

**VISUALISING DYNAMICS IN INNOVATION ECOSYSTEMS: A NEW
METHOD AND DEMONSTRATION IN THE COMMERCIAL AIRCRAFT
MRO ECOSYSTEM**

Alexander Moerchel*

Institute for Manufacturing, University of Cambridge, Cambridge, UK
amm211@cam.ac.uk

Frank Tietze

Institute for Manufacturing, University of Cambridge, Cambridge, UK
frank.tietze@eng.cam.ac.uk

Florian Urmetzer

Institute for Manufacturing, University of Cambridge, Cambridge, UK
ftu20@cam.ac.uk

ABSTRACT

A review and evaluation of 34 visual methods for ecosystem research revealed that there was no method to visually capture the dynamics of innovation ecosystems. To fill this gap, we develop and demonstrate a new visual method, the ecosystem dynamics mapping (EDM) language, for capturing and analysing (i) structural elements, (ii) structural changes and (iii) dynamic forces in evolving innovation ecosystems over time.

To develop the EDM language we applied the design science research methodology (DSRM), conducting a demonstration case in the commercial aircraft maintenance, repair and overhaul (MRO) sector. The sector's innovation ecosystem is currently experiencing profound dynamics, with a focus in this paper specifically on dynamics that result from servitizing manufacturers. For the demonstration case, we conducted 18 in-depth semi-structured interviews with 10 decision-makers at a large incumbent service provider, producing a total of 13 ecosystem dynamics maps.

This study attempts to make three contributions. First, it identifies, summarises and evaluates the existing ecosystem visualisation methods. Second, we introduce the new EDM language for visualising the dynamics of innovation ecosystems. Third, we present an EDM demonstration case validating its applicability. The EDM language

can be used by researchers, practitioners and policy-makers to better understand how innovation ecosystems are changing, thereby supporting strategic decision-making or policy interventions.

Keywords

Ecosystem mapping, visual methods, innovation ecosystems, ecosystem dynamics, servitization, incumbent service provider, services-essential intellectual property

1. INTRODUCTION

Starting from Moore's (2006, 1993) analogy between the co-evolution of species in natural ecosystems and companies co-evolving around innovations in business ecosystems, the ecosystem paradigm has gained traction with researchers and practitioners. This rise in popularity is due to its ability to capture and analyse value exchanges among a multilateral set of firms that are aligned towards a focal value proposition (Adner, 2017), and because it represents 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). Concurrently, a plethora of ecosystem-specific visualisation methods have been proposed to facilitate the capture and analysis of inter-firm collaboration and competition, as well as value exchanges and alignment towards a common value proposition, both quantitatively (e.g. 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 instrumental property to activate a human's high capacity for visual perception, while at the same time rapidly and economically reducing complex data streams (Johnson et al., 2006; van Wijk, 2005) typically found in the analysis of ecosystems.

However, after systematically identifying and critically reviewing existing visualisation methods for the analysis of ecosystems in the management sciences, we 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 they focus on visually representing dynamic processes and structural changes occurring in ecosystems over time. A gap remains for a visual method that combines both requirements, thus enabling researchers and practitioners to capture and analyse dynamic processes affecting industrial organisation and inter-firm alignment for theorisation about ecosystem dynamics and more informed decision-making, respectively. To that end, we pose the following methodological research question: *How can static structure, structural changes and dynamic forces and effects in evolving innovation ecosystems be visually captured to analyse dynamic processes affecting industrial organisation and inter-firm alignment over time?*

We address this methodological gap by proposing a new visual method, namely, the ecosystem dynamics mapping (EDM) language, which enables the capture and analysis of an evolving innovation ecosystem's static structure, structural changes, as well as dynamic forces and effects occurring over time. Specifically, EDM allows the visualisation of ecosystem actor roles, goods flows, value propositions, temporal changes to actor roles and goods flows, and the exertion of leverage or power between actors. Our method builds on existing visualisation methods for value exchanges in innovation ecosystems (Urmetzer et al., 2018a) and is conceptually grounded in the state-of-the-art in ecosystem research (Adner and Kapoor, 2010; Granstrand and Holgersson, 2020). The EDM language represents a methodological contribution that advances the methods toolbox of researchers and practitioners for the interpretation of dynamic processes in evolving innovation ecosystems, namely, the longitudinal processes that are empirically observable in the exchange of actions and responses between firms pursuing market opportunities (Chen and Miller, 2012), through capturing and analysing structural changes, dynamic forces and effects over time. We hereby also answer calls for further research into theory-based methods that support researchers and practitioners in the development of process- and practice-oriented theories and the effective management of technological innovation (Bell and Davison, 2013; Romme and Holmström, 2023).

In this paper we furthermore demonstrate the functionality of the EDM language in the empirical context of the commercial aircraft maintenance, repair and overhaul (MRO) sector. This sector recently experienced a period of structural evolution because of manufacturers increasingly offering services that complement their products (Michaels, 2018; Pozzi, 2020; Shay, 2019). By pursuing this transformational process

denoted as the servitization of manufacturing (Baines et al., 2017; Vandermerwe and Rada, 1988), manufacturers generally strive for differentiation and continuous revenue from their installed product base (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, increasingly 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 existing providers of integrated MRO services incumbent service providers¹, or ISPs, in contrast to servitizing OEMs, which we consider ‘new entrants’ in the commercial aircraft MRO sector. We define the former as established service firms that have previously (often over a long time) developed the necessary capabilities, infrastructure and relationships with both suppliers and customers to deliver integrated services for the maintenance of physical assets manufactured by third parties.

In the following sections, we first present the systematic identification and critical review of existing visual methods for the analysis of ecosystems in the management sciences (Section 2). Subsequently, we describe the research approach based on the design science research methodology (DSRM) for the development of our new visual method (Section 3) and introduce the EDM language, with its constituting elements (Section 4). This section also comprises a demonstration of the EDM language on the basis of aggregate ecosystem maps from the empirical context of the aerospace industry. The paper concludes with a discussion, statement of the limitations, and recommendations for future research (Section 5).

2. LITERATURE REVIEW: VISUALISATION METHODS FOR ECOSYSTEM RESEARCH

Applying the ecosystem lens as a conceptual method for delineating dynamic processes in industrial organisation inherently requires researchers and practitioners to effectively handle a plethora of constructs with complex interrelationships.

¹ The term incumbent service provider was previously used in literature related to the telecommunication sector and typically denotes companies that have previously licensed a frequency spectrum from governmental agencies, which have built up the necessary infrastructure and which have an existing customer base for wireless and cellular services as opposed to new entrant service providers (Mukherjee, 2019; Nguyen et al., 2011). However, we are not aware of any previous studies using this term in the analysis of dynamics between manufacturers and pure service firms in the context of servitization.

Specifically, these include the various basic elements, namely, actors, artefacts and activities, as well as the institutions surrounding and multilateral relations among them (Granstrand and Holgersson, 2020), which cannot be reduced to aggregate bilateral relationships but which necessitate the consideration of interdependencies (Adner, 2017). Furthermore, accounting for temporally ordered information and evolutionary trends is essential in the holistic and complete analysis of ecosystems in the management sciences (Battistella et al., 2013; Trier, 2008). While this concentration of constructs offers a powerful conceptual framework for the capture and analysis of dynamic processes when industrial organisation changes, the resulting complexity in data collection and analysis challenges the natural human cognitive abilities of researchers and practitioners (Bach et al., 2014). This calls for new methods that facilitate the collection and analysis of empirical data for the purpose of theory building and strategy formulation.

2.1. Visual methods in the management sciences and for ecosystem research

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 not be accessible when relying on established methods that are exclusively based on language (Bell and Davison, 2013). Furthermore, visualisation helps researchers and practitioners to digest a multitude of constructs and the respective complexity of interdependencies, economically and efficiently, by capturing them in a medium that caters for the unique abilities of human visual capacity (Johnson et al., 2006; van Wijk, 2005). At a very basic level, visualisations, such as written symbols, labels, visual and spatial layouts, which are hereafter 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 et al., 2005).

However, several scholars suggested that the process of effectively and efficiently discovering new knowledge in complex information and data through visualisation requires researchers and practitioners to interact with applied methods and to continuously adjust their specifications for the purposes of extending their human cognitive abilities and knowledge generation (Johnson et al., 2006; van Wijk, 2005).

Several scholars have called for future work on theory-based visual methods and tools that support researchers and practitioners in the development of process- and practice-oriented theories and the effective management of technological innovation (Bell and Davison, 2013; Romme and Holmström, 2023).

2.2. Review of the current state-of-the-art in ecosystem visualisation

We conducted a systematic identification and a critical review of relevant literature to ascertain the state-of-the-art in existing visualisation methods for capturing and analysing dynamics and evolution in ecosystems and to evaluate their efficacy with respect to the objective of this study.² The systematic search was executed using the Scopus electronic database and searching for the keywords ‘ecosystem’, ‘dynamic’ and ‘evolution’, in combination with either ‘visualisation’ or ‘mapping’.³ As illustrated in the overview of the literature review process in Fig. 1, the initial search returned 1,816 records of peer-reviewed, scientific journal articles, conference proceedings and books. The subsequent application of inclusion criteria, namely, the limitation to journal articles and conference papers to ensure the quality of the reviewed literature, as well as the restriction to relevant subject areas, further reduced the search results to 762 records. Screening their titles and abstracts led to the exclusion of any records unrelated to the objectives of this study (Xiao and Watson, 2019) and further decreased the search results to 30 records, as shown in Fig. 1. Finally, a subsequent backwards and forwards search for studies that were cited by, or cite, the already identified records (Xiao and Watson, 2019) revealed an additional 4 relevant studies, bringing the total number of relevant records to 34.

