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A Study on Finding Partners through Patent Network Analysis of UAM (Urban Air Mobility)

ChangHan Ryu [1], SeongKi Kim [2] and SungRyong Do [3,*]

[1] Technology Planning Team, HYUNDAI AUTOEVER Co., Ltd., Seoul 06176, Korea
[2] National Center of Excellence in Software, Sangmyung University, Seoul 03016, Korea
[3] Department of Computer Software, Kyungmin University, Uijeongbu 11644, Korea
* Correspondence: imdosungryong@gmail.com

Abstract: This paper presents an open innovation strategy by identifying the patent impact index and cooperation network through patent analysis for leading companies developing technology in the UAM field. Among companies developing UAM technology, patent analysis was conducted on the leading companies with active patent activities, technology classification was used to match companies by parts, and a technical capability index was utilized to identify the companies. When developing UAM technology in the future, this can help companies seek effective partners to improve competitiveness in technology development. To the best of our knowledge, the work done in this paper is unprecedented, as it suggests methods for patent analysis and verifies them by analyzing the UAM patents with the proposed method.

Keywords: UAM; partner finding; supplier management; patent analysis; intellectual property; R& D strategy; open innovation

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1. Introduction

In recent decades, as urbanization has progressed rapidly around the world, populations have become more concentrated in the city center, and movement on the ground has become troublesome [1]. On-demand services and Urban Air Mobility technology are emerging as new alternatives to solve urban traffic problems as it helps streamline mobility and transportation [2]. The average speed of cars in urban centers is approximately 30 km/h, which has become a significant issue. For example, in Tokyo, people spend a considerable amount of time traveling at 25.4 km/h on the road [3]. In the past, only a small number of enthusiasts and startups conducted R&D in the personal aviation (PAV) field, but now global aviation, automobile, and IT companies are actively investing in PAV, and the growth potential of the Urban Air Mobility (UAM) market combined with PAV as a means of future transportation is being noted [1].

UAM is a next-generation mobility solution that maximizes urban mobility efficiency with private aircrafts (PAV) capable of vertical take-off and landing (VTOL), using the sky as a transit route [4]. However, to implement UAM technology, one individual company cannot develop all the relevant technology, which includes the propulsion system, aerodynamic design, material/structure, battery, control/safety, navigation/communication, and cybersecurity technology; therefore, technical cooperation based on conventional technology development practices through open innovation is essential [5].

The contributions of this paper can be summarized as follows: First, this paper presents a strategy for technology analysis and technology development through patent analysis. Second, this paper describes the UAM Overall Technology Classification System (Tech-tree), which is a detailed technology-specific competitiveness analysis. Third, relevant partners were derived and analyzed through various patent analysis indicators in this paper.

This paper is organized as follows: Section 2 describes the theoretical background and hypothesis for this paper. Section 3 analyzes the patents in terms of their quantitative and qualitative aspects and describes the method that applies the analysis to find partners suitable for cooperation. Section 4 concludes all these works.

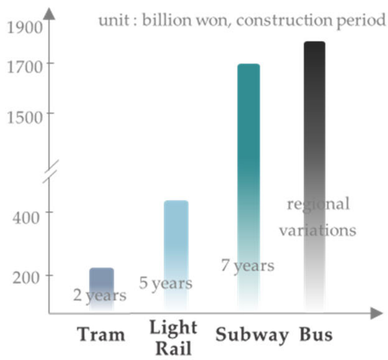
2. Theoretical Background and Hypothesis

2.1. City Traffic Problems in the City Center

According to a 2019 report by the United Nations, urbanization rates were growing by 55.3% in 2018 and are projected to reach 68.4% by 2050. In addition, Tokyo recorded the highest number of urban populations based on administrative divisions for each city at 37.47 million. It was followed by Delhi, Shanghai, and São Paulo. Seoul recorded 34th in the ranking with 9.9 million people living in the city center.

The amount of SOC (Social Overhead Capital) investment required for solving urban traffic problems is astronomical. The cost of solving traffic problems is also taking up increasingly higher proportions of the nation's finances.

Figure 1 shows that the construction of roads and subways in complex two-dimensional spaces—which are already mixed with people, buildings, and cars—is no longer an effective solution for urban traffic problems [6]. The population is likely to continue to be more concentrated in the city center and improving the efficiency of transportation such as public transportation, automobiles, and MaaS (Mobility as a Service) is surely the biggest workload for megacities. With the utilization of 3D space, UAM can be a meaningful alternative to solving megacity traffic problems [7].



Category	Light Rail	Subway	Bus
transport persons per hour	5000 ~ 30,000	30,000 ~ 50,000	fewer than 5000
car forming	1 ~ 6 cars	6 ~ 10 cars	1 car
persons per car	40 ~ 80	150 ~ 160	80
running interval	30 sec ~ 2 min	2 ~ 5 min	7 ~ 10 min
uphill allowable slope	6 ~ 9 %	2.5 %	15 %
real speed from start to finish	35 ~ 40 km	30 ~ 35 km	18 km (Seoul)
construction cost per km (billion won)	400 ~ 500	1500 ~ 1800	1700 (4 lane)

Figure 1. Construction cost per 1 km of public transportation (Seoul metro, 2017, Ministry of Land, Infrastructure and Transport, 2018).

The UAM market is expected to grow at an average annual rate of 30% or higher and will be introduced in 31 cities by 2030. UAM development is most active in the United States, and purely battery-powered vehicles were observed as taking up the largest proportion in classification by energy source [8,9].

2.2. UAM Concept

Urban Air Mobility (UAM) refers to urban aviation mobility, or the entire air traffic industry that seeks to transport passengers and cargo in the city center, and according to the latest development trend, electric vertical take-off and landing (eVTOL)-type aircraft manufacturing is gaining momentum [10]. There are several ways to distinguish between varieties of UAM, and the criteria are summarized as follows:

The first is a UAM classification method by aircraft type [10]. Table 1 shows that the fixed-wing-type is mainly used in the military, and is suitable for high speed and long distance, but requires a runway/launcher. A rotary-wing aircraft can have vertical takeoff and landing and hovering, but its speed range is not as high as the fixed-wing-type. Combining the advantages of both fixed and rotary wing is the hybrid-type, which has high energy efficiency, high-speed flight, and vertical landing [11,12].

Table 1. UAM classification by aircraft type, KIAST.

Category	Key Characteristics
Fixed-wing	- Ideal for high-speed and long-haul flights - Take-off using runway/launcher - Primarily used in military
Rotary	- Vertical take-off and landing and hovering design - Low-speed, troubling compared to fixed-wing
Hybrid	- Includes properties of fixed- and rotary-wing - High-speed flight, vertical landing possible - High energy efficiency compared to rotational income (tension)

Second is a UAM classification based on weight [13]. Table 2 shows that it divides airplanes and lightweight helicopters, etc. with 600 kg as the threshold, and classifies air vehicles that weigh 115 kg as ultra-light. In the case of UAM, the weight is estimated to be around 600 kg, which is the equivalent of a manned rotary aircraft.

Table 2. UAM classification by weight, KIAST.

Category	600↑	600	180	150	115 (kg)
Manned aircraft	- airplane - rotary aircraft	- lightweight helicopter - power parachute - weight-dyed plane - steerable airplane			- powered aircraft - powered paraglider - hang glider - paraglider - fixture - parachute
Drone	- airplane - rotary flyer - unmanned aerial vehicle (airship)				- ultra-light airship (unmanned aerial vehicle) - ultra-light flight (drone)

Third is another UAM classification method that classifies aircrafts according to the shape of the wings [14]. Figure 2 shows that this classification is based on the shape of the wings as defined on the TransportUP website, and UAM classification is possible in an intuitive manner.

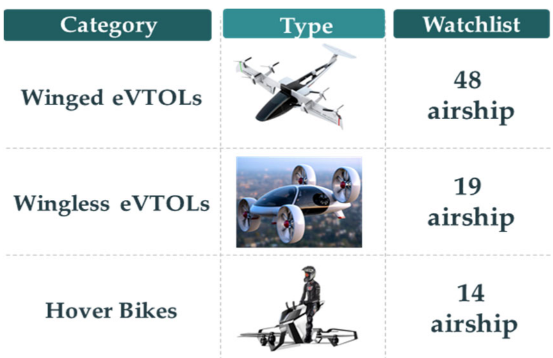


Figure 2. UAM classification by wing shape (https://transportup.com/ (accessed on 7 March 2022)).

Finally, as shown in Figure 3, this is another UAM classification method based on the operating altitude, which can be divided into low altitude (0.15 km), medium altitude (14 km), high altitude (20 km), and stratosphere (up to 50 km); UAM can be seen as corresponding to low and medium altitude [15,16].

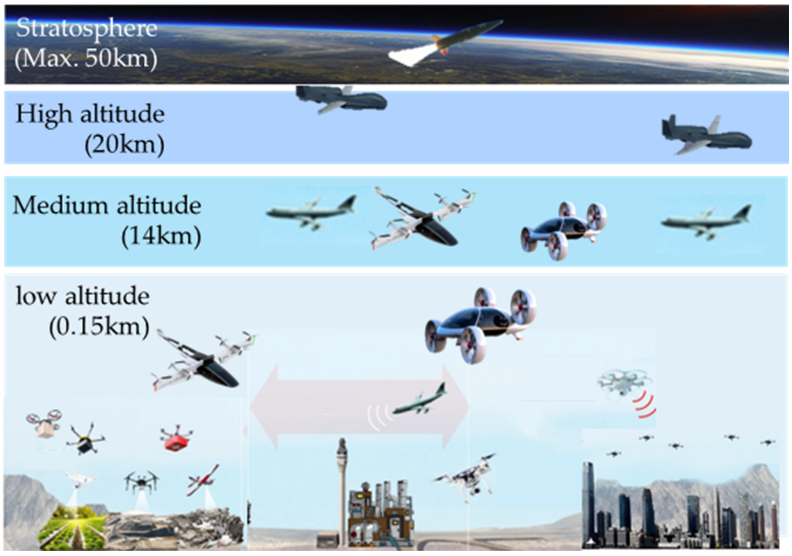


Figure 3. UAM classification according to operating altitude, KIAST.

Comparing the development schedule of the eVTOL manufacturing system, one company that launched the commercialization model is Ehang [17], and the technological gap was confirmed to be approximately 1–2 years, which is not considered significant [18]. The launch plan differed over several years by company, but the comparison between large companies that are developing multiple models in parallel and startups that are developing one model did not lead to much significant difference [19].

As companies in the automotive and aircraft industries are mostly leading the development of eVTOL (electric vertical take-off and landing), it is estimated that a technology development cooperation system will be established in the following form of Figure 4 [20–22].

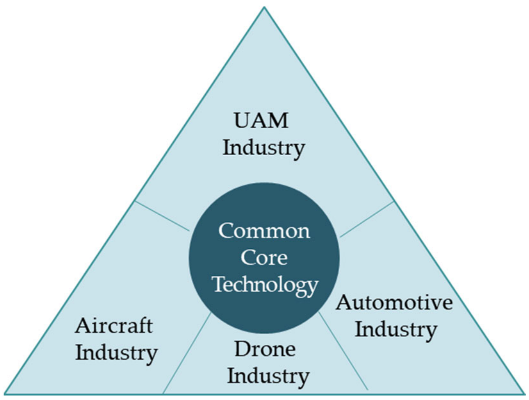


Figure 4. Global UAM ecosystem, KSAE 2021.

Table 3 shows that the automotive industry is developed in the form of multi-product mass production in small businesses, and the aircraft industry consists of small-scale production of props from small companies [23]. UAM production, being a mixture of the two systems, is expected to be characterized by an initial production of small quantities of props and then gradually moving on to mass production of props as the technology stabilizes and lowers the production cost per unit [1,24].

Table 3. Comparison of aircraft, UAM, and automotive industries.

