Centre for Technology Management working paper series
ISSN 2058-8887

No. 1

February 2022

SVEL – Introducing the Standardised Visualising Ecosystem Language for Temporally Capturing Competitive Dynamics in Evolving Innovation Ecosystems

doi:10.17863/CAM.81902

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SVEL – Introducing the Standardised Visualising Ecosystem Language for Temporally Capturing Competitive Dynamics in Evolving Innovation Ecosystems

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Abstract

We propose a visual method, namely the Standardised Visual Ecosystem Language (SVEL), for capturing and analysing the static structure, structural changes, and dynamic forces and effects in evolving innovation ecosystems. SVEL closes a gap in the methods toolbox of researchers, practitioners, and policy makers that we identified from conducting a systematic review and evaluation of 32 relevant visual methods, namely the capture and analysis of processes affecting industrial organisation and interfirm alignment in evolving ecosystems.

We demonstrate SVEL's effectiveness and practicability by validating it in a case study from the commercial aircraft aftermarket sector. In this sector, manufacturers transform to offering services in a bundle with their products in a process called servitization, thereby triggering competitive tensions with established specialist services firms, which we label Incumbent Service Providers (ISP). Empirical data was collected from ten semi-structured, in-depth interviews with senior managers and decision-makers at one large, established, and leading OEM-independent ISP.

The results of our study are two-fold. First, we introduce SVEL that consists of three clusters of standardised symbols: (i) structural elements, (ii) dynamic forces and effects, and (iii) structural changes. Second, using the SVEL we produce a set of four aggregated innovation ecosystem maps that visually capture the static structure of the commercial aircraft aftermarket ecosystem prior to servitization, and the dynamic co-evolutionary processes triggered by manufacturers entering as new competitors to ISPs during servitization.

Thus, we contribute to the methodology literature by narrowing the gap in the methods toolbox for researchers and practitioners in the field of innovation ecosystems by proposing and demonstrating SVEL as a visual method for capturing and analysing changes to industrial organisation and dynamic co-evolutionary processes.

Keywords: Visual Methods, Innovation Ecosystems, Servitization, Competitive Dynamics, Incumbent Service Provider, Services-Essential Intellectual Property

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DOI: 10.17863/CAM.81902 – Version 1 (March 2022)

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1 INTRODUCTION

The rise in popularity of the ecosystem approach in the management sciences[1] is in part due to its focus on interdependences among firms and their activities, as well as its ability to capture and analyse value exchanges among a multilateral set of firms that are aligned towards a focal value proposition (Adner, 2017). Furthermore, the ecosystem paradigm provides researchers, practitioners and policy makers with an effective conceptual framework for measuring both complementary and competitive relations among actors, as well as the dynamic co-evolution of actors, activities and artefacts over time (Granstrand and Holgersson, 2020). An increasing number of studies have recently adopted the ecosystem lens in order to delineate the effects and drivers of competition in various sectors, such as e-commerce (Liu, Kauffman and Ma, 2015), information and communications technology (Basole, Park and Barnett, 2015), and technology standards in Industry 4.0 (Jiang *et al.*, 2020).

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[1] The ecosystem concept in the context of the management sciences emerged from Moore's (1993) analogy between natural ecosystems, as well as the co-evolution of interdependent species, and business ecosystem with companies co-evolving around new innovations.

According to the Austrian School, competition and rivalry amongst firms are dynamic processes that are continuously driven by the search for competitive advantage and economic value (Jacobson, 1992; Young, Smith and Grimm, 1996). Furthermore competition is no longer confined to companies offering similar products to the same customers, but increasingly occur among firms upstream and downstream in a product's or service's value chain (Wise and Baumgartner, 1999; Markman et al., 2009), stem from unanticipated new entrants diversifying from other sectors (Porter, 2008), or are driven by substitute products or services effectively fulfilling the same function (Granstrand and Holgersson, 2020). Adopting the competitive dynamics perspective, interfirm competition and rivalry are longitudinal processes, empirically observable in the exchange of actions and responses between firms pursuing market opportunities, and considered relatively between two firms' positions, intentions, perceptions and resources (Chen and Miller, 2012).

Concurrently with the emergence of the ecosystem concept, a plethora of visualisation techniques have been proposed to facilitate the capture and analysis of interfirm collaboration and competition, as well as value exchanges and alignment towards a common value proposition, both quantitatively (e.g. is Basole et al.'s (2018) Ecoxight tool, which uses network visualisation to explore the structure and dynamics of complex ecosystems) and qualitatively (e.g. Phillips and Srai's (2018) exploratory ecosystem mapping for the identification of innovation ecosystem boundaries). The popularity of visualisation methods for analysing and depicting ecosystems appears to be primarily driven by their inherent property to activate human's high capacity in visual perception, while at the same time rapidly and economically reducing complex data streams (Johnson *et al.*, 2006).

After systematically reviewing existing visualisation techniques for the analysis of ecosystems in the management sciences, we however found that they either demonstrate adequacy in terms of explicitly capturing an ecosystem's static structure including various actors, activities, artefacts, and the multiplicity of relationships among them, or focus on visually representing dynamic processes and structural changes occurring in ecosystems over time. A gap remains in the methods toolbox for a visual approach that combines both requirements, thus enabling the capture and analysis of dynamic co-evolutionary processes affecting industrial organisation and interfirm alignment in evolving ecosystems. Furthermore, the multitude of approaches and diversity of external representations used in existing ecosystem visualisation techniques forgo any kind of standardisation or conceptual convergence, thus impeding meaningful contrasting juxtaposition of results. This leads us to pose the following methodological research questions: *how can static structure, structural changes and dynamic forces and effects in evolving innovation ecosystems be visually captured in a standardised format to analyse dynamic co-evolutionary processes affecting industrial organisation and interfirm alignment?*

We address this method gap by introducing a new standardised visual method, namely the Standardised Visual Ecosystem Language (SVEL) that allows for both, capturing and analysing ecosystem static structure as well as dynamic forces, effects, and structural changes in evolving innovation ecosystems. Our new method builds on existing visualisation methods for value exchanges in innovation ecosystems (Urmetzer, Gill and Reed, 2018) and is conceptually grounded in the state-of-the-art in ecosystem research (Adner and Kapoor, 2010; Granstrand and Holgersson, 2020). SVEL represents a methodological contribution that advances the methods toolbox for researchers, practitioners, and policy makers for the interpretation of competitive dynamics in evolving innovation ecosystems through capturing and analysing structural changes, dynamic forces and effects. We hereby also answer to calls for further research into effective theory-based visualisation methods and their transfer into multidisciplinary working practice (Johnson *et al.*, 2006; Bell and Davison, 2013).

In this paper, we furthermore demonstrate SVEL's effectivity by applying it to visually map structural elements and changes, as well as the related dynamic forces and effects in the commercial aircraft Maintenance, Repair and Overhaul (MRO) innovation ecosystem. This sector is currently experiencing a period of rapid structural evolution as a result of manufacturers increasingly offering aftermarket services complementing their products (Michaels, 2018; Derber, 2019a; Shay, 2019a; Pozzi, 2020). By pursuing this transformational process denoted as the servitization of manufacturing (Vandermerwe and Rada, 1988; Baines *et al.*, 2017), manufacturers generally strive for differentiation and continuous revenues from their installed base of products (Neely, 2008). In the specific context of the commercial aircraft MRO sector, Original Equipment Manufacturers (OEMs), such as Airbus, Boeing, Pratt & Whitney and Rolls-Royce, compete directly with established providers of integrated MRO services for aircraft (Ballantyne, 2015) thereby creating competitive tensions in the innovation ecosystem that are best analysed by applying a multi-actor perspective (Burton *et al.*, 2016). We call such established providers of integrated services Incumbent Service Providers[2] or ISPs and define them as pure services firms that have previously developed the necessary capabilities, infrastructure, and relationships to both suppliers and customers to deliver integrated services for the maintenance of physical assets manufactured by third parties. In addition to confirming our method's ability to capture static structure, structural changes, and dynamic forces and effects in the commercial aircraft MRO innovation ecosystem, the application of our proposed SVEL method to mapping the competitive tensions between servitizing manufacturers and ISPs allows us to uncover co-evolutionary processes, thereby contributing to the literature on servitization[3].

In the following sections, we first present the results from a systematic literature review of existing visual methods for the analysis of ecosystems in the management sciences, identify the methods gap and derive our research question (section 2). Subsequently, we describe the research approach for the development of the new visual method (section 3) and introduce SVEL with its constituting elements (section 4). We continue with a discussion

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[2] The term incumbent service provider was previously used in literature related to the telecommunication sector and typically denotes companies that previously licensed a frequency spectrum from governmental agencies, built-up necessary infrastructure, and have an existing customer base for wireless and cellular services as opposed to new entrant service providers (Nguyen *et al.*, 2011; Mukherjee, 2019). More recently, incumbent service providers were the subject of discussions related to antitrust regulations and fair competition (Zhang, 2019; Bethell, Baird and Waksman, 2020). In the context of service innovations in manufacturing, Ettlie and Rosenthal (2012) noted that incumbent service firms have yet to be studied to uncover their primary strategies for the development and implementation of service innovations, and hinted at their origins primarily in the financial and healthcare sectors. We are not aware of any previous studies using this term in the analysis of competitive dynamics between manufacturers and pure service firms in the context of servitization.

[3] This contribution also addresses a call for further research raised by Wirths (2019), namely to take a multilateral perspective on servitization in the commercial aircraft MRO sector with the goal to uncover the dynamics of competition between OEMs and existing pure services firms. In this context, Wirths coined the phrase "*the dark side of servitization*", which describes a set of mechanisms driven by manufacturers to raise barriers for pure service firms to provide integrated services solutions, thereby actively reducing service choices to customers.

of the results from the case-study, in which we demonstrate the SVEL's effectiveness in capturing and analysing competitive dynamics in the commercial aircraft MRO innovation ecosystem resulting from the servitization of manufacturing firms (section 5). The paper concludes with a summary, statement of the limitations and recommendations for future research (section 6).

2 LITERATURE REVIEW: VISUALISATION TECHNIQUES FOR ECOSYSTEM RESEARCH

Applying the ecosystem lens as a conceptual tool for delineating competitive dynamics when changes in industrial organisation unfold, inherently requires researchers, practitioners, and policy makers to effectively handle a plethora of constructs with complex interrelationships that are changing with time. More specifically, Granstrand and Holgersson (2020) highlight that innovation ecosystems are characterised by three distinct entities, namely actors, artefacts and activities, as well as institutions surrounding and relations among them, which collectively represent a dynamic system. Adner (2017) furthermore emphasises that these activities and relationships succumb to a multilateralism that cannot be reduced to aggregate bilateral relationships, but instead necessitate the consideration of interdependencies among them. Finally, Trier (2008) and Battistella et al. (2013) agree that considering temporally ordered information and evolutionary trends are essential ingredients in the holistic and complete analysis of ecosystems in the management sciences. While these characteristics of the ecosystem offer a powerful conceptual framework for the capture and analysis of competitive dynamics during changing industrial organisation, the resulting dynamically changing networks challenge the natural human cognitive abilities of researchers, practitioners and policy makers (Bach, Pietriga and Fekete, 2014). This calls for new methods and tools facilitating the collection and analysis of empirical data for the purpose of theory building, strategy formulation and policymaking.