² Conducting a systematic search and screening of the extant literature based on broad search terms maximised the initial number of identified relevant visualisation methods and minimised bias by ensuring a replicable, scientific and transparent process (Grant and Booth, 2009; Snyder, 2019; Tranfield et al., 2003). The subsequent critical review manually revealed weaknesses and inconsistencies in these relevant visualisation methods by comparing them with a set of criteria that are established by the reviewer based on the study’s objectives (Pare et al., 2015; Xiao and Watson, 2019).

³ Combining keywords with Boolean operators ‘AND’ and ‘OR’ to join concept domains and include synonyms (Xiao and Watson, 2019) resulted in the following search strings: TITLE-ABS-KEY (‘ecosystem’ AND ‘dynamic’ AND (‘visuali?ation’ OR ‘mapping’)); TITLE-ABS-KEY (‘ecosystem’ AND ‘evolution’ AND (‘visuali?ation’ OR ‘mapping’)). Scopus was chosen because it has developed into a world-leading citation database that has been widely used in meta-analysis-related studies since its launch in 2004 (Zhu and Liu, 2020).

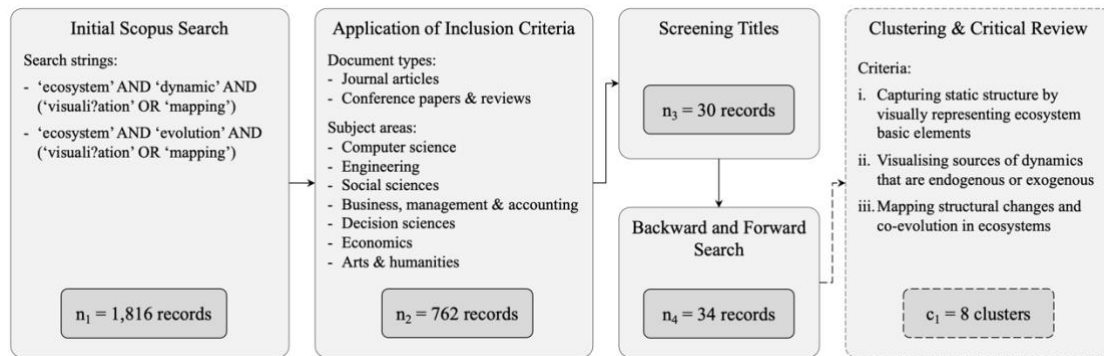


Fig. 1: Overview of systematic identification and critical review process of visualisation methods for ecosystem research

After systematically identifying and screening the 34 relevant journal articles and conference proceeding papers, the visualisation methods presented therein were clustered and critically reviewed with respect to 3 relevant criteria for the objective of this study. Clustering was accomplished based on the methodological affiliation that is documented in each study.⁴ Furthermore, the critical review was accomplished with respect to the following criteria: (i) capturing static structure by visually representing the ecosystem’s basic elements (i.e. actors, activities, artefacts, positions and links), (ii) visualising sources of dynamics that are either endogenous or exogenous to the ecosystem, and (iii) mapping structural changes and co-evolution in ecosystems. Scoring of each of the 34 visualisation methods with respect to the 3 evaluation criteria was based on a 5-point Likert scale.⁵ Furthermore, a single composite index was subsequently calculated as a weighted average, whereas scores for criteria (ii) and (iii) (mentioned above) counted twice to account for the conceptual focus of this study on capturing dynamics in evolving innovation ecosystems. Table 1 summarises the findings from the systematic search and critical review of existing visualisation methods for ecosystem research by listing eight method clusters ranked by their average

⁴ For example, Phillips and Srari (2018) state in their research design section that ‘*during these 23 interviews, draft ecosystem maps were made, supplemented by other evidence*’ (Phillips and Srari, 2018, p. 5), which enabled the affiliation of this study to the ecosystem mapping cluster.

⁵ A five-point Likert scale was used because it represents a scientifically accepted and validated technique for ranking an item’s quality (Allen and Seaman, 2007; Joshi et al., 2015). For the critical review of the visualisation methods with respect to the three criteria, the 5-point Likert scale ranges from the low extreme value, ‘very weak focus’ (i.e. numeric value ‘1’), to the high extreme value, ‘very strong focus’ (i.e. numeric value ‘5’), in equidistant intervals, with the central option being ‘neutral’ (i.e. numeric value ‘3’). The logical sequence, close interrelatedness, and coherence of the three evaluation criteria furthermore enabled the transformation of evaluation scores into a single composite index for each visualisation method (Joshi et al., 2015).

composite indices, documenting their respective strengths and weaknesses, and listing the respective studies from the extant literature.

2.3. Identifying the methods gap in the current state-of-the-art in ecosystem visualisation methods

The critical review of the state-of-the-art of visual methods for ecosystem research (as summarised in Table 1) suggests that five of the eight method clusters achieved a composite index close to or above 3.0, which suggests that none of the reviewed visual methods came close to meeting all the three evaluation criteria listed in Subsection 2.2. This set of method clusters comprises, in descending order based on their composite indices, VM1 (ecosystem mapping), VM2 (ecosystem pie model), VM3 (social network analysis/co-citation network analysis), VM4 (path/evolution mapping) and VM5 (node-edge network analysis).

Specifically, visualisation methods in cluster VM1, such as Ghazinoory et al. (2020) and Urmetzer et al. (2018a), excel at evaluation criterion (i) by providing detailed representations of basic ecosystem elements, namely, actors, activities, artefacts and the relationships among them. However, VM1 methods satisfy evaluation criterion (iii) to a lesser degree because they only implicitly capture structural changes in ecosystems through juxtaposing snapshots of ecosystem maps at discrete time intervals. Furthermore, method cluster VM1 struggles with evaluation criterion (ii) because of its inability to effectively represent sources of dynamics in the ecosystem.

Furthermore, method cluster VM2, containing the ecosystem pie model (EPM) tool (Talmar et al., 2020), also performs well with respect to evaluation criterion (i), and it achieves this with its unique ability to capture intricate relationships between ecosystem-relevant constructs at actor level, such as resources, value creation and incurred risks pertaining to equitable value capture. To satisfy evaluation criteria (ii) and (iii), however, method cluster VM2 would require separate documentation to capture structural changes and to infer sources of dynamics from the juxtaposition of intricate representations of inter-actor relationships.

Visualisation methods in the two closely related method clusters, VM3 and VM5, such as Basole et al. (2018) and Trier (2008), perform well in relation to evaluation criterion (i) because the standardised use of nodes and edges enables them to efficiently

Table 1: Summary of findings from the systematic search and critical review of existing visualisation methods for ecosystem research

Cluster ID	Cluster Name	No. of Papers	Method	Strengths	Weaknesses	Relevant Studies	Composite Index ^a	Cluster Average ^b
VM1	Ecosystem mapping	7	Qualitative	<p>Detailed representation of ecosystem actors, artefacts, activities and institutions using different shapes, sizes, colours and labels to distinguish between types and roles.</p> <p>Clear depiction of relationships using separate set of symbols, but mainly arrows or edges of varying forms, sizes or colours.</p> <p>Allows explicit capture of ecosystem static structure at discrete points in time.</p>	<p>The capture of time-dependent structural changes is implicit by comparing snapshots of the ecosystem at discrete time intervals.</p> <p>Representation of dynamic forces and effects is limited to analyses of 2D plots of time-dependent variables measured as the ecosystem evolves.</p>	<p>Ghazinoory et al. (2020)</p> <p>Urmetzer et al. (2018a)</p> <p>Lin and Lin (2006)</p> <p>Lungu et al. (2010)</p> <p>Benitez et al. (2020)</p> <p>Phillips and Strai (2018)</p> <p>Lüftenegger et al. (2013)</p>	<p>3.9</p> <p>3.4</p> <p>3.1</p> <p>3.0</p> <p>2.9</p> <p>2.7</p> <p>2.7</p>	3.1
VM2	Ecosystem pie model	1	Qualitative	<p>Capture of relationships between actor-level constructs, such as resources, activities, value addition and capture, between actors.</p> <p>Guided step-by-step systematic analysis of ecosystem static structure leading to a holistic picture of actors' dependencies, value addition and value capture, as well as the resulting ecosystem risks.</p> <p>Clustering of ecosystem actors into users (or customers), direct chain adopters (or focal firm and its suppliers) and subsystems (or complementors).</p>	<p>Explicit capture of structural changes in ecosystems (e.g. changes in the actor's roles, emergence of new relationships) requires separate documentation of these constructs as the EPM tool is being populated.</p> <p>The capture and analysis of dynamics and longitudinal developments in ecosystems need to be inferred from juxtaposing EPM charts created at different levels during ecosystem maturity.</p>	<p>Talmar et al. (2020)</p>	3.1	3.1