Category	Aircraft	UAM	Automotive
Development period	10 years	7 years	4 years
Mass-production period	30 years	10 years	5 years
Age	30 years	20 years	10 years
Ordering method	pre-order	post-delivery payments	post-delivery payments
Key customers	company (carrier)	company (carrier)	personal
Development production method	development → order → production→	development → production → sales	development → production → sales
Division structure (Supply chain)	international joint development (RSP)	verticalization	verticalization
R&D ratio to sales	10%	10%	3.5%
Production method	manual	automation	automation
Development	large aircraft (10 trillion won) fighter (7 trillion won) midsize aircraft (3 trillion won)	small (1 trillion won)	medium car (450 billion)
Mass production?	small-scale production of props	mass production of props	multi-product mass production
Production by model	1000 units	100,000 units	40–500,000 units

2.3. Network Analysis

As the automotive industry shifts more into ICT and autonomous driving technology spreads, the leading power is shifting from a pyramidal structure in which end-vehicles monopolized the initiative to a more diamond-shaped or network-type structure, where the initiative is distributed across multiple companies [25]. As shown in Figure 5, the conventional value chain of the automotive industry has been changing from a pyramid structure (past) with the OEM at the top to a diamond structure (present) and is now moving even further to a hub-and-spoke structure (future) [26].

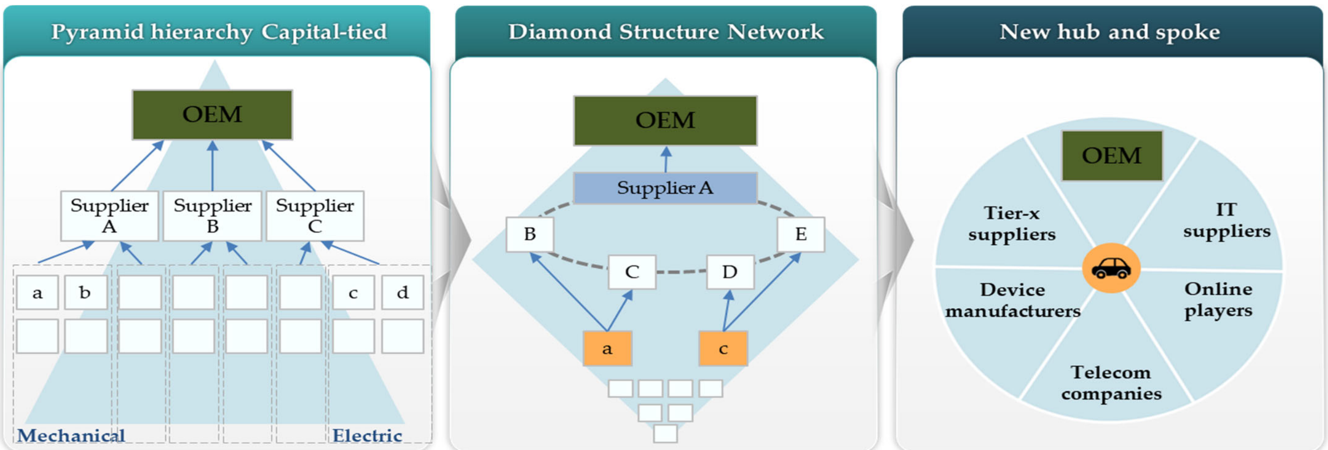


Figure 5. Changes in the automotive industry structure [25,26].

By continuing to work on ways to strengthen market acceptance, and by leveraging external resources through open innovation, we can reduce the cost of innovation and increase the likelihood of success to maximize value-added creation [27]. Chesbrough observed a shift in the knowledge landscape surrounding companies, noting that companies are increasingly expanding and are being required to expand [28]. Through the 20th century, a series of changes in the knowledge environment made open innovation imperative for the modern era. The reasons for this can be summarized into three reasons: (1) the end of the knowledge monopoly of large corporations, (2) the increase in manpower liquidity and the development of venture capital, and (3) the increase in the cost of technology development and the shortening of the product cycle [29].

While the process of research, development, and commercialization known as closed innovation takes place within a single enterprise [30], open innovation refers to a process whereby knowledge exchange between the inside and outside of the enterprise is seamless at each stage, external technologies are introduced into the enterprise, or vice versa, and technology within the enterprise is commercialized through different external channels [31].

The purpose of the network analysis used in this study was to find and interpret the pattern of the network [32] using three indices: degree centrality, closeness centrality, and betweenness centrality [33]. Degree centrality is a statistical indicator that shows whether one company in the network is directly connected with other companies.

The degree of these nodes can be considered a measure of local centrality [33,34]. The degree centrality of node k (i.e., p_k) is defined as shown in Equation (1). The normalized degree centrality is the degree divided by the maximum possible degree expressed as a percentage. This normalization allows comparisons between nodes of graphs of different sizes.

$$C_D(p_k) = \sum_{i=1}^{n} a(p_i,\ p_k) \tag{1}$$

It is normalized by

$$C_{D^*}(p_k) = \frac{C_D(p_k)}{n-1} \tag{2}$$

where n is the number of nodes in the network and (p_i, p_k) = 1 if and only if node i and k (i.e., p_i and p_k) are connected; (p_i, p_k) = 0 otherwise. Degree centrality only plays an analysis role in the local scope, as it only considers statistics by connection relationship. The study did not consider the direction of in-degree or out-degree, but only confirmed partnerships.

Closeness centrality is a statistical indicator of centrality that considers not only direct connections but also indirect connections. It indicates how close a company is to other companies in virtual space and can be expressed in C_c (P_k) as shown in Equation (3) when there are companies named P_i and P_k among n companies. In Equation (3), d $(P_i,\ P_k)$ is the number of shortest distances between node i and node k, and n is the number of total enterprises.

$$C_C(p_k) = \left[\sum_{i=1}^{n} d(p_i,\ p_k)\right]^{-1} \tag{3}$$

It is normalized by

$$C_{C^*}(p_k) = \frac{C_C(pk)}{n-1} \tag{4}$$

The global centrality of the network can be determined by calculating the virtual distance between all nodes connected to each node. In other words, when closeness centrality increases, it is easy to access and secure influence, status, information rights, etc. in the network. Betweenness centrality is a statistical indicator of whether the node is good at acting as a broker (intermediary).

$$C_B(p_k) = \sum_{i<j}^{n} \frac{g_{ij}(P_k)}{g_{ij}}\ ; i \neq j \neq k \tag{5}$$

It is normalized by

$$C_{B^*}(p_k) = \frac{C_B(pk)}{[(n-1)(n-2)/2]} \tag{6}$$

In Equation (5), $\mathrm{g_{ij}}$ is the shortest path linking pi and p_j, and $\mathrm{g_{ij}}$ (p_k) is the geodesic distance linking p_i and p_j that contains p_k. Betweenness centrality expresses how much a node contributes to the interconnection of other nodes, and if betweenness centrality is large, it can be interpreted as a node having high influence in the flow of communication within the network.

In this study, patent analysis of 19 companies leading the eVTOL market established a total technical classification system (Tech-tree) of the eVTOL market and derived detailed technology-specific competitiveness analysis and related component companies through various patent-analysis indicators. While we cannot claim that patent indicators directly represent the R&D performance of a particular company, as patents have been used as a main indicator for measuring R&D activity in many existing studies [35], it is reasonable to say that it does indicate a certain level of R&D activity, as evidenced by quantitative empirical studies that examined the relationship between R&D activities, patents, and corporate market changes [32,36,37].

After analysis of prior research that patent activity and patent quality increased with sales growth and per employee sales, prior research that patent holders with high-quality patents were more successful than patent holders with low-quality patents [38], and development trends of eVTOL companies, the following hypothesis was established.

- **H1.** ***Patent holders with high-quality patents will have higher levels of technology development than patent holders with low-quality patents.***

Recent studies have evolved to apply more precise analytical methods using large volumes of surge information, moving away from the level of analysis and evaluation of the potential and growth of a small number or individual patents. Through this, research can provide a more credible macro view of the technology's in/out linkage structure for technological development trends [39]. Network analysis, as is used in the analysis, is a methodology suitable for identifying complex structures of interconnection between specific subjects or technologies [40,41]. It is meaningful in that it provides a preview of the knowledge connection, relative status, and change of companies in terms of technical knowledge.

- **H2.** ***Technology development through open innovation will accelerate the pace of technology development.***

UAM technology is in the early stage of technology development, and as the business environment changes rapidly, the speed of innovation is emerging as a key factor in competition. To speed up R&D, companies quickly take internal R&D processes and utilize external R&D through open innovation to innovate their businesses [28]. The reason for the increased interest in becoming either a first-mover or fast-follower through open innovation is that the speed of competition has increased, the number of industries competing for speed has increased, and the impact of speed on business performance has increased.

3. Analysis

3.1. Analysis Method

To verify the above hypotheses, joint applicants were analyzed based on raw patent data for 19 leading eVTOL companies from 6 March 2002 to 5 March 2022 in the patent DB (keywert.com). Population extraction was selected as KR, JP, US, EP, and CN. Technical classification was completed through four stages: First, Main IPC technical classification; Second, classification as a combination of three sub-classes; Third, reclassification based on the name of the invention; Fourth, reclassification based on applicants. When establishing the Tech-tree, functions and detailed technologies were classified based on the AEROSPACE ISSUE data published by the Korea Aerospace Research Institute (see Appendix D).

Patent statistics are deemed appropriate for representing one's technology and innovation activities. Indeed, analysis of patent information is considered one of the best-established, most readily available, and most historically reliable methods for quantifying the output of scientific and technological systems. Patent indicators in Table 4 can be tracked over relatively long periods of time and can accurately map the timepoints of technological innovation across multiple levels of analysis.

Table 4. Patent indicators.

Category	Indicators	Meaning	Formula
Quantitative	Number of Patents	Patent Activity	-
Qualitative	Patent ActivityIndex	Relative Patent Activity	$A.\,I = \frac{\frac{\text{Number of specific applications in specific technical fields}}{\text{Total number of applicants in specific technical fields}}}{\frac{\text{Number of specific applicants}}{\text{Total count}}}$
	Cites Per Patent	Citation Index, Influence	$CPP = \frac{\text{Nmber of citations}}{\text{Total number of registrations}}$
	Patent Impact Index	Relative Influence	$PII = \frac{\text{Citation fee of a specific applicant in a specific technical field}}{\text{Total citation cost}}$
	Technology Strength	Technology	TS = number of patents x Current Impact Index
	Patent Family Size	Market Index, Market Size	$PFS \frac{\text{Average number of faimly countries for one skill in a specific technical field}}{\text{Average number of family countries for total patents in a specific technology field}}$

Active patent activities aim to generate profits through licenses by exclusively banning competitors' patented products from entering the market or directly infringing on patents. If a technology is superior, it is likely to lead to direct infringement by competitors. For active patent activities, entities continue to apply for patents with a wide range of claims and a narrow range of claims at the same time, consequently forming a patent portfolio covering a wide range of claims and various embodiments. On the other hand, passive patent activities involve only the necessary resources for the protection of intellectual property. It centers around watching competitors and acting only in response to certain steps taken by them (e.g., infringements or accusation of infringements). This is a common approach in, for example, the IT industry due to the short life of the products and strong competition [38,42,43].

In this study, patent indicators were used for quantitative/qualitative analysis of patents [42] and Gephi 0.9.2 was used to calculate the network analysis index for network analysis. Gephi is a tool for exploring graphs and analyzing data. In the case of graph data, users can discover hidden patterns by manipulating representation and interaction, structure, shape, and color. The purpose of using Gephi is to help you formulate hypotheses, discover patterns intuitively, and isolate structural outliers or defects.