2.1 Visual Methods in the Management Sciences

Researchers studying the changing nature of organisations have increasingly embraced visual research despite inherent challenges related to demonstrating academic rigour because it promises insights that would otherwise not be accessible when purely relying on established methods that are exclusively based on language (Bell and Davison, 2013). At the very basic level, visualisations, such as written symbols, labels, visual and spatial layouts, which are hereinafter collectively referred to as external representations, provide direct access to information without the need for explicit formulation and interpretation (Zhang, 1997). Furthermore, the visualisation of dynamic networks using external representations augments theoretical intuition and is thus likely to be superior to single-dimensional analysis, particularly in the ecosystem context (Moody, McFarland and Bender-DeMoll, 2005). However, the process of discovering new knowledge in complex information and data through visualisation requires researchers to interact with respective methods and to adjust their specifications in order to effectively and purposefully extend human cognitive abilities (Johnson *et al.*, 2006). Bell and Davison (2013) call for future work to focus on developing theory-based visual methods in which researchers and research participants collaborate to develop a deeper understanding of spatially and temporally dynamic organisational processes.

2.2 The State-of-the-art in Ecosystem Visualisation

To ascertain the current state-of-the-art in ecosystem visualisation methods in the context of the management science, we conducted a detailed review of the relevant literature, which was identified to consist of 32 papers[4]. All 32 relevant journal articles and conference proceeding papers were systematically reviewed, clustered, and evaluated by assessing their effectiveness in capturing (i) ecosystem static structure, namely visually representing actors, artefacts, institutions, activities and (ii) relationships among them, as well as with respect to (iii) visually mapping dynamic forces and effects and related structural changes in an ecosystem that evolves over time[5]. Table 1 summarises the findings from the evaluation of the current state-of-the-art in ecosystem visualisation methods by grouping studies exhibiting methodological similarities in seven distinct method clusters. They are listed in descending order with respect to the mean evaluation score.

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[4] The literature search was executed by using the Scopus abstract and citation online database, applying the keyword “ecosystem” in combination with either “dynamic” or “evolution”, as well as either “visualisation” or “mapping”, and choosing Boolean operators. The subject areas were limited to computer science, engineering, social sciences, business, management and accounting, decision sciences, economics, the arts and humanities, as well as multidisciplinary subjects. The literature search revealed a total of 573 journal and conference proceeding papers, whereas after review of titles and abstracts the number of relevant articles reduced to 32.

[5] Each of the 32 visual methods was scored based on the three evaluation criteria on a five-point-scale ranging from ‘1’ to ‘5’ representing low to high effectiveness in terms of visually representing each criterion, respectively. The aggregate score for each method was subsequently calculated as a weighted average, whereas the categories for visualising dynamic forces and effects, as well related structural changes, counted twice to account for the higher-order methodological focus on the interpretation of competitive dynamics in evolving innovation ecosystems in our study.

Table 1: Summary of the state-of-the-art in ecosystem visualisation methods

Cluster ID	Cluster Name	No. of Papers	Method	Strengths	Weaknesses	Top Example Papers[a]	Individual Score[b]	Mean Score[c]
VM1	Ecosystem Mapping	7	Qualitative	Detailed representation of ecosystem actors, artefacts, activities and institutions using different shapes, sizes, colours and labels to distinguish among types and roles Clear depiction of relationships using separate set of symbols, but mainly arrows or edges of varying form, size or colour Allows explicit capture of ecosystem static structure at discrete points in time	The capture of time-dependent structural changes is implicit by comparing snapshots of the ecosystem at discrete time intervals Representation of dynamic forces and effects is limited to analyses of 2D plots of time-dependent variables measured as the ecosystem evolves	Ghazinoory et al. (2020) Urmetzer, Gill & Reed (2018) Lin & Lin (2006)	3.9 3.4 3.1	3.1
VM2	Social / Co-citation Network Analysis	4	Quantitative, Qualitative and Mixed	Actors, artefacts, activities and institutions are represented by nodes and a standardised set of properties (e.g. node size, colour, rings, etc.) Relationships among actors and artefacts are represented by edges or links, whereas properties (e.g. thickness, colour, labels) are used to capture additional information Representation of static structure of social networks is complemented using node and edge properties and established metrics (e.g. network size, betweenness, centrality, centrality, etc.)	Capturing structural changes and dynamic process relies on 2D / 3D longitudinal simulations or contrasting snapshots of social networks at discrete time intervals Identifying structural changes is cognitively challenging and obscure for large social networks involving large numbers of nodes and edges	Trier (2008) Teixeira, Mian & Hytti (2016) Reale et al. (2020)	3.6 3.3 2.7	3.0
VM3	Path / Evolution Mapping	3	Quantitative, Qualitative and Mixed	Structural ecosystem changes are explicitly captured by external representations of evolutionary paths of actors or artifacts over time Dynamic forces and effects are represented by relationships between activities of one actor and another actor or artifact	Effective representation of spatial structure and relationships among actors, artefacts, activities and institutions is traded for capturing temporal causalities The external representations and overall logic of capturing ecosystems lack standardisation	Liu et al. (2020) Sanchez-Nunez, Heraz-Pedrosa & Pelaez (2020) Pagano & Neubert (2015)	3.4 2.7 2.7	3.0

Cluster ID	Cluster Name	No. of Papers	Method	Strengths	Weaknesses	Top Example Papers[a]	Individual Score[b]	Mean Score[c]
VM4	Node-Edge Network Analysis	12	Mainly Quantitative, but also Mixed	Standardised representation of actors and relationships by nodes and edges Node sizes, colours and edge thickness are used to capture additional information about actors, artefacts and relationships Ecosystem structure can be quantitatively analysed using metrics (e.g. centrality, connectedness, density, etc.)	Changes in ecosystem structure are captured only implicitly either by taking snapshots at discrete time intervals or running a time-dependent animation The limitation of external representations to nodes and edges does not allow for an explicit representation of dynamic forces and effects Comparing snapshots of large ecosystems at discrete time intervals or viewing animations of the evolution of large ecosystems to observe structural changes is cognitively challenging	Basole et al. (2018)	3.9	2.9
						Huhtamäki et al. (2013)	3.4	
						Rothe, Täuscher & Basole (2018)	3.3	
						Natsukawa et al. (2021)	3.3	
VM5	System Dynamics	1	Quantitative	Visualisation is focused on a set of metrics empirically measuring the state of the ecosystem (e.g. density, fluidity, connectivity and diversity) and thus tracking evolutionary processes in the ecosystem	No explicit visualisation of actors, artefacts, activities or institutions in the ecosystem or relationships among them Ecosystem structural changes are only implicitly captured through visualisation of the dynamic evolution of ecosystem metrics	Auerswald & Dani (2017)	2.3	2.3
VM6	Node/Agent Based Model	3	Mainly Quantitative, but also Mixed	Large numbers of actors (i.e. populations) are represented by nodes in a standardised fashion Node colour and spatial position are used to identify clusters of actors in the ecosystem	Relationships among actors and overall ecosystem structure are only implicitly observable through clusters of actors Capturing and analysing of dynamic processes is limited to 2D plots of time dependent ecosystem metrics (e.g. population sizes) Structural changes are represented implicitly and relies on analysing the behaviour and spatial distribution of clusters of actors	Skute et al. (2019)	2.4	2.1
						Xiao et al. (2019)	2.3	
						Gras et al. (2009)	1.6	

Cluster ID	Cluster Name	No. of Papers	Method	Strengths	Weaknesses	Top Example Papers[a]	Individual Score[b]	Mean Score[c]
VM7	Mind Mapping	2	Qualitative	Actors, artefacts, activities and institutions are represented using rectangles with colours and labels adding extensive details Hierarchies among actors, artefacts, activities or institutions are explicitly captured	Relationships among actors, artefacts, activities and institutions are not visually captured (apart from hierarchies) No representations of dynamic forces and effects, as well as structural changes Limited range of external representations inhibits effective capture of complex structures and ecosystems evolution	Passaro et al. (2020)	2.3	2.0
						Introne et al. (2020)	1.7	

Notes:

[a] Top example papers received the highest evaluation score relative to other papers in the method cluster.

[b] Individual evaluation scores were calculated based on each paper's effectiveness with respect to the three criteria of capturing (i) ecosystem static structure, (ii) relationships, and (iii) dynamic forces and effects, as well as structural changes in an evolving ecosystem. Each method was scored for each criterion on a five-point-scale from '1' till '5', whereas the aggregate score equals to the weighted average with criteria (ii) and (iii) counting twice.

[c] The mean score represents the average of all individual evaluation scores in the visual method cluster.

Table 1 suggests that VM1 (Ecosystem Mapping), VM2 (Social / Co-citation Network Analysis), VM3 (Path / Evolution Mapping), and VM4 (Node-Edge Network Analysis) constitute the most developed and promising ecosystem visualisation method clusters based on their average score with respect to the evaluation criteria. More specifically, VM1 methods, such as Ghazinoory et al. (2020) and Urmetzer, Gill and Reed (2018), contain detailed representations for ecosystem actors, artefacts, activities and institutions, as well as relationships among them. However structural changes in the ecosystem are only implicitly captured by snapshot comparisons of ecosystem maps at discrete time intervals. The VM1 method cluster also suffers from the inability to represent dynamic forces and effects apart from tracking time-dependent ecosystem metrics, such as size of actor populations.

Furthermore, the two closely related method clusters VM2 and VM4 use nodes to represent actors, artefacts, activities and institutions, and edges to visually describe relationships among them in a highly standardised fashion as exemplified by Natsukawa et al. (2021), Basole et al. (2018) and Trier (2008). While the high degree of standardisation of external representations allows these method clusters to effectively represent complex networks consisting of large numbers of actors and relationships, it also means that neither structural changes nor dynamic forces and effects are explicitly captured as ecosystems evolve. Instead, VM2 and VM4 rely on comparisons between static snapshots at discrete time intervals, as exemplified by Basole and Karla (2011, p. 318), similarly to methods in the VM1 cluster. This becomes cognitively challenging for researchers, practitioners and policy makers if the network size (i.e. number of nodes) and the density (i.e. connectedness of a network's nodes) of the ecosystem that is being visually captured and analysed increases.

Finally, methods in the VM3 cluster are specifically designed to visually capture the time dependent evolution of artefacts, as exemplified by Liu et al.'s (2020, p. 2060) technology path mapping, or the dynamic forces and effects resulting from one actor's activities on another actor's artefact, such as Pagano and Neubert's (2015, p. 166) mapping of stakeholder interaction and value creation or destruction. This methodological focus on longitudinal causalities in VM3 however compromises its ability to effectively capture spatial structure and relationships among actors, artefacts, activities, and institutions.

While each of these four method clusters typically excels in at least one evaluation criterion, that is either capturing ecosystem static structure through effective visual representation of actors, artefacts, institutions, activities and relationships among them, dynamic forces and effects, or structural changes over time, none of them were found to holistically address the full spectrum of requirements underlying the effective capture of competitive dynamics in evolving innovation ecosystems. Based on this review of 32 existing ecosystem visualisation methods we conclude that a gap remains in the methods toolbox for researchers, practitioners and policy makers for the effective, comprehensive, and standardised capture and analysis of dynamic co-evolutionary processes affecting industrial organisation and interfirm alignment in innovation ecosystems.