Cluster ID	Cluster Name	No. of Papers	Method	Strengths	Weaknesses	Relevant Studies	Composite Index ^a	Cluster Average ^b
VM3	Social/co-citation network analysis	4	Quantitative, qualitative and mixed	Actors, artefacts, activities and institutions are clearly represented by nodes and a standardised set of properties (e.g. node size, colour, rings, etc.).	Capturing structural changes and dynamic processes relies on longitudinal simulations or contrasting snapshots of social networks at discrete time intervals.	Trier (2008)	3.6	3.0
				Relationships among actors and artefacts are clearly represented by edges or links, whereas properties (e.g. thickness, colour, labels) are used to capture additional information.	Identifying structural changes is cognitively challenging and obscure for large social networks involving large numbers of nodes and edges.	Teixeira et al. (2016)	3.3	
				Representation of static structure of social networks can be complemented by quantitative measures of node and edge properties (e.g. network size, density, centrality, etc.).		Réale et al. (2020)	2.7	
						Sloane and O'Reilly (2013)	2.3	
VM4	Path/evolution mapping	3	Quantitative, qualitative, and mixed	Structural ecosystem changes are explicitly captured by external representations of evolutionary paths of actors or artefacts over time.	Effective representation of spatial structure and relationships among actors, artefacts, activities and institutions is traded for capturing temporal causalities.	Liu et al. (2020)	3.4	3.0
				Dynamic forces and effects are represented by relationships between the activities of one actor and another actor or artefact.	The external representations and overall logic of capturing ecosystems lack standardisation.	Sánchez-Núñez et al. (2020)	2.7	
						Pagano and Neubert (2015)	2.7	

Cluster ID	Cluster Name	No. of Papers	Method	Strengths	Weaknesses	Relevant Studies	Composite Index ^a	Cluster Average ^b
VM5	Node-edge network analysis	12	Mainly quantitative and mixed	<p>Standardised representation of actors and relationships by nodes and edges.</p> <p>Node sizes, colours and edge thickness are used to capture additional information about actors, artefacts and relationships.</p> <p>Ecosystem structure can be quantitatively analysed using metrics (e.g. centrality, connectedness, density, etc.).</p>	<p>The limitation of external representations to nodes and edges does not allow for an explicit representation of dynamic forces and effects.</p> <p>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.</p>	<p>Basole et al. (2018)</p> <hr/> <p>Huhtamäki et al. (2013)</p> <hr/> <p>Rothe et al. (2018)</p> <hr/> <p>Natsukawa et al. (2021)</p> <hr/> <p>Briscoe et al. (2011)</p> <hr/> <p>Nischak and Hanelt (2020)</p> <hr/> <p>Basole and Karla (2011)</p> <hr/> <p>Battistella et al. (2013)</p> <hr/> <p>Faber (2017)</p> <hr/> <p>Aldea et al. (2018)</p> <hr/> <p>Yu et al. (2020)</p> <hr/> <p>Cavaller et al. (2020)</p>	3.9	2.9
VM6	System dynamics	2	Quantitative	<p>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.</p>	<p>No explicit visualisation of actors, artefacts, activities or institutions in the ecosystem or relationships among them.</p> <p>Ecosystem structural changes are only implicitly captured through visualisation of the dynamic evolution of ecosystem metrics.</p>	<p>Yung et al. (2022)</p> <hr/> <p>Auerswald and Dani (2017)</p>	2.7	2.5

Cluster ID	Cluster Name	No. of Papers	Method	Strengths	Weaknesses	Relevant Studies	Composite Index ^a	Cluster Average ^b
VM7	Agent-based modelling	3	Mainly quantitative and 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. The capture and analysis of dynamic processes is limited to 2D plots of time-dependent ecosystem metrics (e.g. population sizes). Structural changes are represented implicitly and rely on analysis of 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	
VM8	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 Composite index calculated as a weighted average of individual scores for each evaluation criterion; criterion (i) counts once, and criteria (ii) and (iii) count twice.

^b The cluster average is the mean value of the individual composite indices in the method cluster.

represent large and complex networks of actors and artefacts, albeit to a limited extent with respect to encoding additional attributes. Concerning evaluation criterion (iii), method clusters VM3 and VM5 exhibit a neutral performance, on average, as they rely on comparisons between static snapshots at discrete time intervals or simulations for the capture and analysis of structural changes, which typically becomes cognitively challenging for researchers and practitioners in the case of large and dense networks. Regarding criterion (ii), sources of dynamics are only implicitly discernible through the tracking of quantitative network measures, such as network density for capturing interaction intensity and centrality metrics for expressing the relative power of nodes in the network.

Finally, the methods in cluster VM4 excel in relation to evaluation criterion (ii) because they are specifically designed to visualise sources of dynamics in ecosystems, as exemplified by Pagano and Neubert's (2015) visual canvas, which maps event, value and stakeholder interactions. Furthermore, this method cluster performs well with respect to evaluation criterion (iii) because it enables the visualisation of co-evolution in ecosystems, as illustrated by Liu et al.'s (2020) technology path mapping, which traces the temporal changes of actors and artefacts. The inherent focus on longitudinal phenomena in ecosystems, however, compromises method cluster VM4 in terms of its ability to effectively capture spatial structure and relationships among ecosystem basic elements, thus negatively impacting its performance concerning criterion (i).

Overall, each of these five method clusters excels in at least one of the three evaluation criteria, that is, capturing the ecosystem's static structure through effective visualisation of the ecosystem's basic elements, illustrating sources of dynamics or representing structural changes over time. However, none of these five method clusters (with the highest average composite index being 3.1 out of 5.0) were found to address all three criteria. The critical review of existing visual methods for ecosystem research uncovered a gap in the toolbox of researchers and practitioners that enables the effective visual capture of static structure, sources of dynamics and co-evolution in innovation ecosystems. Closing this gap promises to stimulate researchers' theorisation of dynamics and co-evolution in ecosystems and to assist practitioners' sense- and decision-making in systemic innovation environments (Aarikka-Stenroos and Ritala, 2017; Holgersson et al., 2022; Romme and Holmström, 2023).

3. RESEARCH METHODOLOGY

We followed the design science research methodology (DSRM) approach according to Peffers et al. (2007) to address the gap identified in the methods toolbox and to develop our new visual method. Furthermore, we conducted a demonstration case in the empirical setting of the commercial aircraft MRO sector. DSRM was chosen as a methodological basis because it inherently represents a problem-solving approach, enables the design and development of theory-informed useful artefacts, and ensures empirical and qualitative evaluation in a relevant organisational context (Hevner et al., 2004). Previous studies have shown the effectiveness of the DSRM approach in developing visual methods for ecosystem research, namely, Moerchel et al.'s (2022) visual method for capturing IP dynamics in evolving innovation ecosystems, and in devising semantic languages for business process modelling in the banking sector (Becker et al., 2010). Peffers et al.'s (2007) nominal DSRM process comprises six steps: (i) problem identification and motivation, (ii) definition of objectives, (iii) design and development, (iv) demonstration, (v) evaluation and (vi) communication. Fig. 2 provides an overview of how each step of the nominal DSRM process model was implemented for the development and demonstration of our new EDM language in this study.

3.1. Problem identification and motivation

According to Peffers et al. (2007), this step requires definition of the specific research problem and justification of the value that its solution brings to research and practice. From our systematic identification and critical review of existing visual methods for ecosystem research (refer to Section 2), we identified that none of the existing method clusters effectively combines the ability to visually capture static structure, sources of dynamics, and co-evolution in ecosystems. A solution to this methods gap would, however, be valuable because it could potentially enable ecosystem researchers to develop a deeper understanding and theorise about dynamics and co-evolution in ecosystems (Aarikka-Stenroos and Ritala, 2017) and support practitioners in constructing maps that clearly reflect their organisation's position in complex technical systems for more effective innovation management (Holgersson et al., 2022).