3.2. Quantitative Analysis

3.2.1. Number of Patents

The number of patent applications filed by 19 of the world's leading eVTOL companies related to UAM is shown in Table 5. Among the 19 companies, most of the eVTOL companies—except for BOEING, AIRBUS, and BELL—were pursuing passive patent strategies, and it was confirmed that 3 companies were in leading positions for most of the areas. In the comparison by country, the US, Europe, China, Japan, and Korea appeared to be leading in that order. Most companies applied for key patents in the US, but Ehang filed most patents in its home country, China. In the above analysis, it was judged that it was meaningful to derive a partner company after analyzing the patents of the 3 leading companies that are actively applying for patents, so a patent analysis was conducted with a focus on these 3 companies. As a result of examining the joint application patents of the other companies, it was found that these companies' research focused on developing their own aircraft rather than on joint research, which led to the conclusion that these cases were not suitable for research on finding partners.

Table 5. Number of patents.

No.	Company Name	Model	KR	JP	US	EP	CN	Sum
1	Boeing	Boeing PAV	430	1800	8936	3554	2110	16,830
2	Airbus	Airbus Vahana	313	927	6920	4971	2897	16,028
3	Bell helicopter	Bell Nexus Air Taxi	29	1	1211	689	218	2148
4	Moog	Workhorse SureFly	24	35	127	65	44	295
5	Embraer	EmbraerX	-	5	139	80	62	286
6	Kitty Hawk	Kittyhawk cora, KittyHawk Flyer	2	1	216	22	33	274
7	Ehang	Ehang 216	-	-	6	4	116	126
8	Joby aviation	Joby Aviation S4	1	6	9	3	8	27
9	Aston martin	Aston Martin Volante Vision	-	1	7	2	1	11
10	Karem Aircraft	Karem Butterfly	1	1	17	2	1	22
11	Alakai Technologies	Skai by Alaka'i Technologies	-	2	12	2	-	16
12	Volocopter	Volocopter 2X	-	-	30	17	20	67
13	Lilium	Lilium Jet	-	-	3	-	-	3
14	Opener	Opener BlackFly	-	-	-	-	-	-
15	Pipistrel	Pipistrel 801	-	-	1	2	-	3
16	Jaunt Air Mobility	Jaunt Air Mobility	-	-	14	-	-	14
17	Beta Technologies	Beta Technologies Ava	-	-	-	-	-	-
18	LIFT Aircraft	LIFT Hexa	-	-	-	-	-	-
19	Vertical Aerospace	Vertical Aerospace Seraph	-	-	-	-	-	-
	Sum		800	2779	17,648	9413	5510	36,150

Table 6 shows that the total number of UAM-related patents and joint applications of BOEING, AIRBUS, and BELL, the number of joint applications, and the number of patents by technology are as follows.

Table 6. Number of patents from top 3 companies.

Category	BOEING	AIRBUS	BELL	Sum
Total count	16,830	16,028	2148	35,006
Co-application	519	1343	46	1908
Number of co-applicants	102	248	15	365
A (propulsion system)	55	289	5	349
B (aerodynamic design)	63	473	8	544
C (material/structure)	51	99	2	153
D (battery)	29	84	4	117
E (control/safety)	194	154	2	351
F (navigation/communication)	68	46	0	113
G (cybersecurity)	59	198	25	281

Comparing the number of co-applicants also provides some insight into the company's R&D strategy. As shown in Figure 6, in the case of BOEING, joint applications were made due to joint research in 519 (3%) of the 16,834 patents, while in the case of AIRBUS, 1343 (8%) out of 16,033 patents were processed as joint applications. In the case of BELL, only 46 (2%) of the 2148 patents were identified as joint research. In joint research analysis, the presence or absence of joint research had both advantages and disadvantages. In the case of BOEING and BELL, it can be observed that only a minimal amount of technology is developed through external collaboration, and thus, the company holds ownership for most of the technology. If you compare this to the automotive industry, it would be like a company such as Tesla that controls all systems in the form of technological development and creates innovation through cooperative control. In contrast, for AIRBUS, traces of collaboration were found in 1343 patents, which had some similarity to existing automotive OEMs that achieve innovation through mass production. Without wasting time on non-critical technologies, efforts were focused on core technologies, through which the company can receive assistance in securing technology and achieve innovation in a stable manner.

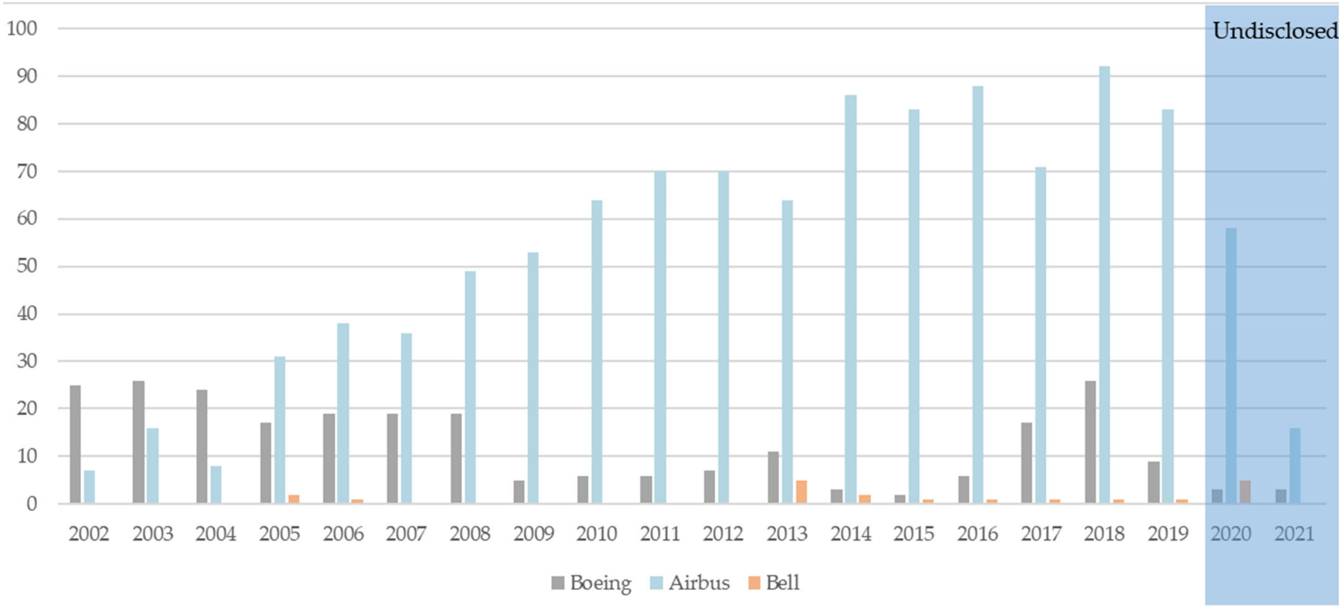


Figure 6. Time series analysis of 3 companies' joint research.

In the case of BOEING, the results of the collaboration in the time series were reviewed, and we were able to confirm an average of 20 joint applications per year from 2000 to 2008. BOEING was passive in joint research from 2009 to 2016 but has become more active with joint research from 2017. AIRBUS filed an average of 30 to 40 joint applications per year from 2005 to 2009, and more than 80 joint applications per year from 2010 to the present. In the case of BELL, joint research was found to be weak.

In recent automotive technology, the gap in hardware competitiveness is gradually narrowing and the focus is set on securing software competitiveness [44]. The automotive industry does not follow a path of radical innovation [45]. There is a tendency to favor incremental, process-oriented innovation because of its complex operating methods, low profits, and high risk [46]. In addition, as a capital-intensive and traditional, mature industry with strong competition, companies do not try to allow the emergence of new competitors and the emergence of alternative business models and technologies through the concentration of core competencies [47]. However, as there are limitations to internal technology and R&D capabilities, the proportion of ICT companies and telecommunication companies is expected to increase within the industry [48–50].

Among the detailed UAM technologies, which are the convergent technologies of the automotive industry and the aviation industry, there is a limit to clearly classifying the full range of technologies into HW and SW, but HW can be divided into propulsion system, aerodynamic design, and material/structure technologies, and SW can be divided into battery, control/safety, navigation/communication, and cybersecurity technologies. Comparison by applying this to the three companies is as follows.

BELL is judged to be lacking in securing intellectual property in all fields, AIRBUS is judged to be a company that has improved its performance by focusing on traditional hardware technology, and BOEING is judged to be a company that creates technological innovation based on software. In recent years, the importance of software has been growing due to the separate ordering of hardware and software in the automotive industry. UAM technology also requires software-oriented technological innovation to respond to the trends of the times. In this respect, it is judged that BOEING is highly likely to respond flexibly to changes in the times.

3.2.2. Patent Activity Index

The Patent activity index (AI) refers to the percentage of a particular research subject's total number of patents in a particular technology field [49,51]. If the AI is larger than 1, patent concentration is high. It is possible to compare the AI value by year, and the AI value between competitors in the same period, by expanding the range of data required to check the patent activity index. AIRBUS showed high patent activity index in most areas, BOEING showed high patent activity index in categories E (control/safety) and F (navigation/communication), and BELL showed high patent activity index in category G (cyber security) following Table 7.

Table 7. Patent activity index.

Category	BOEING	AIRBUS	BELL
A (propulsion system)	0.3	1.7	0.2
B (aerodynamic design)	0.3	1.8	0.3
C (material/structure)	0.7	1.4	0.3
D (battery)	0.5	1.5	0.5
E (control/safety)	1.2	0.9	0.1
F (navigation/communication)	1.3	0.8	0.0
G (cybersecurity)	0.4	1.5	1.5

3.3. Qualitative Analysis

3.3.1. Cites Per Patent

The citation index has a limitation in that its value is relatively small for patents filed in recent years, so it is usually measured without the patents obtained within 3 years from the present time [52]. As can be observed in the citation index measured by excluding patents within the last 3 years, BOEING took the lead in most areas, AIRBUS showed high patent citation index in category E (control/safety), and BELL showed high patent citation index in category A (propulsion system) following Table 8.

Table 8. Cites per patent.

Category	BOEING	AIRBUS	BELL
A (propulsion system)	11.0	9.1	19.5
B (aerodynamic design)	23.2	12.1	14.0
C (material/structure)	8.3	6.7	0
D (battery)	17.8	6.1	3.7
E (control/safety)	8.5	9.2	6.0
F (navigation/communication)	15.0	8.8	0
G (cybersecurity)	25.4	8.9	10.9

3.3.2. Patent Impact Index

As an indicator that reflects past technical activities based on a point in time, it is confirmed that the number of patents and the number of uses can be used to assume the relative technical level of a particular subject. PII numbers indicate average reference frequency, and 2 means that it is cited at twice the frequency of the average. Boeing was ahead of AIRBUS in most areas in terms of impact index, AIRBUS showed high PII in category E (control/safety), and BELL showed high PII in category A (propulsion system) following Table 9.

Table 9. Patent impact index.

Category	BOEING	AIRBUS	BELL
A (propulsion system)	0.8	0.7	1.5
B (aerodynamic design)	1.4	0.7	0.9
C (material/structure)	1.1	0.9	0.0
D (battery)	1.9	0.7	0.4
E (control/safety)	1.1	1.2	0.8
F (navigation/communication)	1.3	0.7	0.0
G (cybersecurity)	1.7	0.6	0.7

3.3.3. Technology Strength

The technical quality weight index was calculated by weighting citation frequency, which views the number of patents for qualitative evaluation. In quantitative terms, AIRBUS and BOEING showed similar levels, but the latest five-year technical index confirmed that AIRBUS has the upper hand following Table 10. In the case of AIRBUS, UAM-related research was conducted at various AIRBUS points around the world, and it was determined that it was fully utilizing the open innovation strategy. For BELL, the technical index was confirmed to be deteriorating in the most recent 5 years.

Table 10. Technology strength.