3 RESEARCH METHODOLOGY

We adopted a qualitative research strategy to address the identified gap in the methods toolbox. At the top level, we conducted a single case study in an industrial sector exhibiting dynamic changes in its industrial organisation. We started by applying Urmetzer, Gill and Reed's (2018) ecosystem value mapping process for the collection of empirical data, and subsequently adapted Gioia, Corley and Hamilton's (2012) inductive approach to discovering novel concepts and new theory generation for developing a new visual method and to identify and explain causalities in the empirical data. The case study methodology was chosen due to its effectiveness in capturing multiple sources of empirical data, its focus on contemporary events, as well as its ability to identify causalities and understand dynamics in particular settings (Eisenhardt, 1989; Yin, 2014). Furthermore, Urmetzer, Gill and Reed's (2018) ecosystem value mapping process was identified as best reflecting the current-state-of-the-art in current ecosystem visualisation techniques and, thus, as an appropriate methodological basis. Finally, the adaptation of Gioia, Corley and Hamilton's (2012) inductive approach, which is hereinafter referred to as the graphical coding process, enabled us to iteratively develop a new standardised visual method while incorporating emerging concepts from case study observations. This iterative approach was continued until primary and secondary empirical data, as well as observations were adequately represented and incremental improvements to the visualisation method became minimal (Eisenhardt, 1989).

3.1 Case Study Theoretical Sampling and Data Collection

In order to observe dynamic co-evolutionary processes affecting interfirm alignment and resulting in changes of the industrial organisation we conducted a single revelatory case-study (Yin, 2014, p. 52) in the commercial aircraft MRO sector. Evidence[6] suggests that the commercial aircraft MRO ecosystem is subject to servitization, namely the transformation of manufacturers' offerings from being primarily product-based to becoming services that are integrated with products (Baines and Lightfoot, 2013, p. 5). In this transformational process, manufacturers reposition by forward integration and seeking direct access to customers (Wise and Baumgartner, 1999; Teece, 2010; Huikkola *et al.*, 2020), thereby bypassing existing intermediaries, possibly triggering competitive tensions with those established specialist firms already providing such services to end-users of manufacturers' products (Burton *et al.*, 2016), which we call Incumbent Services Providers (ISP).

In our conceptualisation of the commercial aircraft MRO sector as an evolving innovation ecosystem, ISPs effectively assume the role of the focal firm because they bundle components into and align partners towards a focal value proposition (Adner and Kapoor, 2010; Adner, 2017). We adopted the perspective of the ISP as the focal firm and applied Urmetzer, Gill & Reed's (2018) ecosystem value mapping process as the current state-of-the-art in ecosystem visualisation techniques to capture the alignment structure of its partners, namely its suppliers and complementors, as well as their relative positions and roles, in the

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[6] Leading OEMs of commercial airplanes, such as Airbus, Boeing and Embraer, recently reported substantial increases in the aftermarket services revenues (Hemmerdinger, 2017; Derber, 2019b, 2020). Furthermore, large OEMs of aircraft engines and integrated systems, such as CFM International, Rolls-Royce and Honeywell, affirmed their services strategies and presented new service innovations including digital solutions, remote monitoring and life-cycle cost management (Neely, 2008; Broderick, 2019a; Chuanren, 2019).

pre-servitization phase[7]. In this phase, ecosystem actor roles of ISPs, manufacturers and customers are clearly defined and typical buyer-supplier relationships dominate among these roles (Wirths, 2019, p. 79). Furthermore, we repeated ecosystem value mapping during the servitization phase to observe and capture unfolding changes in industrial organisation and dynamic forces and effects in the evolving commercial aircraft MRO ecosystem. The servitization phase is characterised by aircraft and system OEMs offering services in a bundle with their products, thereby entering into direct competition with ISPs (Wirths, 2019, p. 79f) and challenging the established byer-supplier relationships among ecosystem actors.

Primary empirical data consists of ten semi-structured in-depth interviews (Bryman and Bell, 2015, p. 481) with senior managers and decision-makers at one established and large, manufacturer-independent ISP, which offers an integrated holistic scope of services for established Western aircraft types nose-to-tail. Table 2 provides an anonymised summary of the interviewees, including their roles and additional details about the interviews. The interviews were recorded and complemented with Urmetzer, Gill and Reed's (2018) ecosystem value mapping process, in which the commercial aircraft MRO innovation ecosystem was visually captured together with each interviewee as seen from the ISP's perspective before and during the servitization of OEMs. Each of these ecosystem value maps was confirmed with the respective interviewee after it was transcribed into a digital format during a later follow-up interview and amended for completeness and accuracy if necessary. Secondary empirical data consisting of extensive archival records, such as ISP internal documents, external media reports specific to the commercial aircraft MRO sector, and publicly accessible company annual reports, were reviewed for the purpose of data triangulation, thus strengthening the case-study's construct validity (Yin, 2014, p. 121).

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[7] Wirths (2019) conceived a phase model of servitization consisting of the pre-servitization, servitization, and post-servitization phase. The pre-servitization phase is characterised by stable and established roles and relationships among manufacturers, specialised service firms and customers. In the subsequent servitization phase, manufacturers newly enter the services market and start to aggressively compete with services firms for relationships with customers, which leads to a blurring of established roles and relationships. Finally, the servitization phase sees manufacturers as established competitors to services firms along with respective alliance building and fine tuning of business models.

Table 2: Interviewee summary including services unit or function, role, and additional interview details

ID	**Services unit / functions** [a]	**Interviewee role** [b]	**Date**	**Recorded**	**Length** (hr:min)	**Map confirmed by interviewee**
ID1	Aircraft Engines	Head of Business Development	28-Feb-19	Yes	00:57	Yes; 17-Mar-20
ID2	Aircraft Systems	Head of Business Development	22-Mar-19	Yes	00:35	No [e]
ID4	Digital Solutions	Head of Business Development	04-Mar-19	Yes	00:46	Yes; 16-Dec-19
ID5	Strategy	Head of Business Development	20-Feb-19	Yes	00:43	No [e]
ID6	Aircraft Maintenance	Head of Business Development	01-Mar-19	Yes	00:30	Yes; 06-Dec-19
ID7	Aircraft Systems	Senior Director, Business Development	01-Mar-19	Yes	00:19	Yes; 14-Feb-20
ID8	Special Projects	Senior Director, Aerospace Industry	16-Apr-19	No [c]	01:10:00 [d]	Yes; 06-Dec-19
ID9	Aircraft Systems	Head of Partnership Management	16-Apr-19	Yes	00:51	Yes; 16-Dec-19
ID11	Sales	Vice President, Sales	24-May-19	Yes	00:44	Yes; 02-Mar-20
ID12	Intellectual Property	Senior Director, Patent Office	29-May-19	Yes	01:01	Yes; 12-Nov-19

Notes:

[a] Interviews were conducted across several services units and corporate functions in the leading ISP's portfolio in order to capture a holistic perspective of the commercial aircraft MRO innovation ecosystem from the ISP's point of view

[b] Description of each interviewee's role within the leading ISP's organisation and hierarchy; roles were selected based on potential overview and visibility of static structure, structural changes and dynamic forces and effects in ISP's innovation ecosystem

[c] Recording declined by interviewee due to confidentiality requirements

[d] Approximate length of interview

[e] Confirmation of transcribed ecosystem value maps not possible due to unavailability of interviewees after onset of COVID-19 induced crisis in commercial aviation sector from March 2020

3.2 Data Analysis through the Graphical Coding Process

Attributing to Gioia, Corley and Hamilton's (2012) inductive approach to discovery of novel concepts and new theory generation, the graphical coding process for the analysis of empirical and visualised data consisted of three steps (see Figure 1): (i) Transcription, (ii) Translation, and (iii) Aggregate Maps.

(i) Transcription

The ecosystem value maps that were generated together with the interviewees using the approach by Urmetzer, Gill & Reed's (2018) were transcribed from hard-copy paper into a digital format. The interview recordings were used to enrich the maps with details to capture the interviewee's picture of the ecosystem's static structure prior to the onset of servitization and the ensuing dynamic co-evolutionary processes and changes in industrial organisation resulting from servitizing manufacturers in the sector as closely and completely as possible. This complies with Gioia, Corley and Hamilton's (2012) 1st-order analysis in which the focus lies on terms, codes and visualisations as used by the interviewee. We subsequently reviewed the digitally transcribed maps for completeness together with each interviewee (Urmetzer, Gill and Reed, 2018) and modified them where necessary to ensure construct validity (Yin, 2014, p. 47). The transcription step was accomplished as an ongoing activity during the primary empirical data collection phase in order to start identifying emerging themes that could be made subjects of particular interest in subsequent interviews (Bryman and Bell, 2015, p. 495).

(ii) Translation

In the translation step, emerging visual themes and concepts describing structural elements, dynamic forces and effects, as well as structural changes in the transcribed ecosystem value maps were visually coded into standardised representations. This effectively constituted a visual adaptation of Gioia, Corley and Hamilton's (2012) 2nd-order analysis, in which the focus shifts towards researcher concepts, themes and dimensions. To ensure that theoretical saturation is reached (Bryman and Bell, 2015, p. 432), the emerging standardised visual representations of innovation ecosystem structure and dynamic co-evolutionary processes were applied to all transcribed ecosystem value maps and adapted iteratively until no further changes were necessary to accurately and holistically represent each map and no new or relevant data emerged.

(iii) Aggregate Maps

In the final step, aggregate maps were generated by applying the finalised standardised set of visual representations, namely the SVEL, to create a set of generalised innovation ecosystem maps of dynamic co-evolutionary processes in the commercial aircraft MRO sector under the influence of servitization, including the basic ecosystem structural elements, dynamic forces and effects and ecosystem structural changes. This step represents a visual adaptation of distilling aggregate dimensions from emerging 2nd-order themes and concepts in Gioia, Corley and Hamilton's (2012) inductive approach to discovery of novel concepts and new theory generation. To conclude this last step, data triangulation between the aggregate map and secondary empirical data is conducted to strengthen construct validity (Yin, 2014, p. 120).