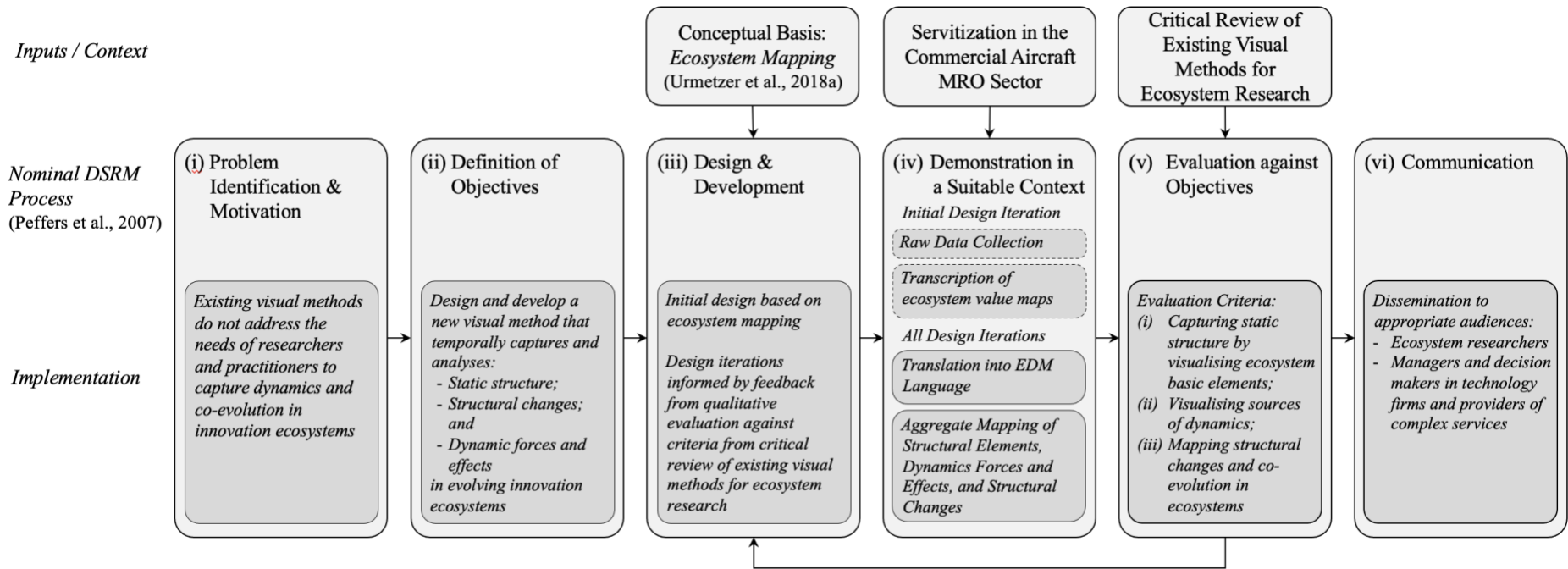


Fig. 2: Overview of nominal DSRM process as applied for the design and demonstration of the EDM language; adapted from Peffer et al. (2007)

3.2. Definition of objectives

The objectives for the solution need to be derived from the problem definition, which requires considering what is possible and feasible based on the existing body of knowledge (Peppers et al., 2007). In our study, we derived the objectives qualitatively from the problem statement, namely, to design and develop a new method that enables researchers and practitioners to capture and analyse static structure, structural changes, and dynamic forces and effects in evolving innovation ecosystems. It thus needs to combine the abilities to (i) capture the static structure of basic ecosystem elements, (ii) visualise endogenous and exogenous sources of dynamics and (iii) map structural changes and co-evolution in innovation ecosystems.

3.3. Design and development

The design and development step represents an iterative process that requires the creation of a new and innovative artefact, such as a construct, model or method, based on an existing body of knowledge and established research approaches (Hevner et al., 2004; Peppers et al., 2007). For the initial design of our new EDM language in our study, we conceptually started from method cluster VM1 (ecosystem mapping) as a methodological basis, most notably, Urmutzer et al. (2018a) and Ghazinoory et al.'s (2020) ecosystem mapping processes, because the critical review in Subsection 2.3 identified these as the most developed and promising ecosystem visualisation methods based on their average composite indices. Furthermore, we used basic visual encoding mechanisms, such as shape, size, colour, texture and orientation (Spence, 2014, p. 63) to devise a set of symbols for externally representing the basic ecosystem elements in Adner's (2017) structural approach, namely, activities, actors, positions and links. As illustrated in Fig. 2, the initial design was subsequently demonstrated in the relevant empirical context and qualitatively evaluated against the same set of criteria as used in the critical review of existing visual methods for ecosystem research (see Subsection 2.2). The results of this qualitative evaluation were fed back into the iterative development of our new method until no further design changes were required to meet the evaluation criteria and theoretical saturation had been reached (Glaser and Strauss, 1999).

3.4. Demonstration in a suitable context

Peppers et al. (2007) suggested that demonstration of the newly designed artefact requires it to be applied to at least one instance of the problem by means of experimentation, simulation, case study or proof. For demonstration of the EDM language we chose to conduct a revelatory case study because it effectively captures multiple sources of empirical data, focuses on contemporary events, and identifies causalities as well as dynamics in empirical settings (Eisenhardt, 1989; Yin, 2014, p. 52). Furthermore, we decided on the commercial aircraft MRO sector for the empirical setting because it exhibits dynamic processes involving a multilateral set of interdependent actors, activities and artefacts and shows signs of co-evolution in an innovation ecosystem. Specifically, evidence suggests that the commercial aircraft MRO ecosystem is subject to servitization (Broderick, 2019; Chuanren, 2019; Hemmerdinger, 2017; Neely, 2008), namely, the transformation of manufacturers' offerings from being primarily product-focused, such as aircraft, engines and aircraft systems, to integrating products with service innovations, such as digital solutions, remote monitoring and life-cycle cost management (Baines and Lightfoot, 2013, p. 5). In this transformational process, manufacturers reposition by forward integration (Huikkola et al., 2020; Teece, 2010; Wise and Baumgartner, 1999) and bypass existing intermediaries, such as incumbent service providers (ISP). Next to causing changes in industrial organisation, servitization thus potentially triggers competitive tensions between manufacturers and established specialist firms already providing such services to end-users of manufacturers' products (Burton et al., 2016), namely, ISPs. We believe that conceptualising the commercial aircraft MRO sector as a currently evolving innovation ecosystem and mapping the changes in industrial organisation triggered by servitization represents a highly relevant demonstration case for our new EDM language.

To execute the case study, we adopted the ISP's perspective. We collected primary empirical data through 18 semi-structured in-depth interviews (Bryman and Bell, 2015, p. 481) with 10 senior managers and decision-makers at various hierarchical levels and functions of an established and large manufacturer-independent ISP with more than 1,000 commercial aircraft under service contracts and revenue exceeding USD1 billion per year, which offers an integrated and holistic scope of services for established Western aircraft types (see Table 2). Next to interview recordings, raw data included handwritten ecosystem value maps captured according to Urmetzer et al.'s

(2018a) process and visualising the structure of the commercial aircraft MRO sector from the ISP's perspective before and during the servitization of OEMs. Secondary empirical data consisted of extensive archival records, such as ISP internal documents, external media reports specific to the commercial aircraft MRO sector, and publicly accessible annual reports, and served the purpose of data triangulation and case-study construct validity (Yin, 2014, p. 121).

To apply the initial design of our newly developed EDM language to capture dynamic processes in the commercial aircraft MRO innovation ecosystem, we followed a gradual process consisting of three steps, namely, transcription, translation and aggregate mapping (see Fig. 3). This gradual process, especially the inclusion of verbal data from interview recordings in visualisations of the innovation ecosystem, was guided by Gioia et al.'s (2012) inductive approach to the discovery of novel concepts and new theory generation. In total, the translation and aggregate mapping steps of this process produced 13 ecosystem maps capturing dynamic processes in the commercial aircraft MRO sector.

Transcription. The transcription step was only applied to the initial iteration of the design process. In this step, we transcribed the handwritten, hard-copy ecosystem value maps from the raw data collection, according to Urmetzer et al. (2018a), into a digital format. Meanwhile, the maps were enriched with terms and codes from interview recordings to capture the interviewee's view of ecosystem static structure prior to the onset of servitization, and the ensuing dynamic processes and changes in industrial organisation, as closely and completely as possible. This corresponds to Gioia et al.'s (2012) first-order analysis, in which the focus lies on expressing the data in the terms, codes and visualisations as used by each interviewee. We subsequently reviewed the digitally transcribed maps, together with each interviewee (Urmetzer et al., 2018a), and modified them, where necessary, to ensure construct validity (Bryman and Bell, 2015, p. 495; Yin, 2014, p. 47).

Translation. For the initial iteration, emerging visual themes and concepts describing structural elements, structural changes, as well as dynamic forces and effects in the transcribed ecosystem value maps were replaced by symbols from the initial design of the EDM language. Subsequent iterations of this step saw the application of modified and more sophisticated symbols from the iterated design of the EDM

Table 2: Interviewee summary including the 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 service 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 the ISP's innovation ecosystem.

^c Recording declined by interviewee because of confidentiality requirements.

^d Approximate length of interview.

^e Confirmation of transcribed ecosystem value maps not possible because of unavailability of interviewees after onset of COVID-19-induced crisis in commercial aviation sector from March 2020.

language, similar to Langley and Truax’s (1994) iterative development of flow charts and detailed keys for visualising large empirical data sets of longitudinal processes. The translation step effectively corresponds to Gioia et al.’s (2012) second-order analysis, in which the focus shifts towards concepts, themes and dimensions that emerge from the data. To ensure that theoretical saturation and sufficient standardisation of symbols and external representations is achieved, the emerging standardised visual representations for structural elements, structural changes, as well as the dynamic forces and effects of the evolving innovation ecosystem, were retrospectively applied to all 10 transcribed ecosystem value maps through iterative revision and adaptation.

