustainability** includes all requirements which deal with monetary factors. Additionally, **social sustainability** takes into account all requirements which are important to the general public. The last requirement cluster **certification** considers every aspect, which ensures that an AT is legally allowed to operate. The requirement clusters are further detailed in TAB 3.

3.1.3. Structuring by product lifecycle phase

The product lifecycle of a good considers every step from an initial vision up to the end-of-life [19]. It allows splitting the life of the good into different PLPs. Different approaches propose different PLPs [66, 73–76]. However, for this paper, the approach of Life Cycle Costing (LCC) is used [21] as it was originally conceived to manage the costs of military projects in the United States and is currently also used for commercial aircraft projects [77]. LCC splits the product lifecycle into four PLPs, which are development, production, usage, and end-of-life.

3.1.4. Interim conclusion

This section shows that requirements can be structured by their characteristic stakeholder, requirement cluster and PLP. When identifying requirements, these characteristics should be documented in addition to their description and value and whether the requirement is fully specified which can be done using classifications like to be determined / resolved / specified (TBD, TBR, TBS). [35, 78] A unique identifying number for each requirement is also advised [32]. Lastly, every requirement should be assigned to one manager or engineer. This person can be consulted if questions about it arise and should be consulted if it is adapted. It ensures that previous decisions can be reconstructed. [37]

3.2. Methods to identify requirements

When identifying requirements, they should be properly determined rather than simply collected. This prevents an unnecessarily long list of requirements which can lead to costly iterations during development. To identify requirements EBERT proposes four distinct groups of techniques: questioning, creative, document-based and observation techniques. [30] All but the last one are considered for the model of this paper, as observation techniques are too sophisticated and hinder fast requirement identification. This section presents specific techniques from the remaining groups.

Within the questioning techniques, expert interviews can be used to gain knowledge from professionals who possess intricate technical or industrial knowledge [79]. Expert interviews are structured beforehand to ensure that all necessary information is collected [80]. Additionally, conversations can be used [32]. To increase the sample size standardised questioning techniques can be used [81]. They can be either online or via telephone [82].

Within creative techniques, brainstorming is a well-known technique [83, 84]. Its goal is to support creative ideas and find solutions that are not obvious. Brainstorming was initially conceived by OSBORN [85] and has since then been adapted by several authors. Usually, different brainstorming methods are used in combination with one another [86]. As a creative technique, a system boundary shift can be used as well. It helps to create new ideas if the identifying process hits a roadblock and gives the adopter a different perspective. [32] An example in the context of this paper is that ATs can be considered both as simple flying objects and also as the centre of a transportation ecosystem.

TAB 3: List of AT requirements

Requirement cluster	Requirement
Operations & performance	Automation
	All-weather capabilities
	Air traffic management
	Ground infrastructure
	Flight dynamics
	Flight performance
	Maintainability
	Flexibility
	Reliability
Comfort & appeal	Window size
	In-Flight Entertainment
	Cabin comfort
	Image
Ecological sustainibility	Climate impact
	Use of sustainable energy sources
Economic sustainibility	Operating costs
	Development costs
	Production costs
	Production ramp-up costs
	Ticket prices
Social sustainibility	Data protection
	Privacy
	Social acceptance
	Noise emissions
	Perception of safety
	Visual disturbance
Certification	Certification
	Certification basis

The re-use of requirements is the first technique within the document-based techniques [30]. Since ATs are not established in the market yet, its feasibility is questionable. However, companies like Lilium or Volocopter have conceptualised AT families with a high degree of commonality [87, 88]. While market studies help to understand what is required to operate successfully in the desired market, benchmarking activities investigate how the competition is positioned [37, 89]. Lastly, checklists can be used to ensure that no requirements are forgotten [30, 32]. This paper determines a list of AT requirements based on the meta-study which can be considered as a checklist. The meta-study first identifies over 400 requirements named in the papers. These are then curated by ensuring consistent naming and excluding those requirements which were not relevant for the AT's success. Finally, requirements are condensed by summarising sub-requirements into a single requirement. The operating costs, e.g., include among others personal, fuel and capital costs. The list is shown in TAB 3 and the requirements are also listed in their respective clusters.