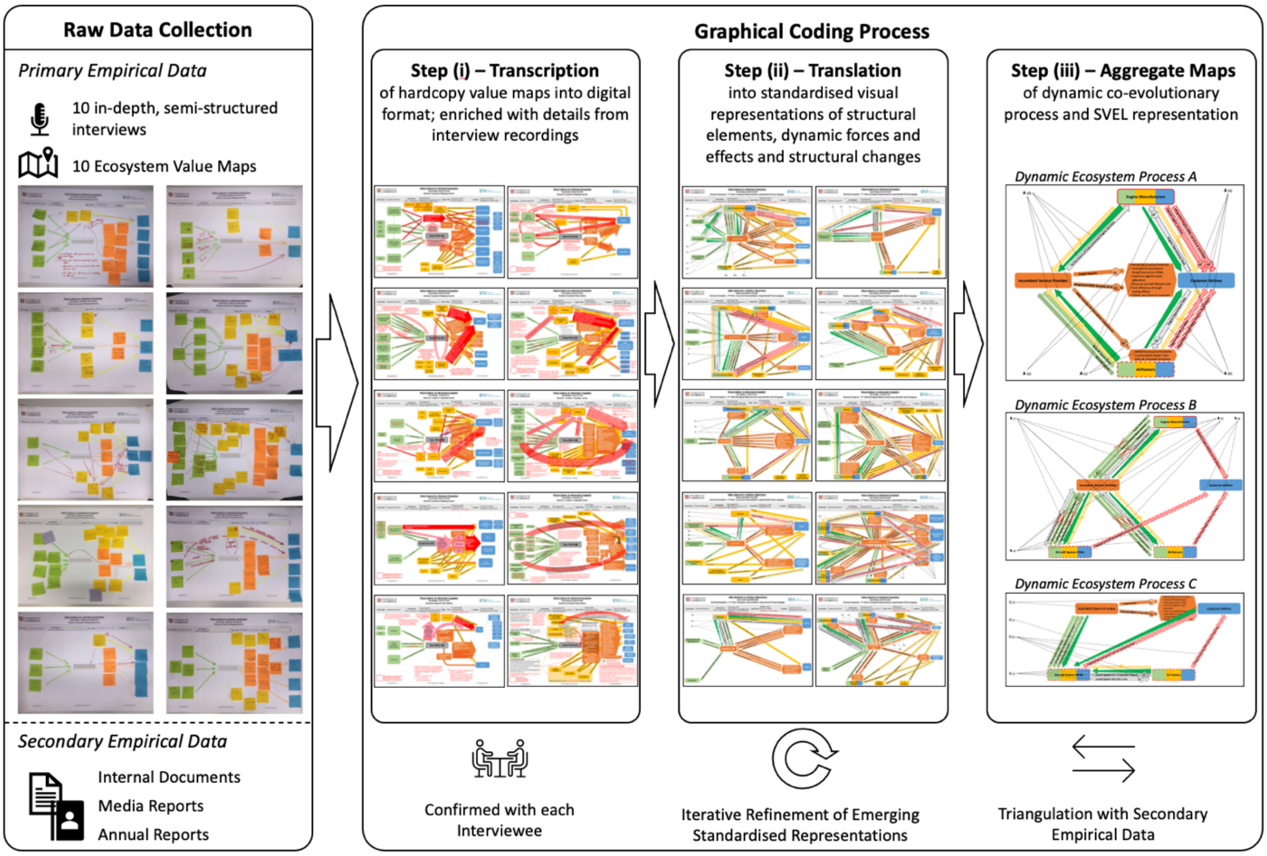


Figure 1: Schematic of research methodology including raw data generation and Graphical Coding Process

4 A NEW STANDARDISED VISUAL ECOSYSTEM LANGUAGE (SVEL)

SVEL represents a new standardised visual method that addresses the gap faced by researchers, practitioners and policy makers when capturing and analysing dynamic co-evolutionary processes affecting industrial organisation and interfirm alignment in evolving innovation ecosystems. It is the result of the single revelatory case study in the commercial aircraft MRO innovation ecosystem, which is subject to servitization, and was conceived using a graphical coding process. SVEL can be described as a visual language consisting of standardised sets of written symbols, labels and colour schemes, collectively denoted as external representation (Zhang, 1997), that are grouped into three clusters (see Table 3): (i) Ecosystem Structural Elements, (ii) Dynamic Forces and Effects, and (iii) Ecosystem Structural Changes.

Table 3: Overview of SVEL symbols and external representations

Table 3a

Ecosystem Structural Elements					
Ecosystem Actor Role			Goods Flows[a]		Value Proposition[b]
Single	Dual	Triple	Tangible	Intangible	
					

Table 3b

Ecosystem Actor Role Colour Coding				
Focal Firm	Customers	Suppliers	Complementors	Other Roles[c]
🟧	🟦	🟩	🟨	🟫

Table 3c

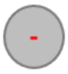
Dynamic Forces and Effects				
Exertion of Leverage/Power	Goods Flow Measurement[d]		Economic Value Capture Changes[e]	
	Growth	Shrinkage	Increase	Decrease
				

Table 3d

Ecosystem Structural Change					
Changes to Actor Roles[f]		Changes to Goods Flows		Restriction of Goods Flows	
Near Match		Near Match[g]		Full Suspension	
Limited Match		Limited Match[h]		Partial Restriction	
		Emerging Goods[i]			

Notes:

[a] Direction from artefact value creating to artefact value capturing Ecosystem Actor Role; adapts to value creating Ecosystem Actor Role Colour Coding

[b] Delivered by Ecosystem Focal Firm to Customers

[c] Other Ecosystem Actor Roles without explicit share in focal Value Proposition

[d] Attached to a Goods Flow and adapts to Goods Flow's colour coding

[e] Direction opposite to respective Goods Flow

[f] Frame adapts to colour Ecosystem Actor Role Colour Coding of new role

[g] Adopts pre-existing Goods Flow colour coding that is nearly matching

[h] Adopts pre-existing Goods Flow colour coding that is limited matching

[i] Adapts to original Goods Flow colour coding

4.1 Ecosystem Structural Elements

The *Ecosystem Structural Elements* are specifically conceived to parsimoniously capture the basic elements of Adner's (2017) ecosystem-as-structure perspective, namely activities, actors, positions and links, that are strictly relevant for the realisation of the ecosystem's focal value proposition. As highlighted in Table 3a, the visual representation of *Ecosystem Structural Elements* in our SVEL consists of the (a) Ecosystem Actor Role and Role Colour Coding, (b) Goods Flow, and (c) Value Proposition symbols.

(a) Ecosystem Actor Role and *Ecosystem Actor Role Colour Coding*

The *Ecosystem Actor Role* symbol (see left section of Table 3a) is represented by a rectangle and captures entities that conduct activities linked to the implementation of the focal value proposition, whereas *Ecosystem Actor Role Colour Coding* (see Table 1b) is used to identify each actor's relative position in the flow of activities and its role in the implementation of the focal value proposition (Adner and Kapoor, 2010; Adner, 2017). Specifically informed by Adner and Kapoor's (2010) generic ecosystem scheme and as shown in Table 3b, ecosystem actor roles are differentiated between *Focal Firms*, which integrate various inputs into the ecosystem's focal value proposition, *Suppliers*, which provide relevant inputs to focal firms, *Complementors*, which provide complementing inputs directly to customers, and *Customers*, who capture the value created by the focal firm and integrate it with complementing inputs for maximised utility and value capture (Urmetzer, Neely and Martinez, 2018). In order to provide a degree of freedom when mapping complex ecosystem structures, a separate colour is reserved for other ecosystem actor roles that do not explicitly add to the ecosystem's focal value proposition, but whose input is still relevant, such as standard setting institutions. The mapping of the commercial aircraft MRO innovation ecosystem furthermore revealed that ecosystem actors can occupy multiple roles simultaneously, for example by both supplying components to focal firms for subsequent integration into products and offering complementary products and/or services directly to customers for downstream bundling (Michaels, 2018; Pozzi, 2018). This multiplicity of ecosystem actor roles is captured by using multiple colours in a single actor role symbol as shown in the left section of Table 3a for single, dual, and triple roles.

(b) Goods Flows

Goods Flows (see middle section of Table 3a) are represented by arrows connecting two ecosystem actor role symbols in the direction from the value creating to the value capturing entity (Urmetzer, Neely and Martinez, 2018) and visualise the flow of either tangible artefacts (solid arrow), such as products and physical components, or intangible artefacts (striped arrow), such as services and intellectual property, (Granstrand and Holgersson, 2020). The colour coding of the Goods Flows arrows follows the ecosystem actor role colour coding of the value creating (or origin) ecosystem actor. With respect to Adner's (2017) basic elements of the ecosystem-as-structure perspective, the visualisation of tangible and intangible Goods Flows captures both the activities conducted by and the respective bilateral links between ecosystem actors that are coherently necessary in order to realise the focal value proposition and to maximise value capture by customers. Furthermore, the Goods Flows visualisation inherently imply a reverse economic value creation and capture flow in exchange for the artefact flow (Urmetzer, Neely and Martinez, 2018), which is not explicitly visualised for reasons of parsimony.

(c) Value Proposition

The ecosystem's focal *Value Proposition* (see right section of Table 3a) is represented by a hexagon and documents the benefits that customers receive from the delivery of the focal firm's products or services, ideally highlighting favourable points of difference compared to competing value propositions and focusing on those product or service traits that are most beneficial to customers (Anderson, Narus and van Rossum, 2006). The case study uncovered that value propositions in the market for commercial aircraft MRO services vary depending on both type of customer and technology of the asset, but typically range from ensuring spare part availability, avoiding unscheduled maintenance through predictive analytics of aircraft operational data, and offering integrated customer support solutions (Agrawal, 2019; Canaday, 2019; Bjerregaard, 2020).

4.2 Dynamic Forces and Effects

This set of external representations visualises exogenous forces that trigger phase changes as the ecosystem evolves between phases in its adaptive lifecycle, such as regulatory changes or sudden abundance/scarcity of resources (Auerswald and Dani, 2017; Granstrand and Holgersson, 2020). This cluster also represents endogenous dynamic effects on bilateral relationships between two ecosystem actors that result from innovations introduced by suppliers, complementors or the focal firm, such as new product introductions leading to enhancements in value proposition (Adner and Kapoor, 2010). Table 3c shows that dynamic forces and effects in the SVEL comprise three types of symbols for (a) Exertion of Leverage/Power, (b) Goods Flow Measurement, and (c) Economic Value Capture Changes.

(a) Exertion of Leverage/Power

The external representation for the *Exertion of Leverage/Power* (see left section of Table 3c) consists of an arrow carrying a flash of lightning and pointing from the ecosystem actor role symbol exerting strategic leverage to the receiving ecosystem actor role symbol. The Exertion of Leverage/Power symbol captures bargaining power of suppliers and buyers (Porter, 2008) or changes to the norms, rules and laws regulating the links between actors introduced by institutions (Edquist, 2006). Exertion of Leverage/Power typically occurs along existing links between ecosystem actors. In the commercial aircraft MRO ecosystem, for instance, aircraft manufacturers and system OEMs have been reported to use their bargaining power as sole suppliers of original spare parts and owners of IP required for maintaining assets as leverage against customers and ISPs (Hemmerdinger, 2018; Shay, 2019b). Institutions, such as the International Air Transport Association (IATA) and the Federal Aviation Administration (FAA), on the other hand, have issued rules and legislation forcing OEMs to provide fair access to original spare parts and IP that are required by customers and ISPs to ensure continued airworthiness of the installed base (Broderick, 2019b, 2021; Broderick and Shay, 2021).

(b) Goods Flow Measurement

Goods Flow Measurement (middle section of Table 3c) are visualised by circles with a (green) plus for growth or (red) minus for shrinkage and are attached to the respective goods flow arrow experiencing either an increasing or a decreasing trend in the intensity of flow of artefacts, respectively. The quantitative dynamics in artefact flow intensity represented by the Goods Flow Measurement symbols primarily have exogenous causes, such as a reduction in demand for the focal value proposition by customers due to external factors, for example, as witnessed in the commercial aircraft MRO ecosystem during the COVID-19 pandemic (Marcontell, 2020). In other words, the Goods Flow Measurements symbols are symptomatic of external disturbances that herald the transition from the conservation phase marked by strong, complex and stable interdependencies to the reorganisation phase characterised by rapid ecosystem structural changes in its adaptive cycle (Auerswald and Dani, 2017).

(c) Economic Value Capture Changes

Changes in Economic *Value Capture* (right section of Table 3c) are represented by a green arrow pointing in the opposite direction of the respective goods flow arrow. A tapered shaft indicates a decreasing trend and an expanding shaft signals an increasing trend in economic value capture by the receiving ecosystem actor role in exchange for providing tangible or intangible goods flow (Urmetzer, Neely and Martinez, 2018), such as supplying components, delivering products or offering complementing services, respectively. In a similar fashion to goods flow measurements, Changes in Economic Value Capture represent quantitative dynamics in economic flow intensity between two actors, but in contrast these are symptomatic of endogenous effects on bilateral relationships within the ecosystems caused by opportunistic behaviour on the part of the economic value capturing ecosystem actor role, such as renegotiating existing contractual relationships (Adner and Kapoor, 2010). Within the commercial aircraft MRO ecosystem, aircraft manufactures and system OEMs have been observed to increase Economic Value Capture from existing business relationships with customers and ISPs, for instance, by increasing royalty rates for accessing and using technical documentation that is required for maintaining aircraft fleets and systems (Shay, 2019b) or by raising annual price escalation rates for the purchase of spare parts (Canaday, 2019).