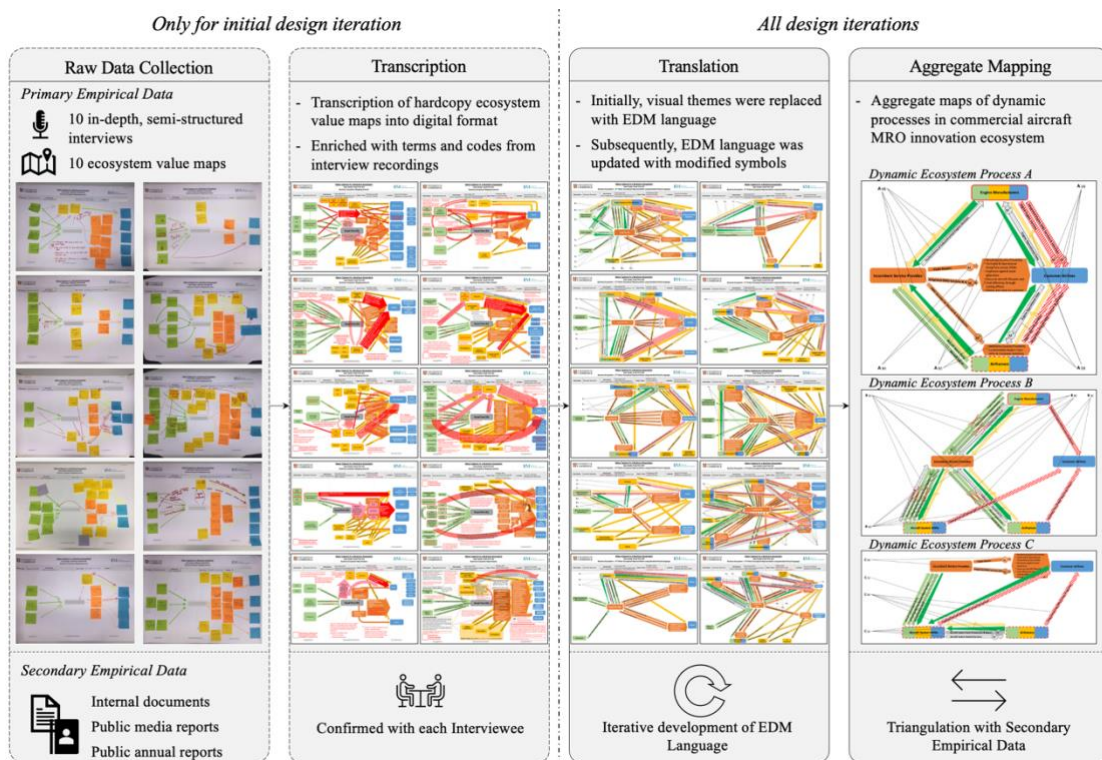


Fig. 3: Overview of demonstration of EDM language to visualise dynamic processes in commercial aircraft MRO innovation ecosystem

Aggregate mapping. In this final step of the demonstration, aggregate maps of three dynamic processes in the commercial aircraft MRO ecosystem under the influence of servitization were created using the EDM language. In this step we paid particular attention to visualising basic ecosystem structural elements, ecosystem structural changes, as well as dynamic forces and effects in the innovation ecosystem. The three aggregate ecosystem maps were updated following each design iteration of the EDM language and represent the basis for the evaluation step in the DSRM process. This step

corresponds to distilling aggregate dimensions from emerging second-order themes and concepts in Gioia et al.'s (2012) inductive approach. To conclude this last step, data triangulation between the aggregate ecosystem maps and secondary empirical data was conducted to strengthen construct validity (Yin, 2014, p. 120).

3.5. Evaluation against objectives

The evaluation step of the DSRM process requires measurement of how well the newly designed artefact supports the solution to the problem (Peppers et al., 2007). For the purposes of evaluating the EDM language, we exposed it to the same evaluation criteria as all identified previous visual methods for ecosystem research, namely, (i) capturing static structure by visually representing the basic ecosystem elements (i.e. actors, activities, artefacts, positions and links), (ii) visualising sources of dynamics that are either endogenous or exogenous to the ecosystem, and (iii) mapping structural changes and co-evolution in ecosystems. Any qualitative deficiencies that were identified, such as issues regarding the usability or effectivity of the EDM language, were fed back into the design and development step in the DSRM process. The resulting modifications were subsequently applied by repeating the translation and aggregate mapping steps of the demonstration case. This iterative process was repeated three times until no further changes were necessary to capture dynamic processes accurately and holistically in the commercial aircraft MRO ecosystem, no new visual themes and concepts had emerged from the primary empirical data, and theoretical saturation had been achieved (Glaser and Strauss, 1999).

3.6. Communication

According to Peppers et al. (2007), effective communication entails describing, to the appropriate audiences, the main elements of the nominal DSRM process, namely, the problem and its relevance, the newly designed artefact, the utility and rigour of its design, and the relevance to researchers and practitioners. In this study we substantiated the problem and its relevance in the literature review (see Section 2), provided details about the design process and the new EDM language (see Sections 3 and 4, respectively) and discussed its utility to researchers and practitioners (see Section 5).

4. INTRODUCTION AND DEMONSTRATION OF EDM LANGUAGE

The EDM language represents a new visual method that addresses the gap faced by researchers and practitioners when trying to capture and analyse evolving innovation ecosystems. The syntax of the EDM language can be described as sets of written symbols, labels and colour schemes, collectively denoted as external representations (Zhang, 1997), that are grouped into three clusters, namely, ecosystem structural elements, ecosystem structural changes, and dynamic forces and effects (see Table 3). In the following we describe and demonstrate the EDM language on the basis of aggregate ecosystem maps depicting dynamic processes in the commercial aircraft MRO sector that are triggered by servitization.

4.1. Ecosystem structural elements

The ecosystem structural elements cluster of symbols was specifically conceived to capture the basic elements of Adner's (2017) ecosystem-as-structure perspective clearly and concisely, namely, actors, activities, positions and links, as well as their alignment structure, which are strictly relevant for realisation of the ecosystem's focal value proposition. As highlighted in Table 3a and 3b, the visual representation of ecosystem structural elements in our EDM language consists of the (i) ecosystem actor role colour coding, (ii) ecosystem actor role, (iii) goods flows and (iv) value proposition symbols.

(i) *Ecosystem actor role colour coding* (see Table 3a). The colour scheme is used to identify each actor's relative position in the flow of activities and its role in implementation of the focal value proposition (Adner, 2017; Adner and Kapoor, 2010). Specifically informed by Adner and Kapoor's (2010) generic ecosystem scheme, ecosystem actor roles are differentiated between *focal firms* (orange), which integrate various inputs into the ecosystem's focal value proposition, *suppliers* (green), which provide relevant inputs to focal firms, *complementors* (yellow), which provide complementing inputs directly to customers, and *customers* (blue), who capture the value created by the focal firm and integrate it with complementing inputs for maximised utility and value capture (Urmetzer et al., 2018b). To provide a degree of freedom when mapping complex ecosystem structures, a separate colour (brown) is reserved for other ecosystem actor roles that do not explicitly add to the

Table 3: Overview of symbols in the EDM language

Table 3a






Ecosystem Actor Role Colour Coding				
Focal Firm	Customers	Suppliers	Complementors	Other Roles ^a
				

Table 3b







Ecosystem Structural Elements					
Ecosystem Actor Role			Goods Flows ^b		Value Proposition ^c
Single	Dual	Triple	Tangible	Intangible	
					

Table 3c














Ecosystem Structural Change					
Changes to Actor Roles ^f		Changes to Goods Flows		Restriction of Goods Flows	
Near Match ^g		Near Match ⁱ		Full Suspension	
Limited Match ^g		Limited Match ⁱ		Partial Restriction	
Emerging / New Entrant ^h		Emerging Goods ⁱ			

Table 3d

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

Notes:

^aOther Ecosystem Actor Roles without explicit share in focal Value Proposition

^bDirection from artifact / value creating to artifact / value capturing Ecosystem Actor Role; adapts to artifact / value creating Ecosystem Actor Role Colour Coding

^cDelivered by Ecosystem Focal Firm to Customers

^dAttached to a Goods Flow and adapts to Goods Flow's colour coding

^eDirection opposite to respective Goods Flow

^fFrame adopts colour coding of newly assumed Ecosystem Actor Role

^gApplied to pre-existing Ecosystem Actor Role symbol

^hUsed independently of any pre-existing Ecosystem Actor Role symbol

ⁱFrame and fill adopt colour coding of pre-existing Goods Flows

^jAdopts neutral colour coding

ecosystem's focal value proposition, but whose input is still relevant, such as standard setting institutions. Fig. 4, which represents an aggregate ecosystem map of the commercial aircraft MRO sector, illustrates how the EDM language is used to capture the alignment structure of a multilateral set of actor roles, namely, suppliers (green) and complementors (yellow), towards the ISP's focal value proposition (orange) to customer airlines (blue).

(ii) *Ecosystem actor role* (see left section of Table 3b). This symbol consists of a rectangle and captures firms and organisations whose activities are directly linked to implementation of the focal value proposition. Mapping 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), as in the case of *alternative parts providers* (see quadrant A:1 of Fig. 4). This multiplicity of ecosystem actor roles is captured using multiple colours in a single actor role symbol, as shown in the left section of Table 3b for single, dual and triple roles.