Category	BOEING	AIRBUS	BELL
2014	7.4	76.3	2.0
2015	1.5	72.2	2.0
2016	11.8	69.7	4.1
2017	26.5	53.3	2.0
2018	33.9	68.1	0.0

3.3.4. Patent Family Size

When the number of patent families is large, it can be judged that the market security power through patents is large [32]. AIRBUS was in the process of filing applications (3 to 16 countries) in most countries where aircraft sales occur, and in the case of BOEING, patent applications were made mainly for the G5 (CN, US, JP, KR, EP) following Table 11. It was identified that G5-oriented patent applications have an advantage in terms of cost reduction, and that the number of countries is determined mainly for important cases. In the case of BELL, it was identified that the application was in progress in major countries after filing for PCT, and the strategy used to selectively apply for mass-produced patents was being used.

Table 11. Patent family size.

Category	BOEING	AIRBUS	BELL
A (propulsion system)	1.0	3.7	1.0
B (aerodynamic design)	0.7	1.2	1.2
C (material/structure)	1.2	1.5	1.1
D (battery)	0.8	1.2	1.1
E (control/safety)	0.6	1.0	1.0
F (navigation/communication)	0.8	0.8	0.0
G (cybersecurity)	0.5	0.8	0.0

3.4. Network Analysis

3.4.1. Network Analysis by Company

Network analysis was conducted using the Fuchterman–Reingold algorithm of the Gephi network analysis tool. Through the network visualization shown in Figures 7–9, the degree of cooperative development for each company can be identified briefly. It can be seen immediately that AIRBUS develops through open innovation, while BELL takes a closed-innovation strategy. AIRBUS filed 1148 UAM patent applications with 212 co-applicants. In the group of company-oriented patent applications (AIRBUS OPERATIONS GMBH, AIRBUS SAS), it was identified that the elementary technology for all UAM fields was being developed.

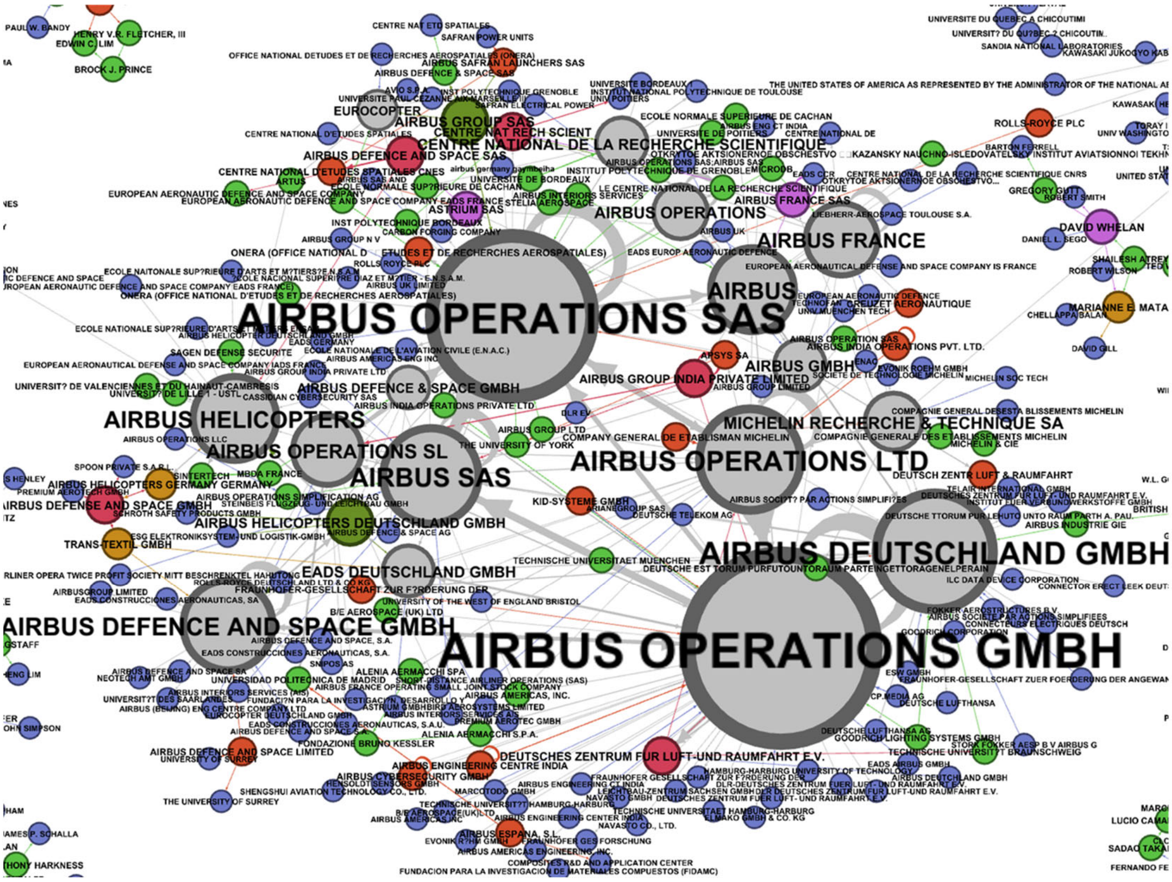


Figure 7. Network Analysis for AIRBUS.

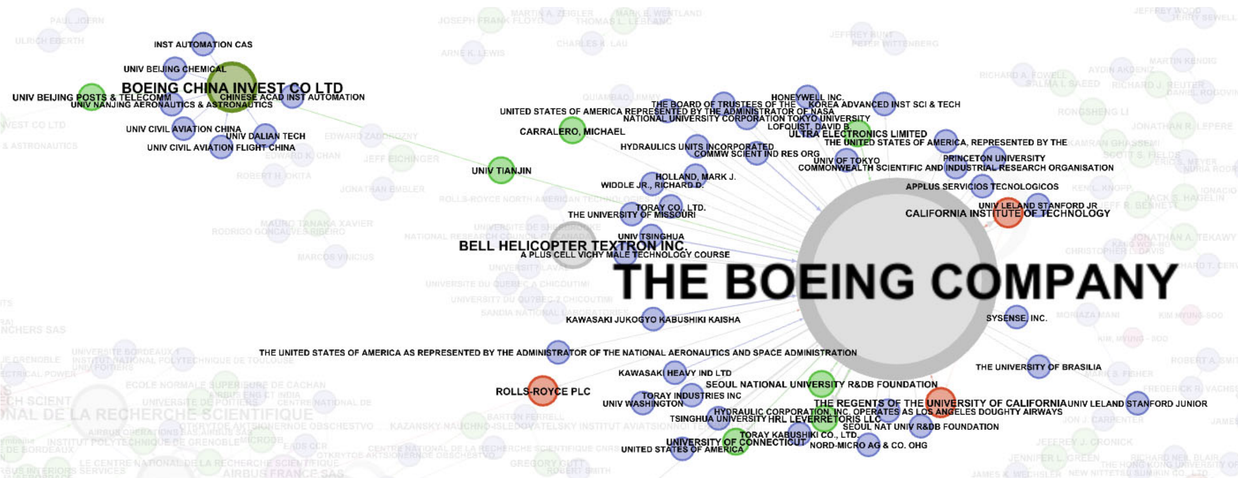


Figure 8. Network Analysis for BOEING.

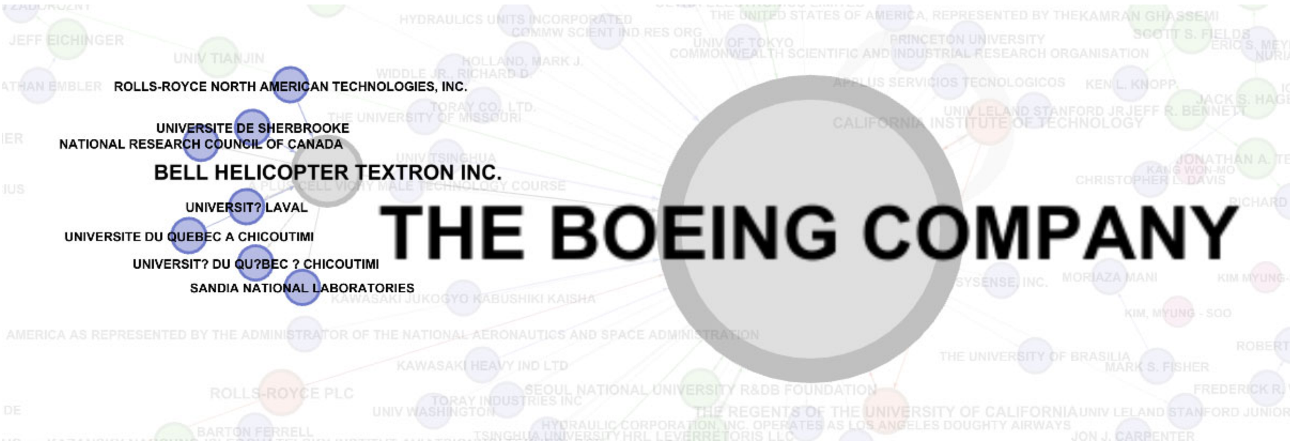


Figure 9. Network Analysis for BELL HELICOPTER TEXTRON.

BOEING filed 444 UAM patent applications with 87 co-applicants. It was identified that the intensity of the joint application with the California Institute of Technology and PH MADISON FUNDING LLC was high. Joint application with universities has the advantage of being able to conduct continuous research in connection with recruitment, but it is judged that filing for patents with NPEs (patent monsters) such as PH MADISON FUNDING LLC is not a strategy with the possibility of future patent litigation in mind.

BELL filed 39 UAM patent applications with 13 co-applicants. Co-applicants are concentrated in category A (propulsion system), and the cooperation index with TEXTRON appeared to be high.

As a result of the degree centrality analysis, the value of a relatively large network is high because the connection centrality is affected by the size of the network. The result of the degree centrality analysis is shown in Table 12. Degree centrality was found to be ordered as AIRBUS, BOEING, BELL, highest to lowest, but because of normalization, it appeared as BOEING, BELL, AIRBUS. The closeness centrality analysis confirmed that AIRBUS's degree of cooperative relationship was higher than that of other companies. As a result of the betweenness centrality analysis, it was confirmed that the co-applicant of AIRBUS plays a good role as a research intermediary.

Table 12. Centrality index comparison by company.

Category	BOEING	AIRBUS	BELL
Degree Centrality	0.9861	0.0820	0.7500
Closeness Centrality	0.3658	0.3916	0.3076
Betweenness Centrality	0.0004	0.0223	0.0003

3.4.2. Network Analysis by Technology

Degree centrality is recognized as an important skill when there are many connections. The result of degree centrality by technology is presented in Table 13. UAM technology is in the early stage of technology development, and the high A and B figures indicate that most UAM developers are still focusing on aircraft development. In addition, it is expected that the values of C, D, E, F, and G will increase when the fuel development is completed.

The betweenness centrality value indicates the degree of control or mediation of relationships between companies that are not directly connected and is an important indicator of the ability to control information exchange or resource flow within a network.

In the case of a university, if a patent application is filed with company x after an industry-related project and the company performs this industry-related project with company y, there is no direct relationship between company x and company y; however, information exchange can occur. It can also be grown or controlled through the company or university as a medium. In the case of UAM technology, 77 universities were found to have joint patent applications in the past in connection with companies, but only the California Institute of Technology, Singapore University of Technology and Design, and Tsinghua University were collaborating with two or more companies. As you can see from the values in Table 14, for year-by-year betweenness centrality, we conducted joint research with many companies which did not have a core partner in the 2000s—showing that partnerships were not well established—and the statistics show the numbers increasing over time. In other words, companies now tend to perform a lot of joint research with companies that have high performance in related fields.

Table 13. Degree centrality by technology.

Category	2000–2004	2005–2009	2010–2014	2015–2019
A (propulsion system)	0.0199	0.0150	0.0225	0.0786
B (aerodynamic design)	0.0113	0.0121	0.0407	0.0711
C (material/structure)	0.0437	0.0169	0.0541	0.0615
D (battery)	0.1429	0.0266	0.0173	0.0857
E (control/safety)	0.0028	0.0054	0.0151	0.0767
F (navigation/communication)	0.0319	0.0203	0.0397	0.1029
G (cybersecurity)	0.0996	0.3333	0.1818	0.2857

Table 14. Betweenness centrality by technology.