4.3 Ecosystem Structural Changes

Ecosystem Structural Changes represent a group of symbols that captures transformations in industrial organisation of the ecosystem while going through a phase of reorganisation. As highlighted by Auerswald and Dani (2017) in their description of the ecosystem adaptive cycle, exogenous forces and endogenous dynamics lead to a release of the complex and stable interdependencies that were established during the previous exploitation and conservation phases and offer opportunities for ecosystem actors to explore and pioneer new links and activities, thereby transforming ecosystem industrial organisation. The three symbols capturing Structural Changes in the ecosystem (Table 3d) consist of (a) Changes in Actor Roles, (b) Changes to Goods Flows, and (c) Restriction of Goods Flows.

(a) Changes to Actor Roles

The visualisation of *Changes to Actor Roles* (left section of Table 3d) is implemented using rectangular frames, whereas the frames' colour coding indicates the new role adopted by the actor during the reorganisation phase of the ecosystem's adaptive cycle. Furthermore, a solid frame indicates that the ecosystem actor nearly assumes the role of another actor by offering a nearly matching value proposition to the same customers, whereas a dashed frame describes a limited match between the actor's newly assumed role and that of another actor in the ecosystem. In either case, this structural change of actor roles captures the inherent existence of substitute relationships in ecosystems (Granstrand and Holgersson, 2020) that continuously drive competition and co-evolutionary dynamics in innovation ecosystems

(Moore, 2006). Frames are typically attached to existing actor role symbols in the ecosystem visualisation to indicate that an existing actor assumes a new role, as is the case with aircraft manufacturers and aircraft system OEMs assuming the role of ISPs in the commercial aircraft MRO ecosystem (Ballantyne, 2015; Pozzi, 2018). However, the frames can also be used independently of an existing actor role symbol to capture new entrants with complementary skills and capabilities diversifying from other sectors (Porter, 2008), as was the case in the healthcare sector during the early phase of the COVID-19 pandemic (Tietze *et al.*, 2020; Moerchel *et al.*, 2021).

(b) Changes to Goods Flows

Similar to the goods flow arrow symbols, the external representations of *Changes to Goods Flows* (middle section of Table 3d) also consist of arrows connecting two ecosystem actor role symbols in the direction from the value creating to the value capturing actor. The colour coding of Changes to Goods Flows arrows, however, adopts that of goods flows that already existed in the previous phase of the ecosystem's adaptive cycle and are being nearly matched (solid frame) or limited matched (dashed frame) by the value creating ecosystem actor role, typically an actor assuming the role of another actor. The combined visualisation of a Change to Goods Flows and the respective Change in Actor Role, whether nearly or limited matching pre-existing Goods Flows and Ecosystem Actor Role combinations, effectively captures the flow of substitute artefacts and indicates the existence of a competitive relationship during the phase of the ecosystem's cycle that is visualised (Granstrand and Holgersson, 2020). Finally, the Changes to Goods Flows group of symbols also comprises a neutrally coloured arrow to provide a degree of flexibility in capturing newly Emerging Goods Flows, such as innovations materialising in new links and flow of artefacts among ecosystem actors. For example, the commercial aircraft MRO innovation ecosystem has recently seen a proliferation in the provisioning of aircraft operational data from operators to aircraft manufacturers, system OEMs and ISPs (Derber, 2021; Pozzi, 2021).

(c) Restriction of Goods Flows

The *Restrictions of Goods Flows* group of symbols (right section of Table 3d) consists of two red crosses and is typically applied to goods flows or changes to goods flows arrows to indicate either a full suspension (solid cross) or a partial restriction (dashed cross) of the flow of artefacts between two ecosystem actors. The visualisation of Restriction of Goods Flows effectively captures qualitative changes in the relationship between two actors, such as the opportunistic renegotiation of the terms and conditions in purchasing and IP licensing contracts leading to restrictions in use or rights allocation on the part of the value capturing ecosystem actor (Adner and Kapoor, 2010; Granstrand, 2020).

5 CASE-STUDY FINDINGS

By applying the graphical coding process and the newly developed SVEL to the ten ecosystem value maps generated with interviewees, we captured the static structure, structural changes and dynamic forces and effects in the commercial aircraft MRO innovation ecosystem. Furthermore, by analysing structural changes and dynamic forces and effects we distilled dynamic co-evolutionary processes affecting the industrial organisation and interfirm alignment that result from the servitization of manufacturing in this sector as higher order dimensions. More specifically, the results of our analysis consist of a set of four aggregate innovation ecosystem maps expressed in SVEL terms, namely one ecosystem map that captures static structure in the pre-servitization phase and three ecosystem maps that visualise structural changes and dynamic forces and effects during the servitization phase, thereby capturing three distinct dynamic co-evolutionary processes that are driven by the servitization of manufacturing in this sector.

5.1 Pre-Servitization Phase of Commercial Aircraft MRO Innovation Ecosystem

Prior to OEMs' servitizing and complementing their product offerings with integrated services, the commercial aircraft MRO ecosystem comprised a variety of complex, but stable relationships among established actors in this sector. In line with this study's conceptual grounding in Adner and Kapoor's (2010) generic ecosystem scheme and Adner's (2017) structuralist conceptualisation of ecosystems, Figure 2 illustrates the alignment structure of multilateral set of actors towards the ISP's focal value proposition to customer airlines. Furthermore, Figure 2 represents an aggregate 2nd-order map of the commercial aircraft MRO innovation ecosystem and was created based on consenting and repeating concepts in individual translated ecosystem maps. In essence, Figure 2 summarises that ISPs' focal value proposition to airline customers, namely an insurance against aircraft asset downtime, as well as technical and operational know-how across various OEMs' products, is provided through a combination of tangible inputs, such as single repairs and original equipment, and intangible inputs, namely integrated MRO services and solutions, that in turn require a multiplicity of tangible and intangible supplies to ISPs and rely on complementing offers for value maximisation by airline customers.

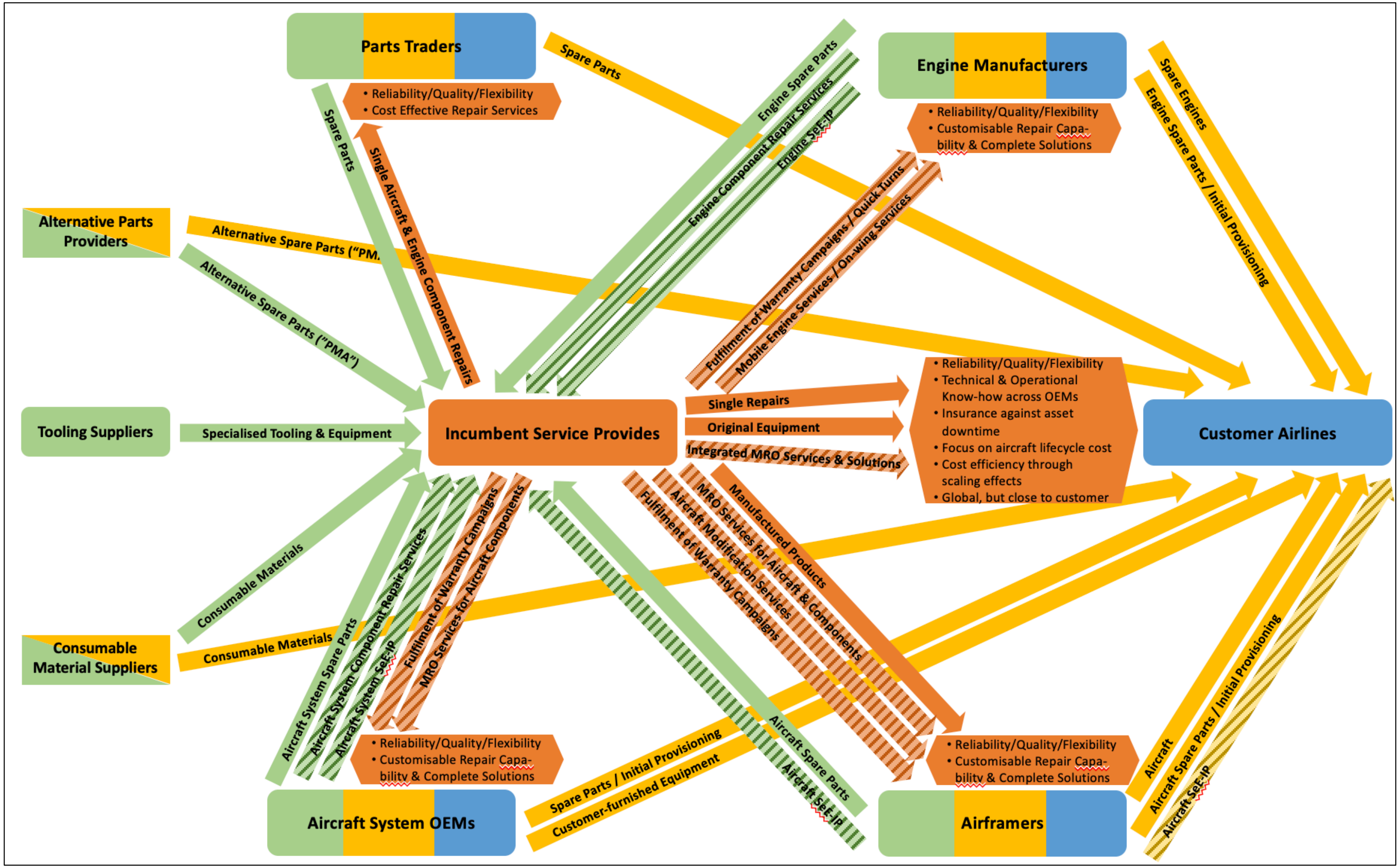


Figure 2: SVEL map of commercial aircraft MRO innovation ecosystem prior to OEM servitization

Interviewees' statements agreed that OEMs in the commercial Aircraft MRO innovation ecosystems are distinguished into three clusters based on the differentiating inputs that they contribute and the inherent technological expertise that they possess. The three clusters comprise (i) manufacturers of aircraft or *airframers*, (ii) *engine manufacturers* and (iii) *aircraft system OEMs*. Next to supplying ISPs with tangible inputs, such as spare parts for aircraft, engines, and systems, respectively, as well as intangible component repair services in the case of *engine manufacturers* and *aircraft system OEMs*, all three OEM clusters also provide ISPs with crucial access to manuals, data and technical documentation that is required to perform integrated MRO services on their products, which we collectively and hereinafter denote as Services-Essential Intellectual Property or SeE-IP. Furthermore, OEMs act as complementors by providing *customer airlines* directly with tangible products, such as aircraft, spare engines, and spare parts for initial provisioning at the time asset sale, and selective intangible SeE-IP, such as asset operational manuals, which collectively enhance the utility of ISPs' focal value proposition to *customer airlines*. Interviewees also consistently documented that OEMs also occupy a customer role in the bilateral relationship to ISPs by selectively receiving a limited, but highly customised scope of MRO services, such as the fulfilment of customer airline warranty campaigns for their products and mobile engine or on-wing services locally at customer airline sites. All things considered, the three OEM clusters occupy a triple role with respect to ISPs in the commercial aircraft MRO innovation ecosystem, namely that of the supplier, complementor and customer.