(iii) *Goods flows* (see middle section of Table 3b). These symbols consist of arrows connecting two ecosystem actor role symbols going from the value-creating to the value-capturing entity (Urmetzer et al., 2018b). They illustrate 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 flow arrows follows the ecosystem actor role colour coding of the value-creating (or origin) ecosystem actor. Fig. 4 shows how this EDM symbol is applied to represent goods flows from the three OEM clusters in the commercial aircraft MRO ecosystem, namely, *airframers*, *engine manufacturers* and *aircraft system OEMs*, in the form of tangible *aircraft/engines/aircraft systems spare parts* (see solid green arrows in quadrants B:3, B:1 and A:3 in Fig. 4), as well as intangible *engine/aircraft system component repair services* to ISPs (see striped green arrows in quadrants B:1 and A:3 in Fig. 4). Furthermore, the analysis of the interview data and ecosystem value maps

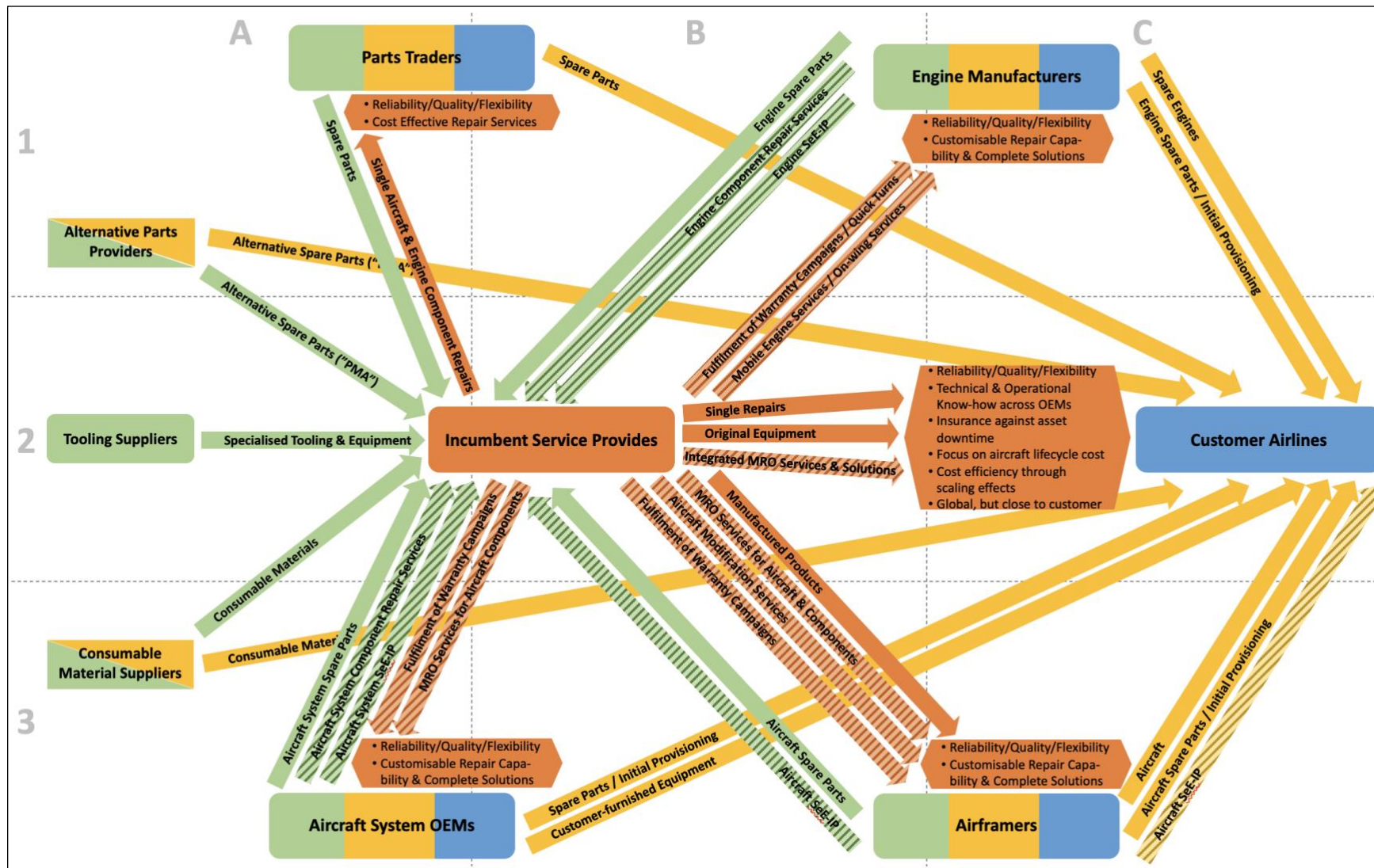


Fig. 4: Aggregate ecosystem map of commercial aircraft MRO sector prior to OEM servitization using EDM language

revealed that ISPs rely on the provision of intangible data and technical documentation, which we collectively and hereafter denote as services-essential intellectual property, or SeE-IP, by OEMs for the formulation of their focal value proposition. The provision of access to *aircraft/engine/aircraft system SeE-IP* is captured by the respective intangible goods flows pointing from each OEM to the ISP (see striped green arrows in quadrants B:3, B:1 and A:3 in Fig. 4).

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 to realise the focal value proposition and to maximise value capture by customers. Furthermore, the goods flow visualisations inherently imply a reverse economic value capture flow in exchange for the artefact flow (Urmetzer et al., 2018b), which is not explicitly visualised by EDM language for the purposes of conserving clarity and avoiding cluttering of the aggregate ecosystem maps.

(iv) *Value proposition* (see right section of Table 3b). This symbol comprises an orange hexagon and documents the benefits that customers receive from 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 et al., 2006). In Fig. 4, the *ISPs'* focal value proposition to *customer airlines*, namely, reliability/quality/flexibility, technical and operational know-how across various OEMs, and insurance against aircraft asset downtime, is represented in EDM language by the orange hexagon between the *ISPs'* goods flow arrows and the *customer airlines* ecosystem actor role symbol (see quadrant C:2 in Fig. 4).

The demonstration of the EDM language furthermore uncovered that value propositions in the commercial aircraft MRO sector vary depending on both type of customer and technology of the asset, as illustrated by the value proposition symbol attached to *parts traders* (see quadrant A:1 in Fig. 4), which differs considerably from the focal value proposition offered to *customer airlines* (see quadrant C:2 in Fig. 4). In summary, *ISPs'* value propositions were found to range from ensuring spare parts' availability, avoiding unscheduled maintenance through predictive analytics of aircraft

operational data, and offering integrated customer-support solutions (Agrawal, 2019; Bjerregaard, 2020).

4.2. Ecosystem structural changes

Ecosystem structural changes represent a cluster of symbols that capture transformations in the industrial organisation of the ecosystem while going through a phase of reorganisation. As highlighted by Holling (2001) and 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 prevailed during the previous exploitation and conservation phases, and they offer opportunities for ecosystem actors to explore and pioneer new links and activities, thereby transforming ecosystem industrial organisation. As highlighted in Table 3c, the ecosystem structural changes cluster of the new EDM language consists of three groups of symbols, namely, (i) changes to actor roles, (ii) changes to goods flows and (iii) restriction of goods flows.

(i) Changes to actor roles (see left section of Table 3c). The visualisation of changes to actor roles 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 represents a limited match between the actor's newly assumed role and that of another actor in the ecosystem. In either case, the changes in actor roles signal the emergence of substitute relationships in the ecosystem (Granstrand and Holgersson, 2020) that drive competition and dynamics in innovation ecosystems (Moore, 2006). Furthermore, the EDM syntax offers the flexibility to use the changes to actor roles independently of an existing ecosystem actor role, that is, as an independent symbol. In this case it captures new entrants with complementary skills and capabilities diversifying from other sectors (Porter, 2008), as observed, for example, in the healthcare sector during the COVID-19 pandemic (Moerchel et al., 2021; Tietze et al., 2022b).

The functionality of the changes to actor role symbols is shown in Fig. 5, which visualises a servitization-triggered dynamic process in the commercial aircraft MRO sector, namely, OEMs' increasingly restrictive treatment of access to their proprietary

SeE-IP to other actors, including *ISPs*. In this aggregate innovation ecosystem map, the orange-dashed frames applied to *airframers* and *aircraft system OEMs* (see label A in Fig. 5) indicate that they partially assume the role of *ISPs*.