When deciding which specific identification technique to employ, FIG 4 can be used. It is based on the work by EBERT and introduces potential usage scenarios. All the previously named techniques are shown in **bold**. It is out of the scope of this paper to introduce further techniques. The separation of the y-axis in FIG 4 considers whether the relevant stakeholder is limited to a small group of people or companies (known principal) or not (unknown). The first would be the case with an airline interested in an AT, while the latter would be customers of ATs, as many different parts of the population can potentially book AT flights. The x-axis considers whether the agent already knows what kind of AT to develop when identifying requirements. It is known if the configuration is already largely defined because the developer aims to integrate a specific propulsion technology into an AT. The agent would be unknown if only a vague vision of the AT exists.

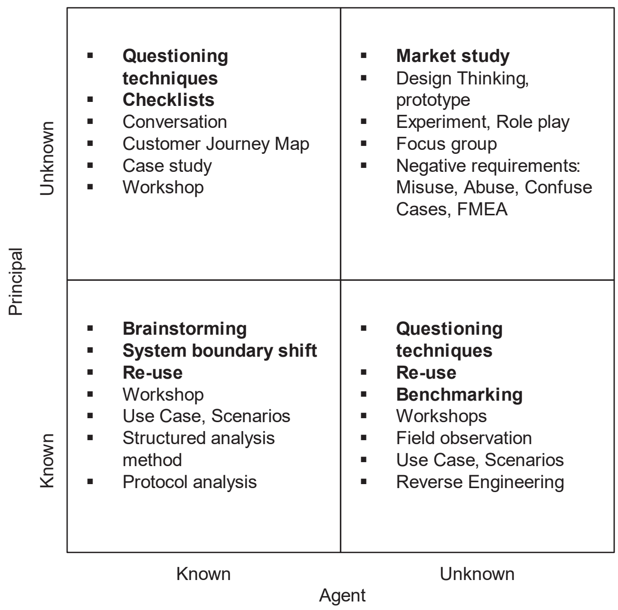

FIG 4: Usage scenarios for identification techniques [30]

3.3. Formalisation of the objective system

To formalise the objective system for the AT development, a pair-by-pair comparison is used. It allows to break down complex decisions into smaller ones to reduce the subjectivity of the decision [90]. This paper compares the different requirement clusters with one another (cf. section 3.1.2) to prioritise the requirements.

If conflicts between certain requirements arise, such prioritisation can be beneficial to solve the conflict by highlighting the concrete focus of the specific AT.

In the pair-to-pair comparison, a cluster can either be more important (2), as important (1) or less important (0) than the other. By standardising row totals with the overall total, the relative importance is determined. [90, 91] An exemplary pair-by-pair comparison is shown in FIG 5. The AT is not able to operate without certification which ensures that it is safe for both the users and residents being overflown.

Legend More (2), As (1), Less (0) important	**Operations & performance**	**Comfort & appeal**	**Ecological sustainbility**	**Economic sustanibility**	**Social sustanibility**	**Certification**	**Sum**	**Relative importance**
Operations & performance	1	1	1	2	2	0	7	**0.19**
Comfort & appeal	1	1	1	0	2	0	5	**0.14**
Ecological sustainbility	1	1	1	2	1	0	6	**0.17**
Economic sustanibility	0	2	0	1	1	0	4	**0.11**
Social sustanibility	0	0	1	1	1	0	3	**0.08**
Certification	2	2	2	2	2	1	11	**0.31**
							∑ 36	

FIG 5: Pair-by-pair comparison

To take this into account the certification cluster is pre-determined to be more important than any other cluster in this paper. This means only twos are set in its row or zeroes in its column. This decision stems from the approach of Design for X (DfX) which aligns product development with a single goal in the case of this paper the Design for Safety. [32, 92]

3.4. Operationalisation of development objectives

For the last model step of operationalisation, a combination of different methods is used. This model step translates requirements into development objectives, which means that a clear development order is defined. This can be used as a starting point for later development. While the previous model defines the objective system, this model step evaluates how these objectives can be achieved.