In addition to the three OEM clusters, interviewees also stated that *parts traders*, *alternative parts providers*, *tooling*, and *consumable material suppliers* have a significant role with respect to ISPs' focal value proposition in the ecosystem by supplying ISPs with essential tangible inputs, such as surplus and alternative spare parts, specialised tooling, and equipment, as well as consumable materials, respectively. Most interviewees observed that while all these additional ecosystem actors, except for tooling suppliers, occupy at least dual roles in the ecosystem by simultaneously providing tangible complements directly to *customer airlines*, *parts traders* occupy the triple role of supplier, complementor and customer by also selectively sourcing customised component repairs from ISPs. In essence, the commercial aircraft MRO innovation ecosystem comprises a complex network of diverse bilateral relationships that are interdependent and aligned towards the ISPs' focal value proposition towards *customer airlines*.

5.2 Servitization Phase of Commercial Aircraft MRO Innovation Ecosystem

As indicated above, servitization denotes the transformational process by which manufacturers innovate their internal capabilities and operational processes (Vandermerwe and Rada, 1988; Baines *et al.*, 2009). All ten interviewees confirmed that this transformation is observable in all three OEM clusters within the commercial aircraft MRO innovation ecosystem[8] to a varying degree and with different characteristics. Interviewees ID1 and ID11 noted that *engine manufacturers* pioneered complementing their products with integrated services about twenty years ago and witnessed that they advanced the transformation of

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[8] Ballantyne (2015) called the "OEM onslaught" by *airframers* and *engine manufacturers* in the aviation MRO sector a "worrying trend" for ISPs. Furthermore, Hemmerdinger (2018) reported that the majority of aviation executives that took part in a recent survey (Costanza and Prentice, 2018) expect OEMs to become the dominant actors in the aviation MRO sector.

their business models from just selling aircraft engines to offering "*thrust-as-a-service*" to customer airlines by developing major in-house engine repair and overhaul capabilities[9]. Interviewees ID2, ID9 and ID11 consistently reported that *airframers* started offering integrated services solutions complementing their products directly to customer airlines only about five to eight years ago, but more aggressively[10] and without building any noteworthy in-house repair capabilities. Regarding *aircraft system OEMs*, the interviewees were less specific about their entry timeframe into the commercial aircraft MRO sector but noted that depending on the specific OEM it typically occurred after pioneering *engine manufacturers* and before *airframers*. Albeit interviewees ID2 and ID9 agreed that *aircraft system OEMs*' MRO services scope is inherently limited to the aircraft systems and technologies for which they possess design and manufacturing expertise. While each of the three OEM clusters started to servitize at different points in time and followed different approaches because of their inherent and newly developed in-house capabilities and technological expertise, they all started to directly compete with ISPs in the commercial aircraft MRO innovation ecosystem, although only partially matching ISPs' value proposition covering the full scope of all aircraft systems across mixed aircraft fleets.

In addition to creating competitive tensions with ISPs by offering increasingly similar value propositions directly to customer airlines, all interviewees documented that OEMs actively reposition themselves, create new relationships and alter the nature of existing relationships with other actors in the commercial aircraft MRO innovation ecosystem. These structural changes and dynamic forces and effects were distilled into three dynamic co-evolutionary processes using the graphical coding process and captured in aggregate innovation ecosystem maps in SVEL terms. The three processes are denoted as A. OEMs' diversion of aftermarket value streams through exploitation of inherent competitive advantages, B. OEMs' increasingly restrictive management of SeE-IP, and C. competitive-cooperative relationships among OEMs undermining ISP's competitive ecosystem position.

A. OEMs' diversion of aftermarket value streams through exploitation of inherent competitive advantages

This dynamic co-evolutionary process taking place during the servitization phase of the commercial aircraft MRO innovation ecosystem was described by a total of six interviewees (ID4, ID5, ID6, ID8, ID11, ID12). Using the SVEL, Figure 3 captures the five steps of this evolutionary process by which OEMs exploit their inherent competitive advantages to divert aftermarket value streams away from ISPs.

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[9] Interviewee ID1 stated that *engine manufacturers*' transformation reached a point at which "*OEMs have no chance to make a profitable business case based on [new engine] production [alone].*" Furthermore, Neely (2007) and Howells (2000) suggest aircraft engine manufacturers, such as Rolls-Royce and General Electric, as role model organisations for the transformation from purely selling physical assets to offering "power by the hour" integrated solutions delivered through the physical asset.

[10] Gubisch (2018) and Derber (2019a) reported that Airbus plans to achieve ten billion US dollars in services revenue by the mid-2020s, effectively trebling current services revenue levels. For Boeing, Hemmerdinger (2017), Trimble (2018) and Shay (2019a) identified an even more aggressive target of fifty billion US dollars in services revenue by 2027 also representing a triplication of current figures.

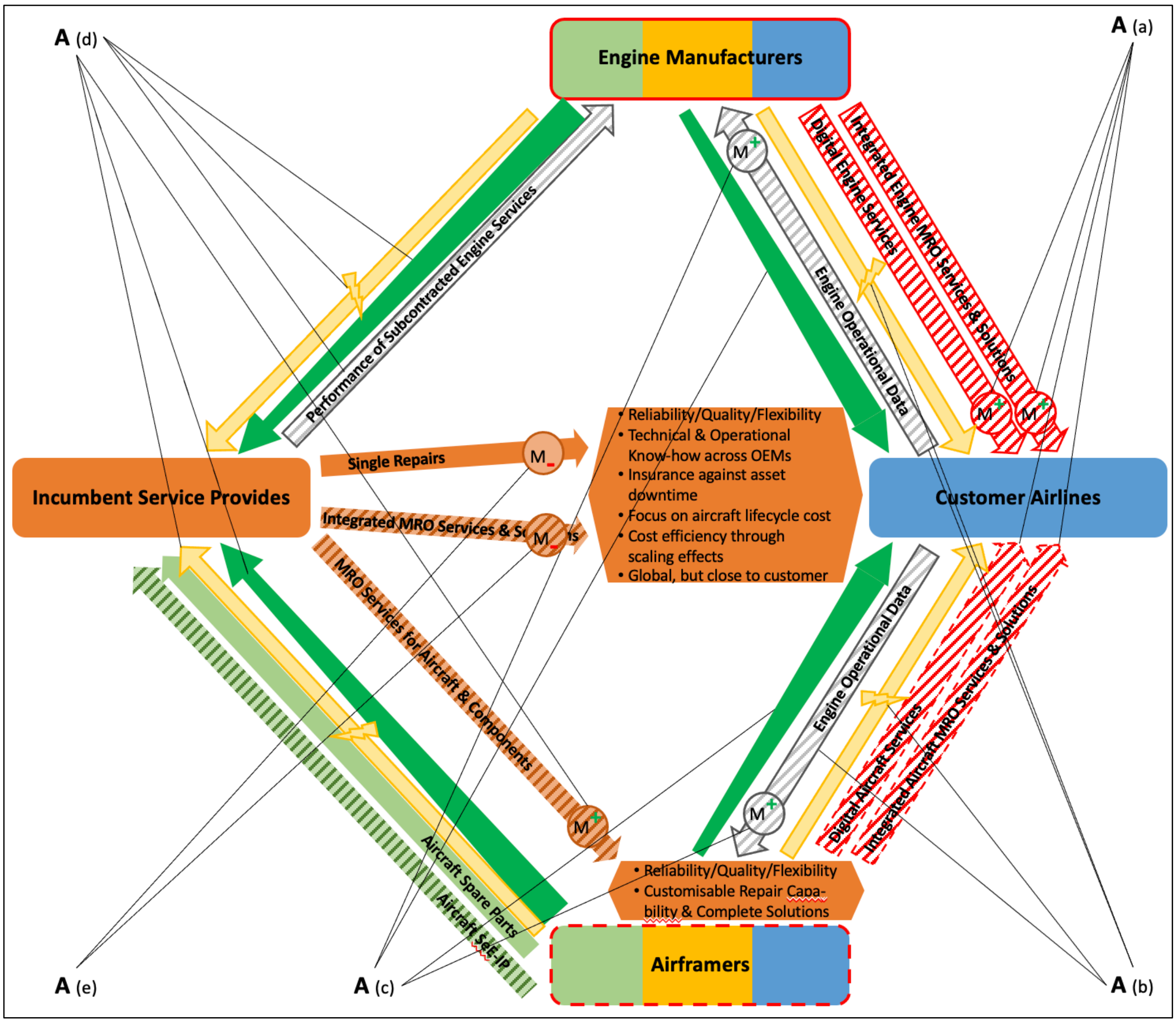

Figure 3: SVEL map of dynamic co-evolutionary process A. OEMs' diversion of aftermarket value streams through exploitation of inherent competitive advantages

In the first step, *airframers* and *engine manufacturers* exploit their inherent competitive advantage, namely earlier direct access to *customer airlines* during the aircraft and engine sales campaigns, to offer their own integrated aftermarket service solutions and digital service innovations (e.g. digital platforms/twins and predictive maintenance capabilities), in a bundle with their physical assets. This is highlighted by the emerging intangible goods flow symbols pointing from *airframers* and *engine manufacturers* to *customer airlines* that are labelled A (a) in Figure 3 and the red frames added to the respective OEM ecosystem actor role symbols. Interviewees noted that this competitive advantage enables *airframers* and *engine manufacturers* to increase their market share for various MRO services solutions to between thirty and eighty percent depending on market segment characteristics, such as type of customer airline and geographic region[11]. Interviewee ID2 and ID11 emphasised that particularly for newly introduced aircraft types and engine technology, OEMs additionally enjoy the benefit of being perceived as the low-risk option compared to ISPs.

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[11] Derber (2019c) found that aftermarket services offerings by aircraft engine manufacturers, such as CFM and Pratt & Whitney, are particularly popular with large low-cost airlines in emerging markets, such as IndiGO and AirAsia in Asia, as well as JetSMART in Chile.

In the second step, *airframers* and *engine manufacturers* that have invested in the required Information and Communication Technology (ICT) infrastructure gain and partially monopolise access to *customer airline* operational data, which is shown by the emerging intangible goods flow arrows pointing from *customer airlines* to both *engine manufacturers* and *airframers* which are labelled A (b) in Figure 3. Furthermore, the accompanying exertion of power symbol in reverse orientation illustrate the observation by Interviewees ID6, ID8, ID11 and ID12 that these two OEM clusters either force *customer airliners* to provide access to their operational data through usage terms and conditions in the aircraft or engine sales contracts or incentivise them by trading in access to valuable SeE-IP.

In the third step, *airframers* and *engine manufacturers* exploit insights gained from analysing customer airline operational data to refine their digital service innovations and to customise their integrated aftermarket services solutions to the individual needs of each *customer airline* (e.g. by advising of maintenance tasks predictively before asset failure occurs, optimising maintenance intervals, modifying product designs, etc.). Thereby, OEMs aim for lower overall life cycle costs of their products and creating additional value for *customer airlines*. In this context, interviewee ID12 highlighted a virtuous cycle that is visualised by the intangible goods flow growth and economic value capture increase symbols denoted by label A(c) in Figure 3. *Airframers* and *engine manufacturers* continuously modify product designs for higher fidelity collection and transmission of *customer airline operational data*[12], thereby further refining their digital service innovations, which, in turn, improves the effectiveness of its aftermarket services solutions and creates additional value for *customer airlines*.