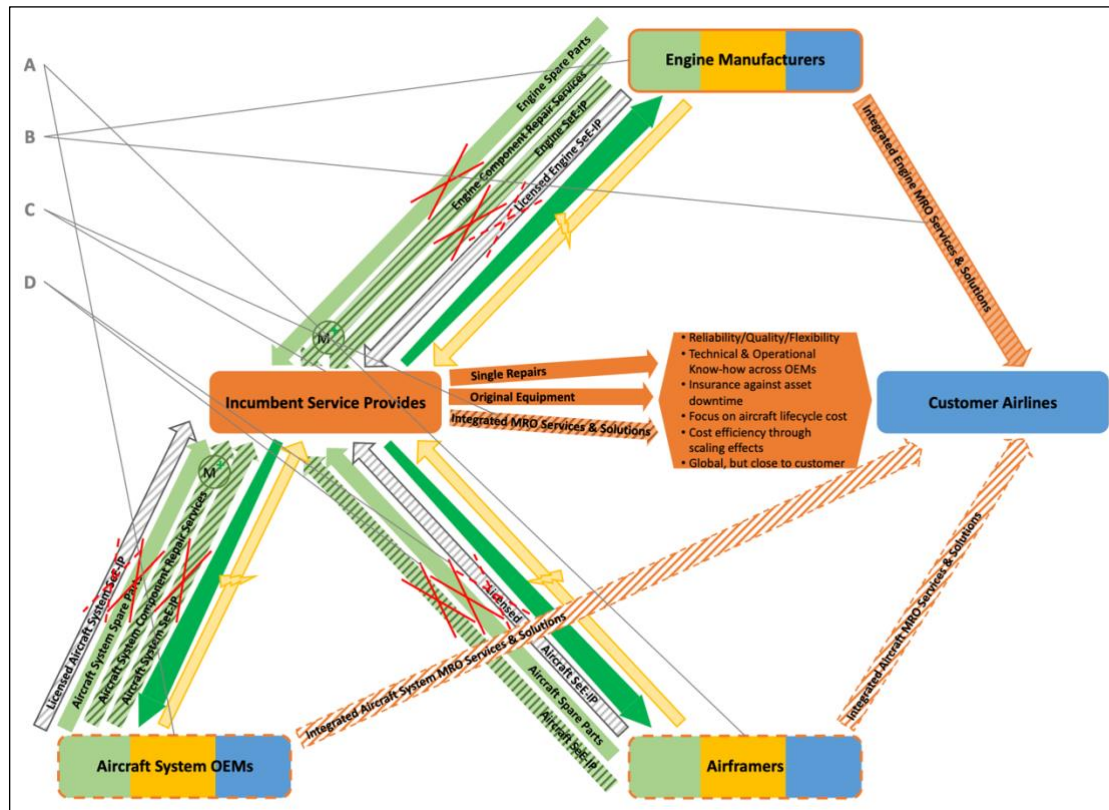


Fig. 5: Aggregate ecosystem map visualising OEMs' increasingly restrictive management of SeE-IP in the commercial aircraft MRO sector in EDM language

(ii) *Changes to goods flows* (see middle section of Table 3c). The changes to goods flow symbols consist of framed arrows representing emerging new links between two ecosystem actor role symbols going from the value-creating to the value-capturing actor. The colour coding of the changes to goods flow arrows is the same as for goods flows that already existed in the previous phase of the ecosystem's adaptive cycle. Furthermore, it exhibits either a solid or dashed frame, depending on whether the change to the goods flow leads to a near or a limited match to a pre-existing goods flow. The combined visualisation of a change to the goods flow arrow and a change in actor role frame, either as a near (solid frame) or limited (dashed frame) match to a pre-existing goods flow and ecosystem actor role combination, effectively captures the flow of substitute artefacts and signals the emergence of a competitive relationship during the phase of the ecosystem's adaptive cycle being visualised (Granstrand and

Holgersson, 2020). Furthermore, the changes to the goods flows group of symbols also comprises a neutral-coloured arrow to provide a degree of flexibility for capturing newly emerging goods flows among ecosystem actor roles, such as tangible and intangible artefact innovations.

In the aggregate ecosystem map of the commercial aircraft MRO sector in Fig. 5, the solid orange frame attached to *engine manufacturers*, combined with the changes to goods flow arrow denoted as *integrated engine MRO services & solutions* pointing to *customer airlines* (see label B in Fig. 5), suggest the emergence of a competitive relationship with *ISPs* and the provision of a substitute artefact to their *integrated MRO services & solutions* (see label C in Fig. 5).

(iii) *Restriction of goods flows* (see right section of Table 3c). This group of symbols consists of two red crosses and is typically applied to goods flows or changes to goods flow arrows to indicate either a full suspension (solid cross) or a partial restriction (dashed cross) of the flow of artefacts between two ecosystem actor roles. The restriction of goods flow symbols illustrate 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 the use or rights allocation on the part of the receiving ecosystem actor role (Adner and Kapoor, 2010; Granstrand, 2020).

The functionality of the restriction of goods flows symbols is highlighted by its application to goods flows *aircraft spare parts* and *aircraft SeE-IP* from *airframers* to *ISPs* (see label D in Fig. 5), which indicates servitizing OEMs' increasingly restrictive supply of vital component inputs to *ISPs*' focal value proposition in the commercial aircraft MRO sector.

4.3. Dynamic forces and effects

The dynamic forces and effects cluster of symbols visualises exogenous forces that trigger phase changes as the ecosystem evolves in its adaptive cycle, such as regulatory changes or sudden abundance/scarcity of resources (Auerswald and Dani, 2017; Granstrand and Holgersson, 2020; Holling, 2001). This cluster also captures endogenous dynamic effects on bilateral relationships between two ecosystem actor roles that result from innovations introduced by suppliers, complementors or the focal firm, such as new product introductions, leading to enhancements in the value

proposition (Adner and Kapoor, 2010). As illustrated in Table 3d, the dynamic forces and effects cluster of the EDM language comprises three groups of symbols for (i) the exertion of leverage/power, (ii) goods flow measurement and (iii) economic value capture changes.

(i) *Exertion of leverage/power* (see left section of Table 3d). The exertion of leverage/power symbol consists of a yellow arrow carrying a flash of lightning and points from the ecosystem actor role symbol exerting strategic leverage to the receiving ecosystem actor role symbol. It captures the bargaining power of suppliers and buyers (Porter, 2008) or changes to the norms, rules and laws that regulate the links between actors introduced by institutions (Edquist, 2006). The exertion of leverage/power typically occurs along existing links between two ecosystem actor roles.

The functionality of the exertion of leverage/power symbol is shown in the aggregate ecosystem map of the commercial aircraft MRO sector in Fig. 6, which visualises another servitization-induced dynamic process, namely, OEMs' diversion of aftermarket value streams through the exploitation of inherent competitive advantage. Specifically, the yellow exertion of leverage/power symbols (see label A in Fig. 6) capture *engine manufacturers'* and *airframers'* use of the bargaining power of buyers resulting from bundling and tendering MRO service volumes of multiple *customer airlines* when subcontracting MRO services to *ISPs*.

(ii) *Goods flow measurement* (see middle section of Table 3d). The measurement of goods flows is depicted by circles with a (green) plus for growth or (red) minus for shrinkage. They are attached to the respective goods flow arrows experiencing either an increasing or decreasing trend in the flow intensity of artefacts, respectively. The quantitative dynamics in artefact flow intensity between two ecosystem actor roles are symptomatic of external disturbances that herald the transition from the conservation phase, which is marked by strong, complex and stable interdependencies, to the reorganisation phase in the ecosystem adaptive cycle, which is characterised by rapid ecosystem structural changes (Auerswald and Dani, 2017).

In the demonstration case of the EDM language, the two goods flow measurement shrinkage symbols that are applied to *single repairs* and *integrated MRO services & solutions* from *ISPs* to *customer airlines* (see label B in Fig. 6) capture the impact of servitizing OEMs on the ISP market share in the commercial aircraft MRO sector.

Furthermore, the recently observed proliferation of operational data collection by OEMs (Derber, 2021; Pozzi, 2021) is captured by the emerging goods flows *aircraft/engine operational data* from *customer airlines* to *airframers* and *engine manufacturers* and respective goods flow measurement growth symbols (see label C in Fig. 6).