The value of a development goal is recorded using the specification types by MATTMANN (cf. TAB 4). The specification types are split into three different classes. They can either be fixed, range or optimum objectives. This means that depending on their relevance, the values of objectives can have different design freedoms.

This gains relevance when investigating the target conflicts of different objectives. Three different conflicts can be identified. Objectives can be **target-independent**, which means that independent features are impacted by contradicting objectives. They can also be **target-supporting** if positive or negative synergy effects arise. This is often the case with similar objectives. Lastly, the strategic targets of a company can change throughout the AT development which can lead to **dynamic changes**. These need to be considered to avoid delays and quality losses. [93, 94]

TAB 4: Specification types by MATTMANN [93]

Specification type		**Representation with a value scale**	**Description**
Fixed		x_{fixed} inadmissible range	Fixed predefined value that must be achieved
Range	Interval	x_{min} x_{max} admissible range	Permissible range of values specified by the requirement
	Minimum	x_{min} admissible range	Permissible value to be achieved as a minimum
	Maximum	x_{max} admissible range	Permissible value that must not be exceeded
Optimum		x_{opt} optimum value	Optimum value to be achieved

To identify target conflicts a correlation matrix is used. In this matrix, the interdependencies of different requirements are recorded. These can be either positive (+), neutral (0), or negative (-) as shown in FIG 6. In this exemplary correlation matrix, the interdependencies of all the requirements from the requirement cluster operations & performance are evaluated.

Legend Positive (+); Neutral (0); Negative (-) interdependencies	**Automation**	**All-weather capabilites**	**Ground infrastructure**	**Flight dynamics**	**Flight performance**	**Maintainability**	**Flexibility**	**Reliability**
Automation		+	0	+	0	0	+	-
All-weather capabilites			0	+	0	0	+	0
Air traffic management				0	0	+	0	0
Flight dynamics					0	0	0	0
Flight performance						0	+	0
Maintainability							+	+
Flexibility								0
Reliability								

FIG 6: Correlation matrix [95]

It can be seen that only one pair of requirements is negatively impacted by another one. The reliability is impaired by automation as this adds more systems to the aircraft which need to function. At the same time, automation supports the pilot and allows for more complex flight manoeuvres or flight dynamic capabilities. This in turn leads to better all-weather capabilities and greater flexibilities in operations.

After identifying the target conflicts, they need to be solved. This can be achieved by finding a compromise between the requirements of the different stakeholders or by changing the AT concept [94]. Additionally, the requirements can be simplified by reducing the model completeness or accuracy [96]. As an information basis for compromises, the Kano model is used. It distinguishes between three types of requirements and their effect on customers or customer relevance (cf. FIG 7). A **dissatisfier** can be understood as a basic requirement and its absence leads to disproportionally low customer satisfaction. An example would be the sense of safety experienced by the customer. A **satisfier** on the other hand leads to exceptionally high satisfaction and allows differentiation from the competition, like a unique view for the customers out of the AT's windows. The **performance requirements** achieve a proportional response in satisfaction like the cruise speed of the AT. The arrow 'time' exemplifies that over time, satisfiers are more and more expected by the customer, meaning they become performance requirements and eventually dissatisfiers. [97–99]

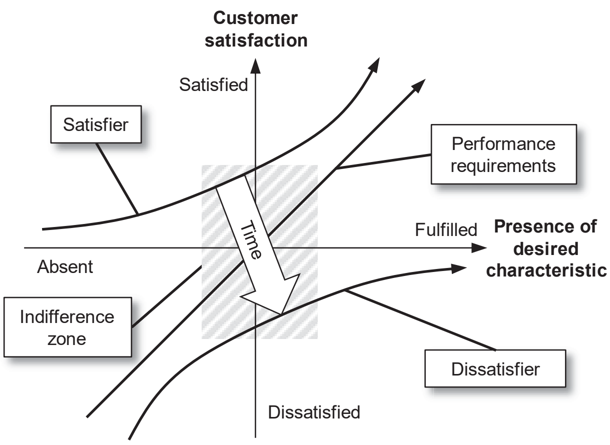

FIG 7: Kano model [99]