Category	2000–2004	2005–2009	2010–2014	2015–2019
A (propulsion system)	0.00011	0.00042	0.00067	0.00423
B (aerodynamic design)	0.00000	0.00018	0.00409	0.00810
C (material/structure)	0.00074	0.00011	0.00076	0.00058
D (battery)	0.00000	0.00025	0.00059	0.00313
E (control/safety)	0.00004	0.00003	0.00034	0.00336
F (navigation/communication)	0.00030	0.00014	0.00088	0.00196
G (cybersecurity)	0.00292	0.00000	0.00404	0.00893

The distance between nodes in the entire network, even indirect connections, is calculated within the closeness centrality network. It indicates how quickly nodes can communicate with each other, either directly or through an intermediary. In the case of important technologies, it is in the center of the network. As shown in Table 15, categories A (propulsion system) and B (aerodynamic design) occupied the center of the network, and companies/universities such as AIRBUS OPERATIONS GMBH, AIRBUS SAS, California Institute of Technology, and TEXTRON showed high numbers.

Table 15. Closeness centrality by technology.

Category	2000–2004	2005–2009	2010–2014	2015–2019
A (propulsion system)	0.50530	0.45253	0.44150	0.41577
B (aerodynamic design)	0.51260	0.49290	0.36910	0.24380
C (material/structure)	0.52480	0.47530	0.35100	0.39230
D (battery)	0.50000	0.50640	0.41080	0.52429
E (control/safety)	0.50471	0.52560	0.45000	0.50998
F (navigation/communication)	0.54280	0.51611	0.44009	0.39663
G (cybersecurity)	0.41866	0.50000	0.39740	0.42917

3.4.3. Implications for Network Analysis

After downloading 36,150 UAM-related patents [Table 5], we organized them by UAM technology field (Appendix D) and conducted network analysis by identifying the relationship between joint applications. In addition, by reflecting technology strength [Table 10] as a weight factor in network analysis, we derived companies/schools that conducted joint research with leading companies that have strong technology (Appendix E) and identified whether these players were leading the patent competition. The company information quantified and visualized by network analysis is reported automatically.

As shown in Figure 10, in the case of aerodynamic design technology, it was confirmed that much of the technology from AIRBUS HELICOPTERS has been applied, and if you check the cooperative relationship, you can see that the contribution of ONERA (the French Aerospace Lab) is high. National institutions and universities perform a lot of cooperative research, so conducting similar tasks can be a strategy to secure the necessary technology.

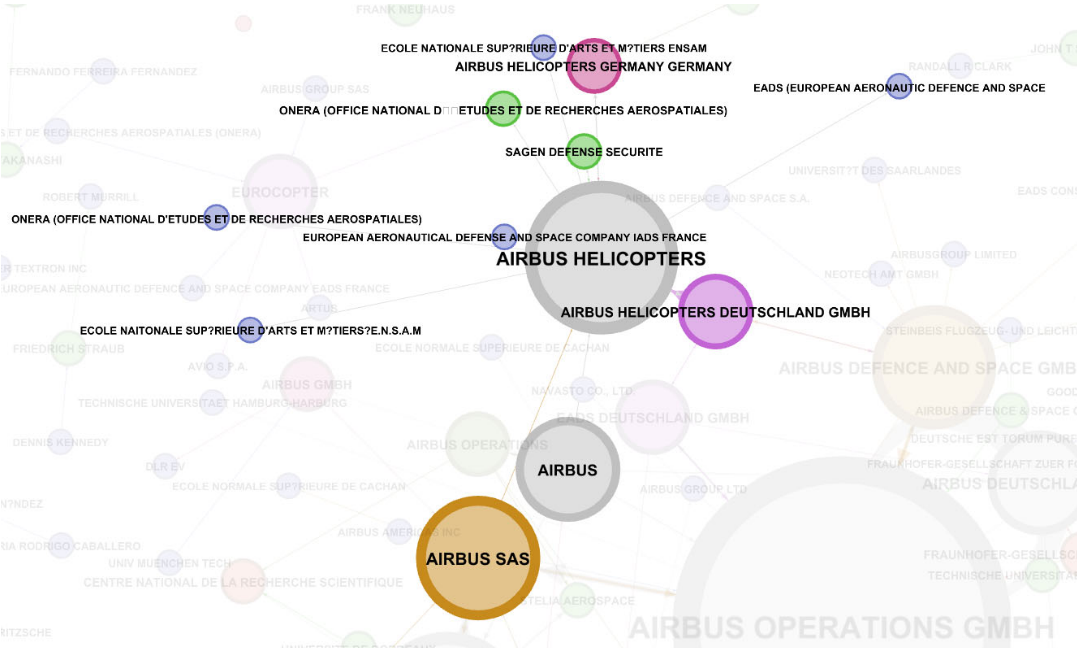


Figure 10. Network Analysis of Cooperative Relationships.

In addition, as shown in Figure 11, it has been identified that there is a cooperative relationship with Michelin Research and Technology, a private company, so it is possible to obtain parts through that company or solve problems quickly through open innovation.

Analyzing co-applicants of patent data can help identify partnerships. We can assume that company A is trying to acquire cloud server technology for UAM map data management. When selecting a target company for technology cooperation, if we check the company information regarding a history of joint research with Google and Amazon through patent data and identify the connection between the partner companies in a virtual 3D space through network analysis, we can see the rankings of companies that have conducted joint research with Google and Amazon numerically. In UAM network analysis, we conducted network analysis to find universities/companies with a history of joint patent applications with BOEING and AIRBUS to acquire the necessary technology. Companies try to avoid patent infringement by competitors (Design Around), but they find professors who have conducted industry–university cooperation with competitors to obtain necessary information or carry out similar projects. Even if they are not directly connected to Company A, start-ups and venture companies that have joint patent applications with renowned companies (Google, Amazon, etc.) are monitored as collaborating companies as they are assigned a weight factor in network analysis.

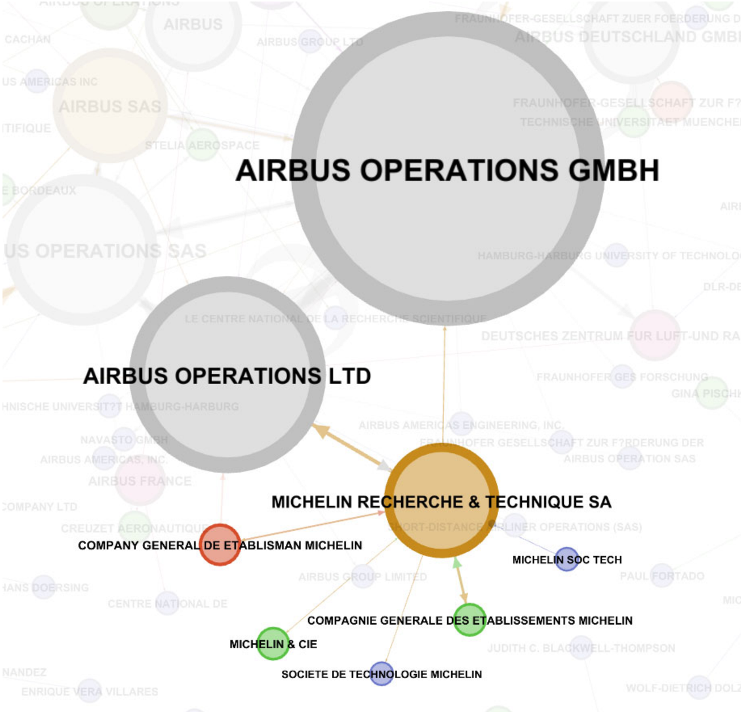


Figure 11. Network Analysis of Joint Research.

Figure 12 below captures a part of the results of network analysis with the betweenness centrality value. MICHELIN RECHERCHE&TECHNIQUE SA, ROLLS-ROYCE PLC is conducting joint research with AIRBUS and BOEING, so the value of betweenness centrality is high. The higher the betweenness centrality, the higher your contribution is as a tech broker.

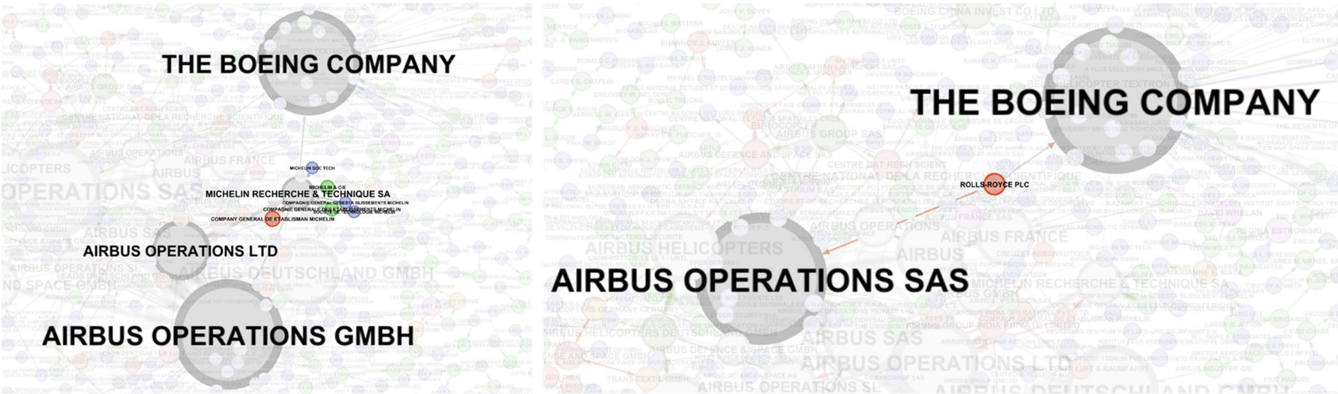


Figure 12. Network Analysis of Tech Broker.

Closeness centrality lets you see which businesses are at the heart of your network. As a result of identifying cooperation through patents in 19 UAM companies, we confirmed that AIRBUS formed many cooperative relationships and was at the center of the network. Next, we can confirm that BOEING is moving to the center of the network. The movement of the network can be identified by selecting a certain section by year, which will confirm the degree of change in the network. The legend shown in Figure 13 is a degree centrality value, meaning a non-normalized value with no direction.

