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Innovating the Innovation System Thinking: a Systemism Model

Kjell Olav Skjølsvik[1] · **Aristidis Kaloudis**[2]

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Abstract

The complexity of an innovation system, how it works and how to achieve high performance, represents a significant management challenge. As in any complex system, in an innovation system it is mandatory to operate with a clear idea of the various key elements and relationships in the system, what constitutes the emerging properties of the system and to identify effective channels to influence the performance of such a system. Bearing this in mind, we adopt a *systemism approach*, applying the principles of Mario Bunge's CESM metamodel. We suggest a new generic model that can be adapted to fit many different aspects of real-life innovation decision making. An important objective for this generic model is to combine all critical internal and external systemic factors, i.e., to depict all critical nodes and interaction processes between subsystems (internal factors) and all critical nodes and interactions processes with the broader innovation ecosystem (external factors). Another key objective was to establish a model suitable for communication and decision making that is compatible with the key terms and the definitions in the new ISO 56000 standard on innovation management. The paper defines the main elements of a generic innovation model and exemplifies the potential usefulness of the model by showcasing three distinct applications. We hope that our new *systemism model* could be an additional tool for better strategic management with respect to emerging properties of knowledge dynamics, risk assessment and mitigation, and the monitoring and continuous improvement of critical innovation processes.

Keywords Innovation · System · Model · Emergence · Management

✉ Kjell Olav Skjølsvik
kjell.o.skjolsvik@ntnu.no

Aristidis Kaloudis
aristidis.kaloudis@ntnu.no

1 Department of Marine Technology, Norwegian University of Science and Technology (NTNU), NO-7050 Trondheim, Norway

2 Department of Industrial Economics and Technology Management, Norwegian University of Science and Technology (NTNU), NO-2815 Gjøvik, Norway

Introduction

Innovation is a critical driver of economic growth, competitiveness, and welfare improvements, and it has been the subject of extensive research over the years. Scholars in the early history of studies of innovations understood innovation as a process mainly within the innovative organisation until the final product is ready to be diffused in the markets (Schumpeter, 1934, 1943). More modern approaches conceptualise innovation as an open, complex, interactive process that involves many businesses and external organisations as well as broader knowledge networks and policies. The in-house innovation perspective focuses on the internal processes, structures, resources, and capabilities of the innovative organisation. It highlights the importance of organisational culture, human capital, and other internal factors that shape the innovation process. This perspective has provided valuable insights into how to foster an innovative culture within organisations.

On the other hand, the open innovation perspective emphasises the role of external networks, markets, and governmental policies in driving innovation. This perspective recognises that innovation often results from the exchange of ideas and knowledge between organisations and their stakeholders. It highlights the importance of collaboration, partnerships, and other forms of inter-organisational relationships in shaping the innovation process.

While both the in-house and open innovation perspectives have valuable insights to offer, there is a growing consensus that there is a need for more pragmatic approaches based on the synthesis of these two logics. Already in 1985 an attempt to synthesise Schumpeter's insight and Herbert Simons systemic thinking resulted in the seminal book of Nelson and Winter (Nelson & Winter, 1985) where it proposed an evolutionary perspective of the innovation activities. This evolutionary perspective, however insightful, still remain a macro level of analysis. Hence, there is a need to understand the micro dynamics of innovation processes. Synthesising the two perspectives (in-house and open innovation systems) would presumably provide a more comprehensive and efficient management of the complexities of innovation processes. This synthesis has to take into account the different types of innovation that organisations may pursue in a vast variety of contexts and organisational layers. For example, some organisations may focus on incremental process innovation at a production line, while others may pursue radical product and process innovations or radical market innovations (e.g. new digital business platform models). It is the main objective of this paper to explore how a pragmatic and effective synthesis of perspectives may be achieved through a model thinking mode combined with terminologies from a new innovation management standard. A secondary objective is by examples to provide a first indication on how this may translate to improved insight and assist the management of an innovation system. Finally, by introducing a systemism model perspective, the paper contributes to identification of topics for further research.

The Open Nature of the Innovation Systems

It can be argued that all innovation is an open context process embedded in a complex web of national regional, sectoral, and local ecosystems. The literature of National Innovation Systems (NIS) and Regional Innovation Systems (RIS), in particular, has emphasised that innovation is a social and systemic phenomenon. This research tradition explored since the late 1980s the interrelationships between firm level exploration and exploitation of knowledge and external knowledge providers, many of them public, and the important role of governance and policy in shaping these dynamics. The concept "national innovation system", first coined by Freeman (1987), became an important analytic for studying what determined the innovation impact of those interactions (Lundvall, 1992; Nelson, 1993). According to NIS, innovation within organisations is therefore first and foremost a goal-oriented social process spanning many different intramural and extramural social contexts and organisational layers and is therefore shaped by a variety of contextual factors, including the institutional and regulatory environment, the distribution of knowledge and skills within the system, and the availability of financial resources. Another related strand of literature is that of the triple helix (Etzkowitz & Leydesdorff, 2000; Etzkowitz, 2008; Carayannis & Campbell, 2009). The triple helix framework highlights the interplay between university, industry, and government in shaping the innovation process in knowledge economies. Malerba (2009) has on the other hand emphasised the importance of sectoral innovation ecosystems in shaping innovation. According to this approach, different economic sectors have distinct patterns of innovation and technological change, which are shaped by the specific characteristics and conditions of each sector. In his 2002 paper, "Sectoral Systems of Innovation and Production", Malerba argues that the interaction between firms within a sector, as well as between the sector and its surrounding environment, has a significant impact on the innovation process of individual firms within the sector. He suggests, therefore, that the sectoral context should be taken into account when analysing innovation, as it can influence the development and diffusion of new technologies throughout the knowledge interactions in the value chains, the firm structure of the industry, and the competitiveness of the firms within the industry.