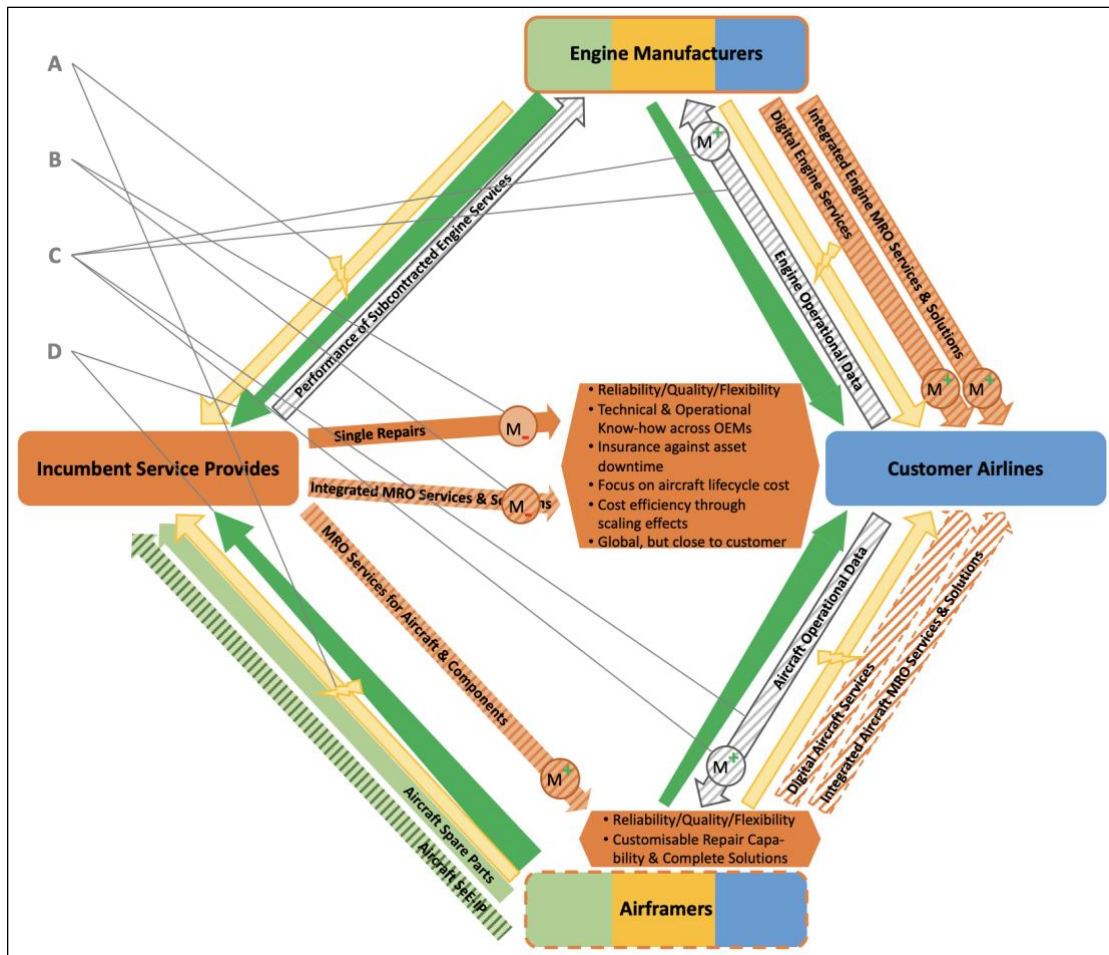


Fig. 6: Aggregate ecosystem map visualising OEM’s diversion of aftermarket value streams through the exploitation of inherent competitive advantage in EDM language

(iii) *Economic value capture changes* (see right section of Table 3d). Changes in economic value capture are visualised by a green arrow pointing in the opposite direction of the respective goods flows arrow between two ecosystem actor roles. A tapered shaft indicates a decreasing trend, and an expanding shaft signals an increasing trend in *economic value capture changes* by the receiving ecosystem actor role in exchange for tangible or intangible *goods flows* (Urmetzer et al., 2018b), such as supplying components, delivering products or offering complementary services,

respectively. Similar to goods flow measurements, changes in economic value capture also represent quantitative dynamics in the relationship between two ecosystem actor roles, but in economic flow intensity. Furthermore, economic value capture changes are symptomatic of endogenous effects on bilateral relationships within the ecosystem that are, for instance, caused by the opportunistic behaviour of the economic value-capturing ecosystem actor role, such as renegotiating existing contractual relationships (Adner and Kapoor, 2010).

Referring to the aggregate ecosystem map from the EDM language demonstration in Fig. 6, the green economic value capture shrinkage symbols pointing from *engine manufacturers* and *airframers* to *ISPs* (see label D in Fig. 6) visually capture the effect of the accompanying exertion of leverage/power by the respective OEMs on *ISPs* during price negotiations for subcontracted MRO services.

5. DISCUSSION

Dynamics are inherent to ecosystems, regardless of whether they are pushed out of an equilibrium by innovation or they are in a constant state of flux, as argued by some ecosystem scholars (Aarikka-Stenroos and Ritala, 2017; Granstrand and Holgersson, 2020; Holgersson et al., 2022). Visualisations can help researchers and practitioners to understand those dynamics. By developing and demonstrating the new EDM language, we contribute a novel method that enables the visualisation of dynamics in innovation ecosystems, thereby addressing a gap that we identified in the literature. Given the limited number of applications to date, a clear opportunity for future research is to study whether using the EDM language leads to better decision-making, such as by practitioners strategising or policy-makers deciding on policy interventions. We suggest that future work should also address the challenge of prior user knowledge in visualisation (Chen, 2005), namely, ambiguities and biases resulting from the interpretation of external representations and maps by those who did not contribute to their creation.

While multiple approaches to mapping ecosystems already exist (e.g. Ghazinoory et al., 2020; Talmar et al., 2020), they barely focus on visualising temporal changes and, if so, only capture specific changes. The proposed EDM language enables the visualisation of three key aspects of innovation ecosystems: (i) structural elements (including relevant actors, activities, artefacts and the relationships among them), (ii) structural changes and (iii) dynamic forces and effects. With these three aspects, we

believe that our new method can facilitate a more holistic understanding of dynamic processes and co-evolution in ecosystems for a wide range of use cases and also address a larger set of future research questions. However, we consider the EDM language to be a (modular) platform method with the potential for further extension and/or customisation to specific research questions and industrial settings, thus allowing researchers, practitioners and policy-makers to explore dynamics of interest in ecosystems. This is similar to other methods, for instance, roadmapping, which has become a widely used and powerful strategic management tool (Phaal et al., 2004). While its original version is generic, more specialised roadmapping versions have been developed over time. For instance, Tietze et al. (2022a) proposed a roadmapping version specifically for formulating IP strategies, and Blümel et al. (2022) introduced a more specialised version to develop IP strategies for service-based business models. An example of how the EDM language was already developed further for a specific use case is the study by Moerchel et al. (2022). Specifically, using an earlier version of the EDM language (then called SVEL), the authors extended it with a specific set of symbols that allow the identification of IP-related risks and uncertainties, which they demonstrated in the context of an evolving manufacturing ecosystem when the COVID-19 pandemic unfolded. In addition to IP, another example could be the development of a specific EDM language version for the visualisation of structural changes and dynamics of economic value flows in evolving ecosystems. Accordingly, future research can further develop the EDM language, hopefully for a wide range of specific use cases.

While we see great potential in applying the EDM language, so far it has only been applied in two empirical contexts, namely, the aerospace and manufacturing sectors. To demonstrate that it is applicable across a wide range of empirical contexts, future research might want to test it for mapping ecosystem dynamics that are considerably more diverse than the two to which it has already been applied. These could be ecosystems that are either structurally different or which exhibit different dynamics. For instance, both the aerospace and manufacturing sectors are highly regulated. Future research could test the EDM language in less-regulated sectors, such as software development or the creative industries.

When it comes to implementation of the EDM language, namely, the process of collecting and transcribing raw empirical data, and then translating it into aggregate ecosystem maps, there appears to be room for future research. The current process is

mostly manual and thus fairly resource-intensive. While we have attempted to minimise complexity, our focus was on reducing conceptual complexity as opposed to application complexity. Future research could focus on identifying and testing ways to increase the new method's practicality and usability. A collaborative software solution could be developed (e.g. with ecosystem templates and sets of EDM syntax) to assist in the process of compiling aggregate ecosystem maps in EDM language and to allow for more effective participant interaction. The various collaborative tools that emerged during the COVID-19 pandemic and enabled hybrid and virtual collaboration (e.g. Miro and Conceptboard) could represent an effective starting point (Becerra et al., 2021). Until the EDM language is sufficiently simplified, and possibly assisted by software tools, its application might be limited to research settings or large organisations that have the necessary resources to make full use of it to create ecosystem maps. For these organisations, we believe that the EDM language has the potential to facilitate strategic decisions in the evolving ecosystem context, for instance, by informing incumbent ecosystem leadership about paths towards higher joint value (Foss et al., 2022) and enabling actors' effective resource management under high uncertainty (Dattee et al., 2018). The EDM language could also be of interest to industry associations, which aim to coordinate actors' activities in a certain sector, similar to the use of roadmapping, for instance, to coordinate industrial players in the semi-conductor industry (e.g. IEEE, 2017), and government agencies, which aim to regulate ecosystems and address concerns over competition (Jacobides and Lianos, 2021).

6. CONCLUSIONS

This study applies the DSRM approach to address an identified gap in the methods toolbox of researchers and practitioners for studying and understanding dynamics in evolving innovation ecosystems. Our systematic identification and critical review of 34 existing visual methods revealed that none of them allow users to capture and analyse ecosystems' basic elements, illustrate sources of dynamics, and represent structural changes over time. To address this gap, we designed and iteratively developed a new visual method, which we named the EDM language, consisting of three clusters of symbols, namely, (i) ecosystem structural elements, (ii) ecosystem structural changes and (iii) dynamic forces and effects.

The design and development of the new EDM language was conceptually informed by state-of-the-art ecosystem research and input from a demonstration case in a relevant empirical setting, namely, the commercial aircraft MRO sector. This sector was chosen for demonstration of the EDM language because it exhibits dynamics in industrial organisation resulting from the servitization of manufacturing, in which OEMs innovate their internal capabilities to complement their products with integrated service solutions, and thereby existing relationships with ISPs change and become competitive. The demonstration case showed the functionality and effectivity of the EDM language in creating aggregate ecosystem maps of dynamic processes in an evolving innovation ecosystem.

We believe that the EDM language represents a modular platform method and contributes to the methods toolbox of researchers and practitioners concerned with ecosystem dynamics. It has the potential to advance the theorisation of dynamics and co-evolution in innovation ecosystems and to facilitate the formulation of effective ecosystem strategy, respectively. Future research, however, needs to test and further develop the EDM language in broader and more diverse empirical settings, possibly resulting in the addition of modular extensions for specific research and practice purposes. In addition, we suggest that further work is necessary for the implementation of dedicated software solutions that improve the usability of the EDM language and reduce its resource requirements.

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