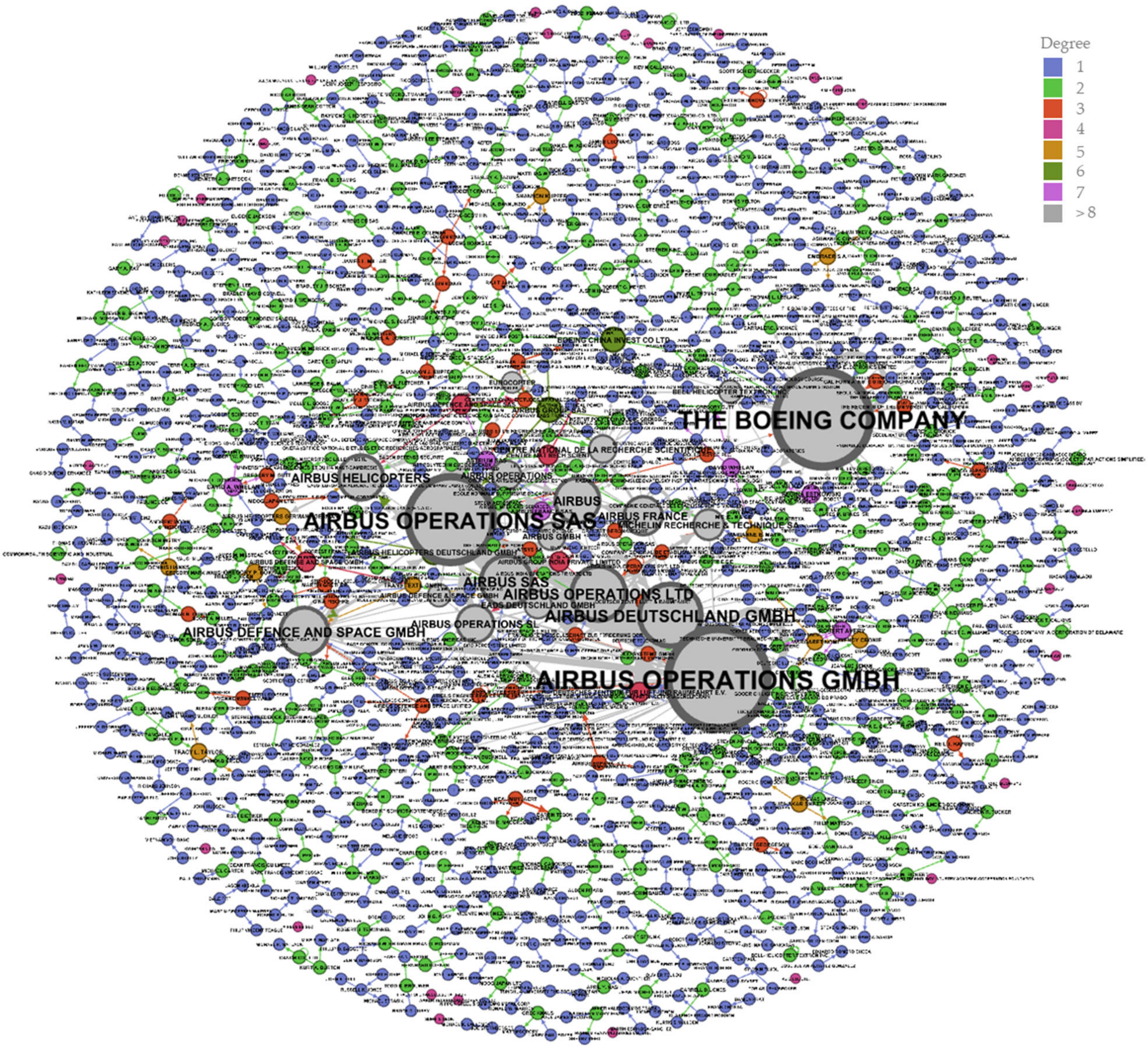


Figure 13. Network Analysis of UAM Technology.

4. Discussion and Conclusions

4.1. Discussion

This study has significance in identifying potential partner companies for future cooperation by analyzing companies' technical power for each UAM component and deriving and analyzing the technology of major component-makers of the competitor. However, it is difficult to simply compare the patents of BOEING and BELL, which are American companies, and AIRBUS, which is based in Europe. AIRBUS is a consortium of European airline companies and has a history of being established through MOUs between British, French, and German governments after European aircraft manufacturers discussed it in the mid-1960s to compete against BOEING. As confirmed through the analysis of the joint patent application, UAM-related research is still in progress at AIRBUS branch offices in each European country, and it has a structure in which joint research is inevitable according to the historical origin of AIRBUS.

Due to the nature of the defense industry, closed innovation is common in cases like BOEING and BELL, but attention is focused on what kind of innovation AIRBUS can create in the UAM field, which is developing technology through open innovation between countries. In addition, there is a limitation in that there is the possibility of omitting startups with significant R&D capabilities when new partners are derived through the analysis of patent application history. Moreover, when tracking inventors through patent analysis, there could be a difficulty in identifying female inventors due to a change of their last name before/after marriage (Japan, United States, etc.). In future research, technology analysis for technology startups that can be applied to the UAM field will be reinforced, and it seems necessary to discuss methods to address the problem in inventor-tracking. The inventor belongs to a university at a specific point in time and then gets a job at a specific company at the time of employment, and if he/she changes jobs after that, know-how related to technology development is transferred to other companies. In the case of core inventors, since they are relevant to R&D, it would be meaningful to identify their movement paths through further network analysis.

4.2. Summaries and Conclusions

This study derived implications regarding UAM companies' technology (H1) and technical cooperation (H2) by analyzing their joint patent applications. Here are some of the things we wanted to see through the research, and suggestions for improving UAM technology in the future.

- H1. As a result of confirming UAM technology through quantitative and qualitative analysis of patents, certain technologies were more advanced than others. There was no significant difference between AIRBUS and BOEING in the quantitative analysis, but there were differences by technology in the qualitative analysis. At this time, AIRBUS and BOEING—the leading groups in UAM technology development—can be confirmed as having consistent patent level and performance and adopting H1 compared to the 19 UAM developers described in Table 5. → ***Adoption***
- H2. UAM companies' technical cooperation showed that AIRBUS was mostly ahead in the centrality figures. → ***Adoption***

It was found that UAM technology is very weak in patent competitiveness in the case of startups that do not have patent organizations in the early stages of development. Patents are territorial, and in the case of EHANG, the competitiveness of products was high due to application in its home country China, but the global competitiveness of such patents was quite low. EHANG's technology is known through patent applications mainly in China, and technology development through EHANG patent analysis can help to shorten the development period. In developing UAM, developing a product that is equal or superior to competitors through low technical cooperation can lead to the judgment that the entity has strong in-house technology, and strategic technology transfer is required from group companies to parts companies for continuous innovation and development. When the subject of open innovation is limited to group companies, if a patent is applied for without a patent organization, compared to those of relatively specialized technology development companies, only the technology disclosure proceeds—as in the case of AIRBUS—and there may be disadvantages in that the scope of the secured rights is narrowed.

To maintain the superiority of UAM technology, it is necessary to identify technology development capabilities through inventor evaluation using patent data of partner companies with low technology among the cooperative structures for each technology field, and to use them to determine whether to cooperate. In the future, companies should also be able to work with the companies that have cooperative relationships with competitors. It is necessary to identify retirees by tracking the application histories of key inventors of competitors and find ways to utilize key inventors. Accumulation and utilization of knowledge is important for innovative growth, and unlike traditional production factors such as capital or labor, intellectual-property-embodying technology and ideas dramatically increases productivity and significantly improves social welfare through development and diffusion of creative ideas [53]. In developing UAM, developing a product that is equal or superior to competitors through low technical cooperation can be judged as denoting high in-house technology, and strategic technology transfer to group companies and parts companies is required for continuous innovation and development [36,54]. In UAM development, core technology and non-core technology should be distinguished; non-core technology should be transferred to group companies and parts companies, and time should be devoted to core technology development.

The automotive industry does not always follow a path of radical innovation and tends to prefer incremental innovation and process-oriented innovation due to its complex operating method, low profit margin, and high risk. Automotive companies have been using a type of open-innovation strategy to manufacture vehicles using the technologies of partners, which are external resources, but lack experience in the aviation field. In the UAM field, automotive companies are carrying out M&A, investment, and self-development, and it is expected that a significant amount of technology from the automotive field will be applied. From basic SW for vehicles to virtual verification environment for vehicles and vehicle development processes, it is judged that most of the interior of UAM will incorporate vehicle technology, and technology convergence of the UAM, aircraft, drone, and automotive industries is expected. When discovering partner companies, it is required to classify common technologies and quickly classify applicable and nonapplicable technologies to accelerate technology development through a new cooperative system.

Category A (propulsion system) is a core technology that must be developed directly or discovered by a partner in the UAM industry. The technology must be secured through M&A or developed directly, and the convergence of hydrogen fuel-cell technology and electric vehicle motor control technology in the automotive industry is expected to help shorten the development period. The results of patent analysis confirmed that it would be helpful to find a partner in the aircraft industry field for categories B (aerodynamic design) and C (material/structure). Technology from categories D (battery) and E (control/safety) needs to be developed by deriving a partner from the automotive industry and drone industry. Category F (navigation/communication) applies the technology of the aircraft industry as it is, but GNSS (Global Navigation Satellite System)-based city navigation requires additional development through collaboration with existing map companies. In the field of category G (cybersecurity), collaboration with OTA (Over-The-Air) companies in the automotive industry is expected to help shorten the development period.

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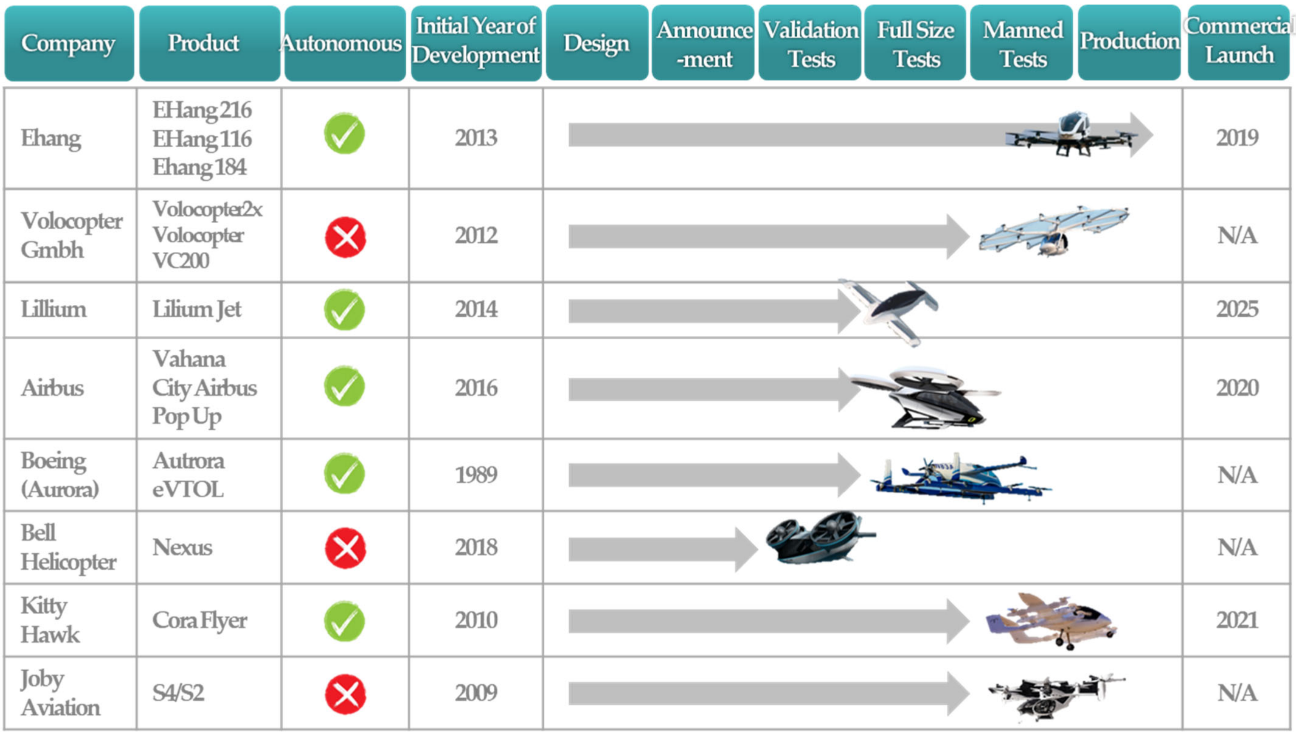
Conflicts of Interest: The authors declare no conflict of interest.