Based on the knowledge gained on requirements with the Kano model the objective values are determined by using the specification types. The noise emissions for a hypothetical AT in the UAM can be determined to be a dissatisfier. If the objective system of the developer puts a focus on social sustainability a noisy AT cannot be successful. This requirement can be operationalised using a maximum objective which limits the maximum noise emissions of the AT. If the AT were part of the RAM on the other hand the noise emissions could be a performance requirement as residents are not as heavily impacted by noise. Therefore, the requirement could be operationalised as an optimal objective, which does not limit it to a maximum. If all target conflicts cannot be solved successfully an iteration is used and either requirements are newly identified, or the objective system is adapted.

When documenting the objective its unit metrics need to be recorded [100]. This might be trivial for physical values like the climb rate which is always a speed or a range which is always a distance. It is not trivial for objectives like operating costs, however. In later stages of development, the AT is compared to its competitors, and it is not advisable to define unit metrics that produce favourable results of the AT in development but should rather result in an impartial judgement. Otherwise, later market success can be hindered. This is exemplified by CORNELL ET AL. in FIG 8. It shows that unit metrics can easily change depending on the definition. It explores potential unit metrics for a hypothetical AT and ride-hailing service.

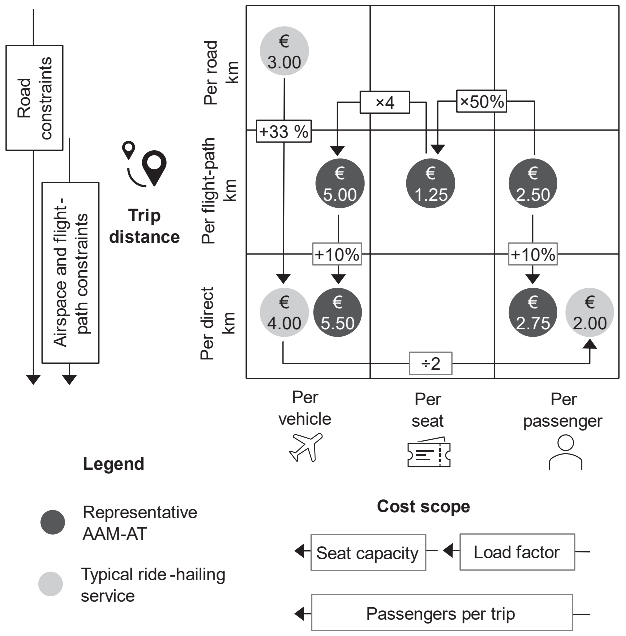

FIG 8: Comparison of unit metrics of an AT and ride-hailing service [100]

4. CONCLUSION & OUTLOOK

In this paper, a model is defined to identify requirements for ATs and transform them into sound development objectives which can be directly applied for the development of ATs.

To do so, a literature review is conducted highlighting the theoretical deficit that justifies this paper. Moreover, the AAM market is introduced and characterised to provide a clear picture of the market status for ATs.

After proposing a structure for the model, four consecutive steps are executed to detail it. First, different approaches for the structuring of requirements are presented such as characteristic stakeholders, requirement clusters, and product lifecycle phases. Moreover, formal guidance for the listing of requirements is given. Second, methods are reported to identify requirements. The authors recommend the usage of questioning, creative, and document-based techniques. Additionally, a meta-study of AT requirements is conducted analysing 15 different sources and deriving 28 aggregated requirements allocated to their respective requirement clusters. Third, a pair-by-pair comparison of the requirement clusters is conducted to help to focus the AT development by assigning a relative importance to each cluster. Finally, requirements need to be transformed into clear development objectives applicable for the AT development. This is assured by using the specification types by MATTMANN and achieving a better understanding of the customer relevance of different requirements. The latter can be supported by the presented Kano model.

Overall, the outlined model provides a clear structure and can be beneficial for the preparation of an AT development. In future work, the model needs to be validated in a real-world use case to further improve its practicability and to assure its added value for the development of ATs.

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