In the fourth step, *airframers*, who completely lack the in-house capability to fulfil integrated aftermarket services, and *engine manufacturers*, whose capacity to perform the required services volume is typically capped, rely on finding suppliers to which these aftermarket services can be subcontracted. By bundling and tendering aftermarket services volumes of multiple *customer airlines*, *airframers* and *engine manufacturers* own substantial bargaining power of buyers that allows them to choose the lowest cost bidder, thereby considerably reducing the potential value capture potential of ISPs compared to them having direct relationship to *customer airlines*. This is represented by the emerging intangible goods flow arrow pointing from ISPs to engine manufacturers and the growth symbol attached to the intangible goods flow arrow pointing from ISPs to airframers, as well as the accompanying exertion of power and economic value capture decrease symbols, all of which are labelled A (d) in Figure 3.

As a final consequence of this servitization-driven process ISPs increasingly lose market share in direct services contracts with *customer airlines* (see shrinkage symbols attached to goods flow arrows from ISPs to *customer airlines* denoted by label A (e) in Figure 3). Interviewee ID5 extrapolated this process into the future by summarising the future risk to ISPs' ecosystem positioning as follows:

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[12] Gottlieb (2021) reported that new aircraft types, namely the Airbus A350 and Boeing 787, capture and share "*terabytes of* [customer airline operational] *data per day*", creating a fruitful ground for new services value propositions. However, this report also notes that ownership of this data remains a contested topic among potential new services providers and customer airlines.

> *"[There are] only two [major] aircraft manufacturers in the world, so they have a certain market power to shape business models. If they decided to sell the aircraft only in conjunction with a maintenance contract [in the future], that of course changes the ecosystem of the MRO industry."*

In summary, ISPs' competitive disadvantage relative to *airframers* and *engine manufacturers*, their inability to bundle integrated service solutions with products, the missing access to customer airline operational data and lack of ICT infrastructure to refine digital service innovations, the inherent incapability to modify product designs, and insufficiency to customise MRO services for optimum product life cycle costs result in aftermarket services volume being diverted away from ISPs[13]. Ultimately, airframers and aircraft engine manufacturers effectively reposition themselves between customer airlines and ISPs, while the bundling of individual customer airline aftermarket services volumes additionally curtails ISPs' value capture potential compared to the pre-servitization phase in the commercial aircraft MRO innovation ecosystem.

B. OEMs' increasingly restrictive management of SeE-IP

Six interviewees (ID1, ID2, ID5, ID7, ID11, ID12), consistently documented a second servitization-induced dynamic co-evolutionary process in the commercial aircraft MRO innovation ecosystem. This co-evolutionary process focuses on the effects of OEMs' increasingly restrictive management of SeE-IP towards ISPs in four steps and is visually captured in SVEL terminology in Figure 4.

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[13] This dynamic co-evolutionary process observed in the commercial aircraft MRO innovation ecosystem can be mapped onto Ulaga and Reinartz's (2011) resource-capability framework for designing and delivering combinations of goods and services. More specifically, steps A (a) and A (b) align to the manufacturers' unique resources "product sales force and distribution network" and "installed base product usage and process data", respectively. Furthermore, step A (c) can be related to manufacturers' distinctive capabilities "service-related data processing and interpretation" and "design-to-service".

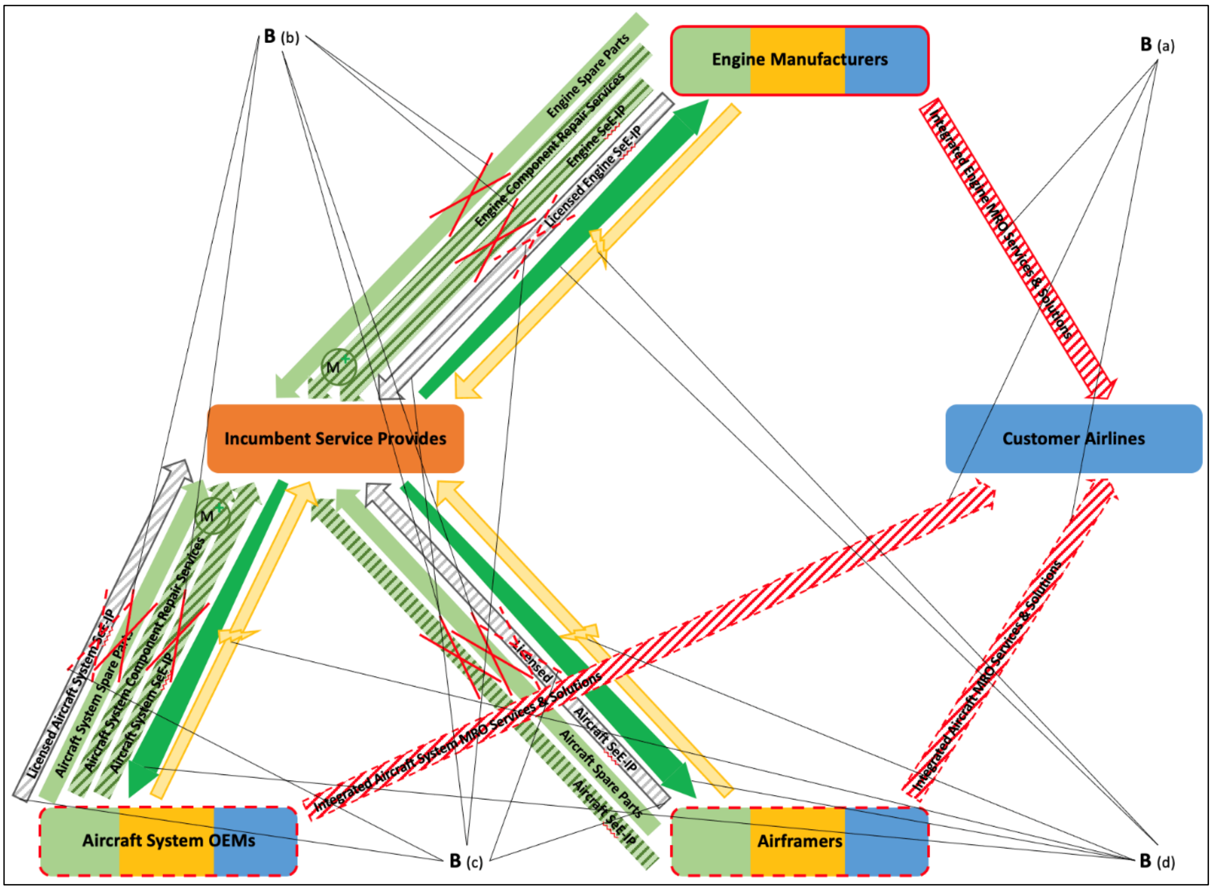

Figure 4: SVEL map of dynamic co-evolutionary process B. OEMs' increasingly restrictive management of SeE-IP

In the first step, all three OEM clusters (*aircraft system OEMs*, *engine manufacturers*, *airframers*) increasingly offer integrated service solutions directly to *customer airlines* in competition to ISPs. The emerging intangible goods flow arrows pointing from them to customer airlines labelled B (a) in Figure 4 illustrate this structural change in the innovation ecosystem. The visual distinction between dashed and solid borders of the emerging goods flow and corresponding OEM ecosystem actor role symbol specifically reflects interviewees' accounts that the approaches and degrees to which the three OEM clusters emulate ISPs' value proposition to *customer airlines* vary. As explained above, *engine manufactures* (solid border) fully match ISPs' value proposition with their integrated service solutions, while *airframers* and *aircraft system OEMs* (dashed border) only partially match ISPs' value proposition due to their inherent limitation to the aircraft types and systems for which they possess the design and manufacturing expertise.

In the second step and concurrently to their entry as providers of integrated MRO services solutions, *airframers*, *engine Manufacturers*, and *aircraft system OEMs* increasingly suspend access to spare parts and SeE-IP as illustrated by the solid crosses denoted by label B (b) in Figure 4. Interviewees ID1 and ID2 noted that this trend of ISPs being increasingly locked out from sourcing spare parts, using specialised tooling and accessing SeE-IP is particularly dominant on new engine products and aircraft systems, for which engine manufacturers and system OEMs handle SeE-IP restrictively compared to legacy products, for which SeE-IP was typically already available in the public domain during the pre-servitization phase of the commercial aircraft MRO innovation ecosystem.

In the third step, *airframers*, *engine manufacturers*, and *aircraft system OEMs* restrictively issue licenses for access to their proprietary SeE-IP to ISPs[14] as shown by the intangible emerging goods flows pointing from each of the three OEM clusters to ISPs and the dashed crosses illustrating partial restriction, which are labelled B (c) in Figure 4. Interviewees documented that by selectively and strategically issuing SeE-IP licenses, OEMs are effectively able to control the aftermarket by either allowing ISPs to access SeE-IP and offering repair services restrictively or by excluding ISPs from accessing SeE-IP, thereby forcing them to purchase repair services and spare parts from OEMs[15]. Interviewee ID1 summarised the characteristics of OEMs' strategic use of proprietary SeE-IP as ranging from restrictive licensing regimes materialising in "*OEM-branded*" services networks to fully closed regimes, in which manufacturers assume a monopolistic position in the commercial aircraft MRO innovation ecosystem, putting it in a nutshell:

> *"[The] OEM decides if we are there, or we are not there!"*

In the fourth step, ISPs are inhibited in their ability to capture value from offering their integrated services solutions to *customer airlines* by either being locked out from using SeE-IP and instead having to source spare parts and repair services from OEMs or by being forced to secure access to SeE-IP for their integrated services solutions through licensing from OEMs. This final step is illustrated by the yellow exertion of power symbol pointing from each of the OEM clusters to ISPs and the green increase in economic value capture symbol pointing in opposite direction (B (d)). Interviewee ID5 specified that when OEMs force ISPs into SeE-IP licensing agreements, ISPs typically face licensing fees and royalties that are set arbitrarily by OEMs[16]. Furthermore, interviewee ID11 explained that if ISPs are locked out from accessing SeE-IP instead and forced to source spare parts and repair services from *airframers*, ISPs will be exposed to commercial terms including year-on-year prices escalations set OEMs[17].

In summary, manufacturers use their monopolistic position, bestowed upon them by the ownership and strategic use of proprietary SeE-IP, as bargaining power of the suppliers to draw both market share and value capture away from ISPs.

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[14] Airbus was recently reported to attempt forcing ISPs into entering licensing agreements comprising royalty payments for access to its technical data (Shay, 2019b). Furthermore, large aircraft system OEM Collins recently issued an MRO licensing agreement for aircraft engine nacelles to Lufthansa Technik AG, thereby allowing the latter to access SeE-IP, as well as spare parts and specialised tooling (Aerospace Technology, 2020). In another instance, Pratt & Whitney provided access to SeE-IP for its newest engine generation, namely the GTF, to Korean Air's maintenance and engineering division for the purpose of building disassembly, assembly and test capabilities for the PW1100G-JM engine (Chuanren, 2021).

[15] Interviewees' accounts of the effects of OEMs' restrictive management of SeE-IP coincides with an industry survey involving about one hundred aviation professionals at senior executive and director level (Costanza and Prentice, 2018). This report found that the majority of respondents ranked "*usage restrictions on existing IP and licensing*" highest with respect to how OEMs will grow their presence in the commercial aircraft aftermarket sector (Costanza and Prentice, 2018, p. 14).