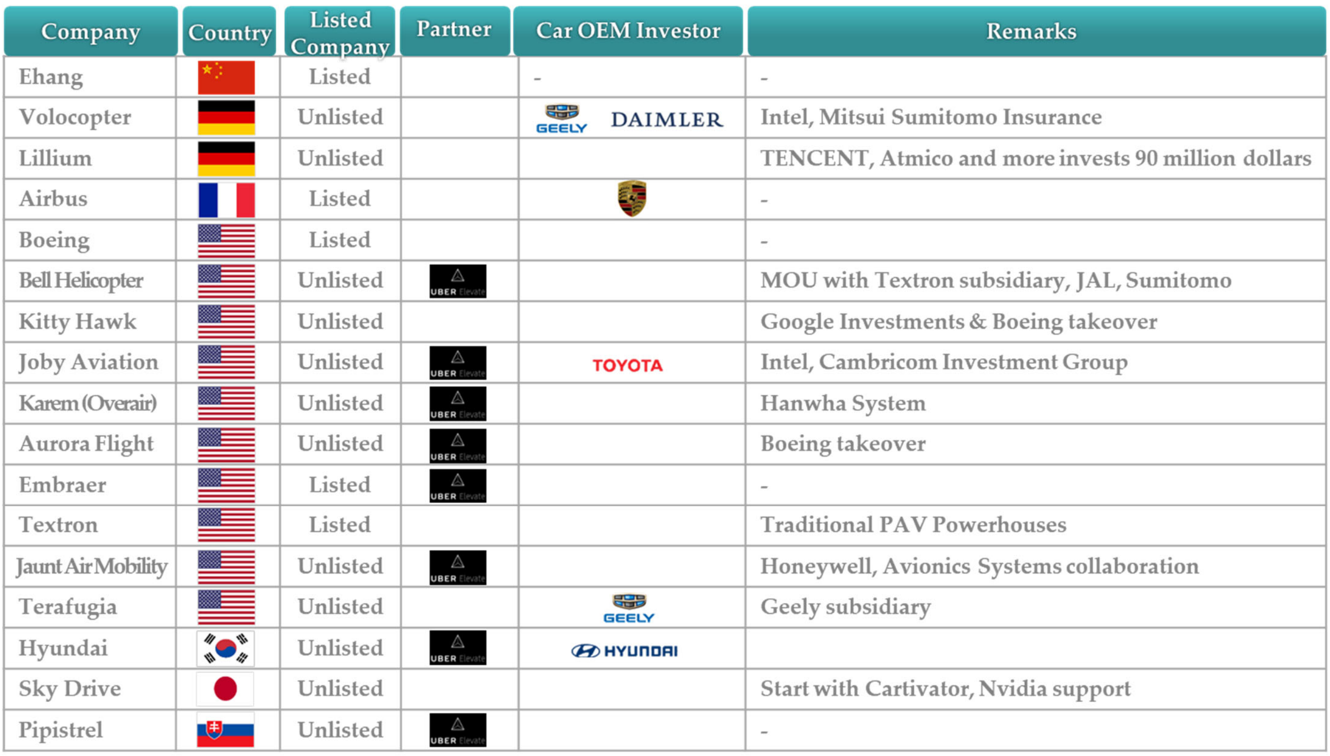
Appendix A



Company	Product	Autonomous	Initial Year of Development	Design	Announce-ment	Validation Tests	Full Size Tests	Manned Tests	Production	Commercial Launch
Ehang	EHang 216 EHang 116 Ehang 184	✓	2013							2019
Volocopter Gmbh	Volocopter2x Volocopter VC200	✗	2012							N/A
Lillium	Lilium Jet	✓	2014							2025
Airbus	Vahana City Airbus Pop Up	✓	2016							2020
Boeing (Aurora)	Autrora eVTOL	✓	1989							N/A
Bell Helicopter	Nexus	✗	2018							N/A
Kitty Hawk	Cora Flyer	✓	2010							2021
Joby Aviation	S4/S2	✗	2009							N/A

Figure A1. eVTOL production schedule.

Appendix B



Company	Country	Listed Company	Partner	Car OEM Investor	Remarks
Ehang		Listed		-	-
Volocopter		Unlisted		GEELY DAIMLER	Intel, Mitsui Sumitomo Insurance
Lillium		Unlisted			TENCENT, Atmico and more invests 90 million dollars
Airbus		Listed			-
Boeing		Listed			-
Bell Helicopter		Unlisted	UBER Elevate		MOU with Textron subsidiary, JAL, Sumitomo
Kitty Hawk		Unlisted			Google Investments & Boeing takeover
Joby Aviation		Unlisted	UBER Elevate	TOYOTA	Intel, Cambricom Investment Group
Karem (Overair)		Unlisted	UBER Elevate		Hanwha System
Aurora Flight		Unlisted	UBER Elevate		Boeing takeover
Embraer		Listed	UBER Elevate		-
Textron		Listed			Traditional PAV Powerhouses
Jaunt Air Mobility		Unlisted	UBER Elevate		Honeywell, Avionics Systems collaboration
Terafugia		Unlisted		GEELY	Geely subsidiary
Hyundai		Unlisted	UBER Elevate	HYUNDAI	
Sky Drive		Unlisted			Start with Cartivator, Nvidia support
Pipistrel		Unlisted	UBER Elevate		-

Figure A2. UAM startup investment and partnership status.

Appendix C

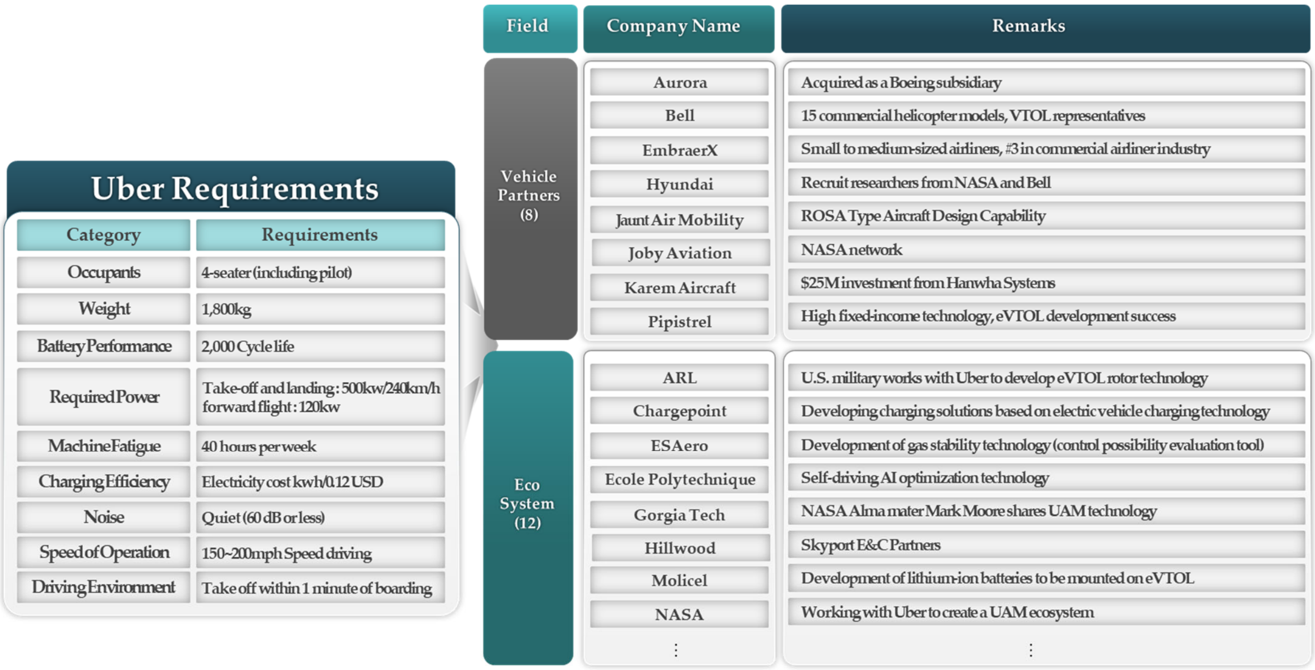


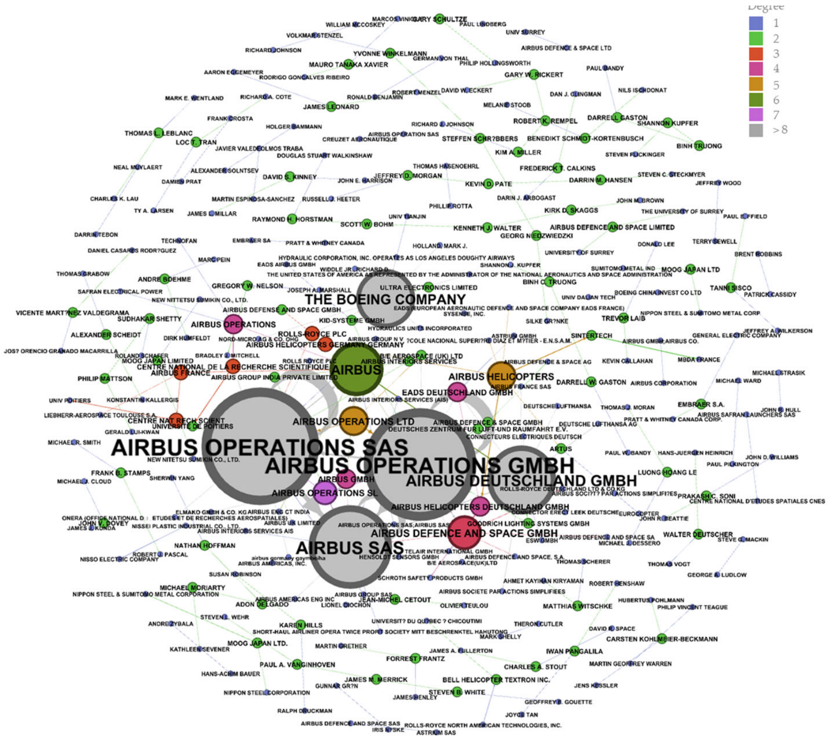
Figure A3. Uber requirements.

Appendix D

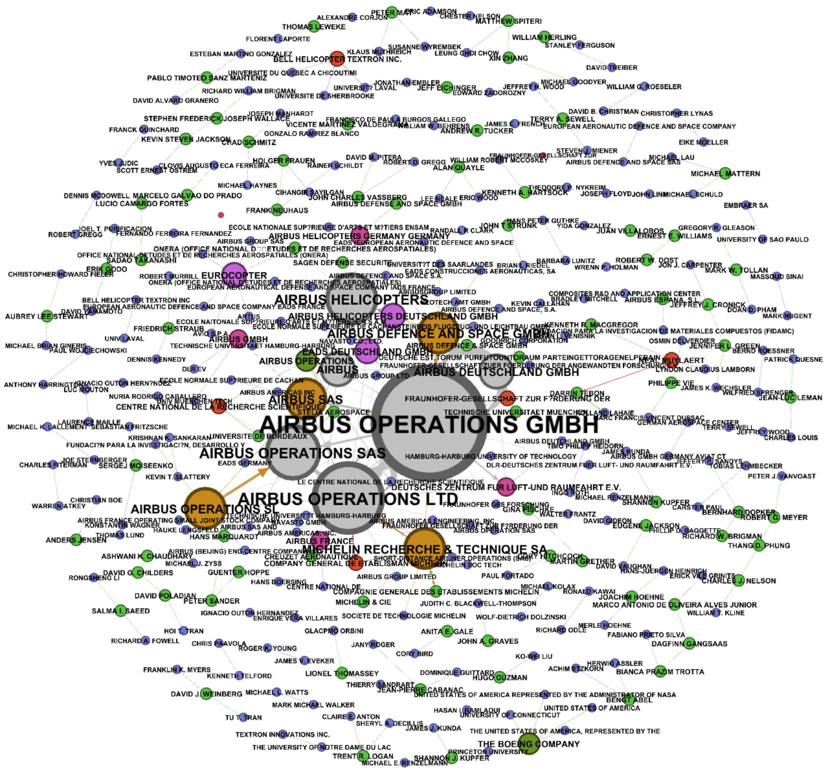
Category	Key technologies	IPC Code
A (propulsion system)	- Electric propulsion vertical landing (e-VTOL) - Improved engine power efficiency - Noise reduction technology in power and thrust system (ducted fan etc.), next-generation rotor/propeller technology (bladeless propeller etc.) - Powertrain (power electronics etc.)	B64D, H02K, F02K…
B (aerodynamic design)	- Maximum tension and minimum drag with optimal body geometry design	B64C…
C (material / structure)	- Developing and applying low-weight, high-strength composites - Optimal design technology for low-weight gas [/propulsion] (fly-by-wire etc.) - Dual mode (road trip/flight) configuration change technology for implementing movement (tiltable fan etc.)	B29C, B60F…
D (battery)	- Improve energy density and next-generation battery technology, including fuel cell, nickel cell, lithium-ion batteries	H01M, H02J, B60L,G01R…
E (control / safety)	- Improved maneuverability and thrust control - Composite safety structure mechanism (fail-safe mechanism) design - Pilot injection system, ballistic recovery parachute etc.	G05D, G06F, G08G, G01D, G01L…
F (navigation / communication)	- Automatic flight and autonomous flight technology - Best route prediction technology - Collective PAV control technology - Obstacle detection and collision avoidance algorithms/sensors, GPS, etc.	G01S, G01C, G06T, G06K…
G (cybersecurity)	- Anti-tracking protection technology such as firmware over the air update	H04L, G06F…

Figure A4. UAM Tech-Tree.

Appendix E

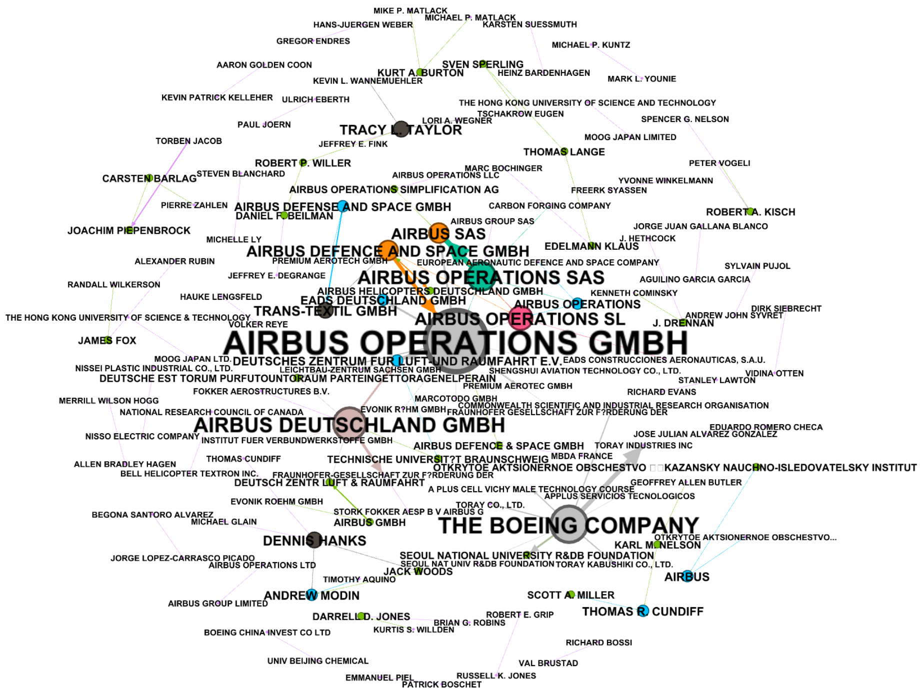


(**A**) (propulsion system)

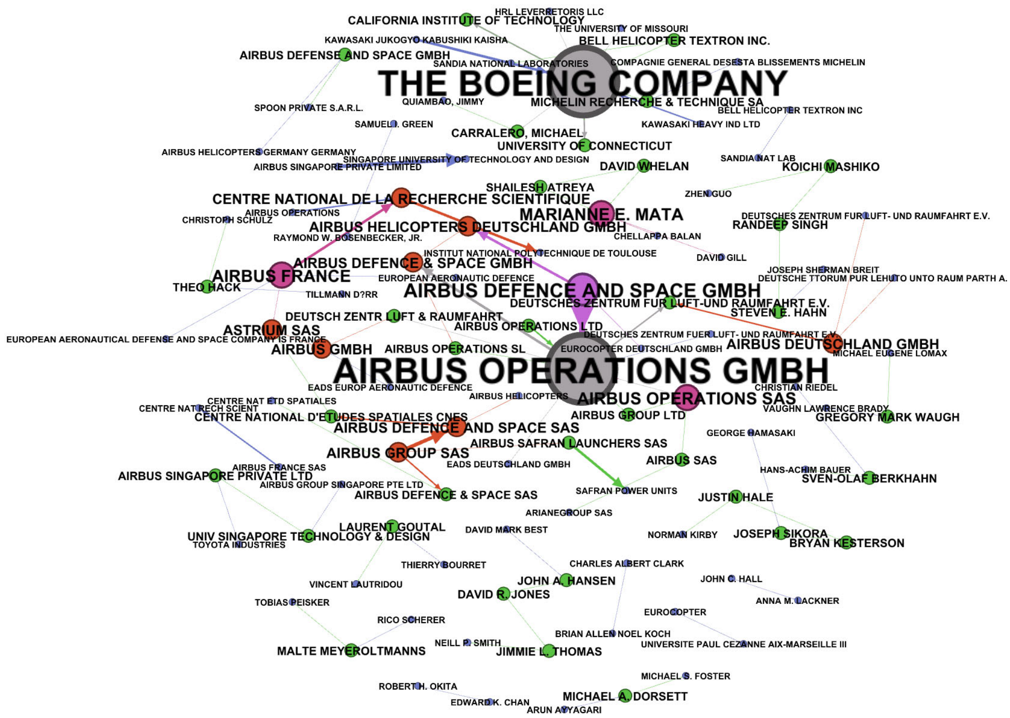


(**B**) (aerodynamic design)

Figure A5. *Cont.*

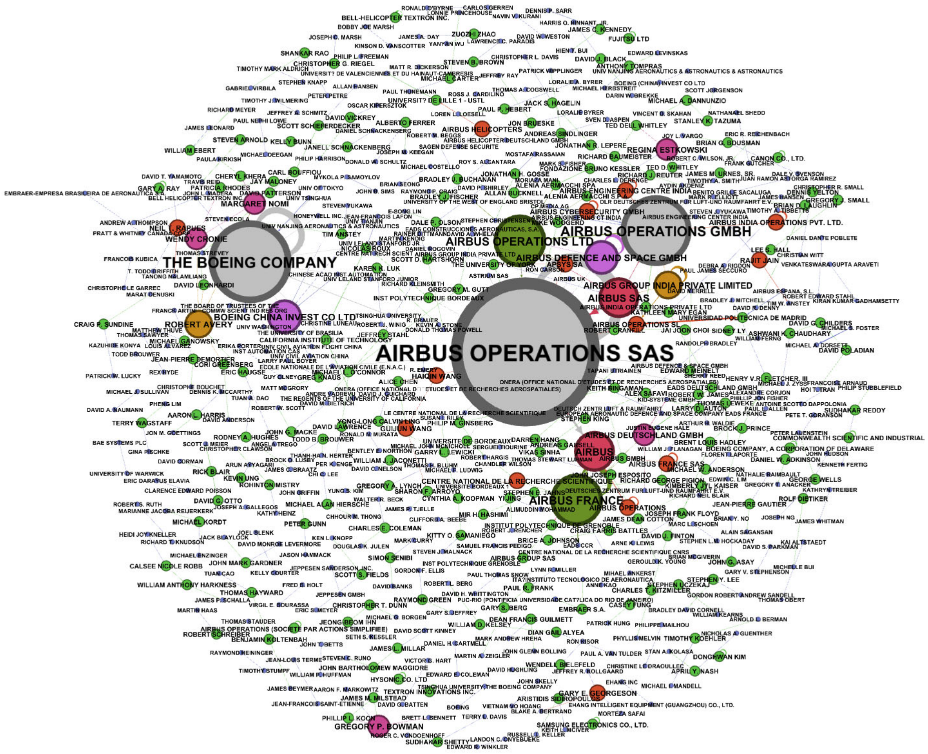


(**C**) (material/structure)

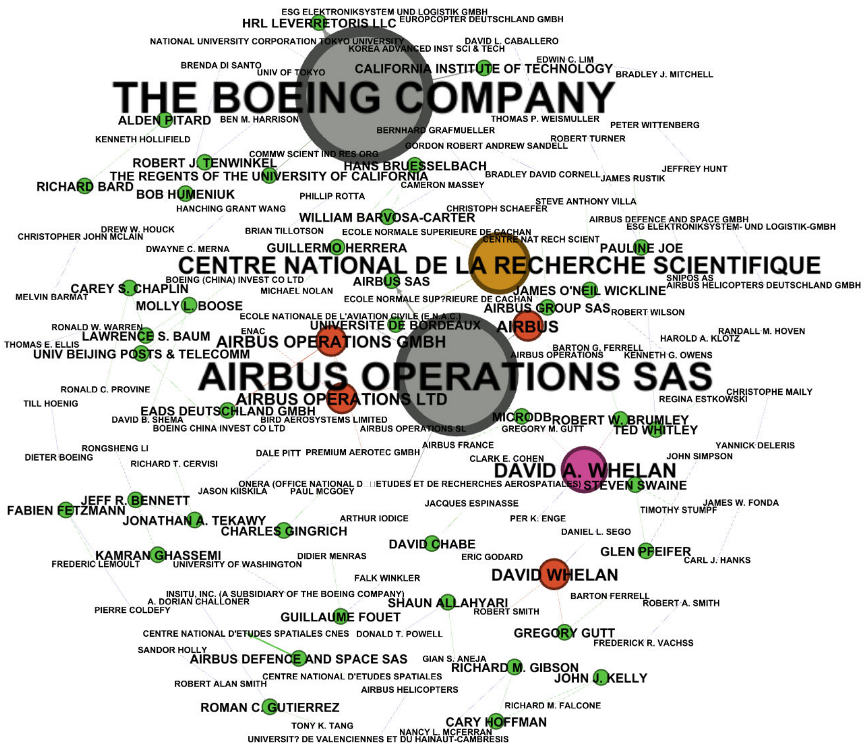


(**D**) (battery)

Figure A5. *Cont.*

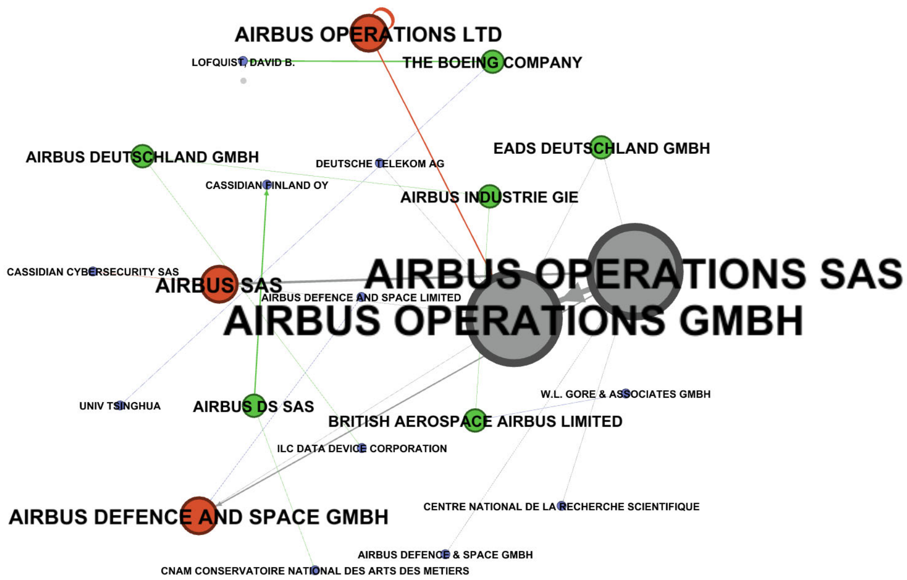


(**E**) (control/safety)



(**F**) (navigation/communication)

Figure A5. *Cont.*



(**G**) (cybersecurity)

Figure A5. Network analysis by technology.

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