[16] Hanke and Koenen (2019) report that the aforementioned Airbus initiative to force ISPs into licensing agreements for access to SeE-IP aimed at royalties in the amount of 0.5% of ISPs' MRO turnover in 2019 with a rise to 1,0% in 2020 and 1,5% beyond. They furthermore estimate that if airframers were to charge royalties in the amount of 2% of MRO turnover generated by ISPs, they could capture additional economic value of up to 1.6 billion Euros on a recuring basis.

[17] Costanza and Prentice (2018) also agree with these interviewee narratives by stating that IP control enables OEMs to gain an economic competitive advantage over ISPs by driving their material usage and prices up.

C. *Competitive-cooperative relationships among OEMs undermining ISP's competitive ecosystem position*

The third servitization-driven dynamic co-evolutionary process in the commercial aircraft MRO innovation ecosystem was described by four interviewees (ID2, ID7, ID8 and ID9). In this process, structural changes and dynamic forces and effects in the competitive-cooperative relationships among OEMs undermine ISPs' competitive position in the innovation ecosystem.

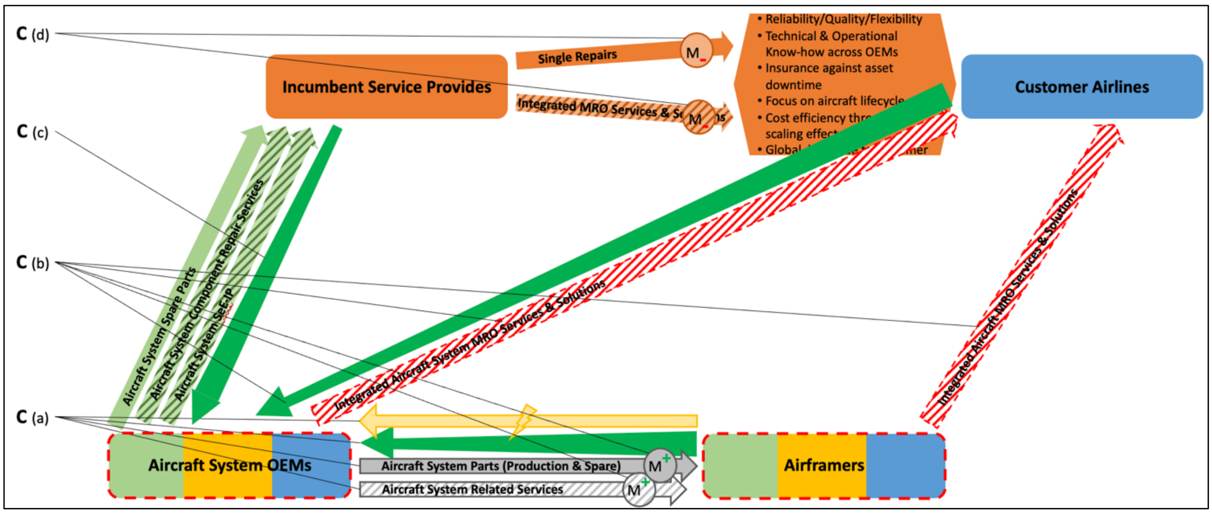

Figure 5: SVEL map of dynamic co-evolutionary process C. - Competitive-cooperative relationships among OEMs undermining ISPs' competitive ecosystem position

In the first step, *airframers* increasingly use new aircraft product platforms to increase the bargaining power of the buyer in negotiations with *aircraft system OEMs* in order to secure low-cost access to aircraft system OEMs' supply of production parts and services for integrated aircraft systems, such as landing gears, engine nacelles, avionics, and composite structures. This is highlighted by the two arrows representing emerging tangible and intangible goods flow arrows pointing from *aircraft system OEMs* to *airframers*, as well as the accompanying yellow exertion of power and green decrease in economic value capture arrows pointing in the opposite direction (see C (a) in Figure 5). Interviewee ID2 noted that this dynamic in the relationship between *airframers* and *aircraft system OEMs* in some cases takes a cooperative nature in the form of risk-sharing partnerships[18], which provide *aircraft system OEMs* design responsibility, as well as exclusivity on the aircraft platform and aftermarket, in trade for conceding low-cost commercial conditions for production parts and services to *airframers*. On the other hand, interviewees ID7 and ID8 highlighted that the relationship between *airframers* and *aircraft system OEMs* also adopts a competitive nature in other cases, particularly when *airframers* face large, consolidated tier-1 suppliers with considerable design and manufacturing expertise across several aircraft systems[19].

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[18] Wagner and Baur (2015) developed a risk-sharing partnership (RSP) model and cite several high profile new product development programmes in the commercial aerospace sector that involved RSP contracts between airframers and tier-1 OEMs, namely the Airbus A350 XWB and Boeing 787 programmes.

[19] Josephs (2019) reported the recent high-profile merger of two large aircraft system and defence OEMs, namely United Technologies and Raytheon into Raytheon Technologies, which is expected to have sufficient leverage "*to push back on big customers like Boeing, Airbus and Lockheed Martin in terms of pricing, aftermarket work and intellectual property.*"

In the second step, *airframers* follow *aircraft system OEMs* in offering integrated aftermarket services solutions complementing their aircraft sales to *customer airlines* in competition to ISPs. This is shown by the emerging red intangible goods flow arrows pointing from *aircraft system OEMs* and *airframers* to *customer airlines* (see C (b)). Interviewee ID9 furthermore emphasised that *airframers* chose to exploit the low-cost commercial terms and conditions for the supply of production parts and services previously conceded by *aircraft system OEMs* to realise their competing value propositions instead of developing any in-house services fulfilment capability for aircraft systems on their own, which is indicated by the two goods flow growth symbols (see C (b))Figure 5. Interviewee ID9 construed this dynamic in the relationship between airframers and aircraft system OEMs as follows:

> *"Airframers and aircraft system […] OEMs had a gentlemen's agreement, namely that airframers would use low pricing enforced through aircraft platform for production only. Airframers broke this agreement by using commercial terms for the aftermarket as well."*

Concurrently, *airframers* impose standard aftermarket policies for their respective aircraft platforms, such as Airbus' Supplier Support Conditions[20] and Boeing's Product Support and Assurance Agreement[21], thereby regulating *aircraft system OEMs*' services provision to *customer airlines* and further exacerbating their ability to capture economic value from supplying aftermarket services in support of their products to *customer airlines*. This is illustrated by the green decrease in economic value capture symbol pointing from *customer airlines* to *aircraft system OEMs* (see C (b)).

In the third step, *aircraft system OEMs* increased catalogue list prices for spare parts and repair services, as well as raise royalties for access to SeE-IP for ISPs in order to compensate for the loss in value capture from providing *airframers* with production parts and services at low-cost commercial conditions and from supplying integrated services solutions to *customer airlines* subject to *airframer* imposed standard aftermarket policies. This development is illustrated by the green economic value capture increase symbol pointing from ISPs to *aircraft system OEMs* (see C (c) in Figure 5. Interviewees ID8 and ID9 emphasised that ISPs are effectively subject to separate and higher commercial terms and conditions for access to spare parts, services and SeE-IP supplied by aircraft system OEMs.

Ultimately in the fourth step, ISPs suffer a loss of competitiveness relative to the pre-servitization phase of the commercial aircraft MRO innovation ecosystem due to the higher relative cost basis compared to both *airframers* and *aircraft system OEMs*. This materialises in decreasing market share relative to *airframers* and *aircraft system OEMs*, which is shown by the respective goods flow shrinkage symbols labelled C (d) in Figure 5, particularly for new

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[20] According to the publicly available Airbus General Terms and Conditions of supply and use of Technical Data, Supplier Support Conditions or SSCs are defined as "*the agreement between Airbus and the Supplier, based on the conditions set out in the "World Airlines Support Guide", which includes warranties, and when applicable, service life policies for a Supplier Part*" (Airbus, 2021).

[21] A purchase agreement between Boeing and United Airlines for the sale and purchase of Boeing 737-900ER aircraft dated 19 February 2010 that was filed with the Securities and Exchange Commission notes under article 3.2 that "*if a product support and assurance agreement (PSAA) with a supplier is effective, then such supplier's Supplier Spare Parts pricing will escalate pursuant to the provisions of such PSAA*" (Boeing and United Airlines, 2010).

aircraft types for which competitive-cooperative relationships among *airframers* and *aircraft system OEMs* prevail. Interviewee ID9 suspects that ISPs may need to turn away from *customer airline* and shift their focus on relationships with OEMs in order compensate for the loss in market share for integrated MRO services and solutions.

6 Conclusions

The primary goal of this paper is to introduce SVEL, which is a new standardised visual language for the capture and analysis of dynamic co-evolutionary processes affecting industrial organisation and interfirm alignment of innovation ecosystems. The introduction of SVEL represents a methodological contribution to the ecosystem research by closing a gap in the literature of missing visual methods that effectively capture ecosystem static structure, structural changes, and dynamic forces and effects. We believe that SVEL is a valuable contribution to the methods toolbox of researchers, practitioners, and policy makers for the evaluation of dynamic processes in evolving innovation ecosystems and the deduction of strategic implications.

Furthermore, we demonstrate SVEL's effectiveness by means of a case study in the commercial aircraft MRO sector. That ecosystem was chosen as an appropriate proving ground for SVEL because it exhibits symptoms of considerable change in industrial organisation because of manufacturers' engagement in the transformational process of servitization, in which they innovate their internal capabilities and operational processes in order to complement their products with integrated services solutions (Baines *et al.*, 2009). By seeking direct customer access, manufacturers reposition themselves, enter into competition with ISPs and cause alignment structures to change in the innovation ecosystem (Wise and Baumgartner, 1999; Burton *et al.*, 2016; Huikkola *et al.*, 2020). Using the SVEL, we were able to capture and analyse three dynamic co-evolutionary processes in the commercial aircraft MRO innovation ecosystem that highlight the important role of access to customer operational data in a product's development towards optimised lifecycle cost (process A), OEMs' strategic leverage over ISPs through ownership of SeE-IP (process B), and the effects of competitive-cooperative relationships among OEMs on ISPs' competitiveness (process C).

We ensured that scientific rigour was practiced in the development of the SVEL method by building on existing visual methods in the ecosystem mapping cluster (Urmetzer, Gill and Reed, 2018; Ghazinoory *et al.*, 2020), relating to the ecosystem elements defined in Adner's (2017) structuralist approach, and following the collaborative graphical coding process actively involving research participants (Bell and Davison, 2013). Furthermore, the use of multiple sources of evidence and the compilation of chronological sequences when analysing the structural changes and dynamic effects of servitization in the commercial aircraft MRO business ecosystem established construct and internal validity of our SVEL demonstration case study (Yin, 2014).

However, having conducted a single revelatory case study and having demonstrated SVEL's effectivity in one industrial setting means that this new method's generalisability remains to be tested. We propose that future research applies the SVEL method to other settings exhibiting structural changes in industrial organisation and develops its visual nomenclature further where necessary. For instance, the SVEL could be extended to devise visual representations for specific artefacts in innovation ecosystems, whose conceptual importance was highlighted by Granstrand and Holgersson (2020). The case study in the commercial aircraft MRO innovation ecosystem, for instance, pointed to the exemplary role of intellectual property in the form of SeE-IP in OEMs' competitive advantage over ISPs, for which specific symbols could be developed.

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