The literature on business and innovation ecosystems refines the ideas proposed by NIS and sectoral innovations systems and emphasises in particular the fact that companies co-evolve capabilities around a new innovation. The notion of "ecosystem" is flexible and fluid, and it suggests a vague collection of organisations with blurred, dynamic boundaries. It may span across sectors, clusters, and often local agglomerations. The actors in the ecosystem engaging in co-creation of innovation never occur exclusively within individual nodes of the ecosystem, but they almost never involve the entirety of the ecosystem either. Higher education innovation ecosystems especially seem to play an important role in supporting innovation by providing the necessary resources, competences and skills, and network interactions and infrastructure for innovation to occur. For example, local universities and research institutions can provide access to expertise and knowledge, while local networks and communities can provide access to funding and mentorship (Kaloudis et al., 2019). Yet, there is not a clear distinction between the notions of innovation ecosystems and national, regional, and/or sectoral systems apart from the idea of knowledge co-creation occurring within the fluid boundaries of the ecosystem (Oh et al., 2016; Cai et al., 2020). And even the idea of knowledge co-creation is ubiquitous in the entire literature of innovation studies since the 1990s, as they have studied minutely interaction processes between the actors of the "system".

In short, there is a consensus in the innovation studies community of scholars that we need to better understand and better manage the micro-dynamics of innovation processes occurring within "innovation ecosystems"; at the same time, however, there is a shortage—a vacuum—of conceptual developments and theoretical ideas for a more precise and practical methodical and methodological approaches. This paper aspires to contribute to the closing of these gaps by proposing a new methodological approach with emphasis on the complexity and emergence phenomena encountered in systems of systems, starting with an inquiry of the ISO 56000 approach towards innovation.

The ISO 56000 Approach to Innovation

"System of systems" as a notion refers to a complex network of multiple systems, each of which is a complete and autonomous system in its own right, that are connected and integrated to form a larger and more complex system. The system of systems is characterised by decentralised decision making, cross-system coordination, and inter-system collaboration and is designed to address problems or challenges that cannot be solved by a single grand system alone. The management of a system of systems therefore requires a holistic and interdisciplinary approach, considering the interdependencies and interactions between the constituent subsystems both within a specific organisation (or network of organisations) and its local, regional, national, and sectoral environment.

The ISO 56000 standard on innovation management defines innovation as a new entity creating or redistributing value (ISO, 2020). The definition is meant to be broad and neutral and with a wide opening of interpretation of innovation types (product, process, service) and impacts (financial, environmental, social, etc.). When focusing on entrepreneurship, one possible pathway for implementation of a new entity, innovation may be described as a combination of invention and commercialisation (Aulet, 2013). In the perspective of an existing large organisation, innovation may be perceived as the outcome of an innovation process based on defined market needs to the realisation of the first use of a qualified solution. The qualified solution is then adapted and further developed based on learning by using dynamics, and these dynamics connect innovation and continuous improvement tools (DUI), such as the LEAN process (Tverlid, 2020).

Open innovation is based on a logic of abundant knowledge. It has been defined as "…the use of purposive inflows and outflows of knowledge to accelerate internal innovation and expand the markets for external use of innovation, respectively" (Chesbrough et al., 2006). Collaborative research and innovation—connecting people from different organisation in open innovation—faces challenges related to alignment of expected value of collaboration, allocation of ownership, and access to immaterial values, as well as the finding of funding for different stages and activities in the innovation process (Chesbrough, 2015; Chesbrough et al., 2018). These perspectives on innovation indicate mechanisms, interactions, and dependencies similar to the behaviour of a complex system.

Complex systems demonstrate irreducible uncertainty with regards to the outcomes of their processes and their impacts (Sornette, 2006). This uncertainty is often linked to nonlinearities between cause and effect. This leads also to sensitivity to initial conditions, path dependency, and emergence phenomena, as well as feedback and feedback loops (evolutionary processes). Such an understanding of a system challenges traditional "orthodox" approaches within economics and management for several reasons, which is why complex systems are regarded as a new scientific methodological paradigm. However, within innovation studies—and increasingly within entrepreneurial and innovation policy makers—there are many scholars arguing that system complexity and evolutionary dynamics (Nelson et al., 2018) is the rule and that many knowledge and innovation processes exhibit clear nonlinearities and power law distributions (Katz, 2016).

We argue therefore that innovation must be understood as a *complex system* with many contributing components at different levels (within the system of systems), such as variations in activities, network of people and management, and alignment of objectives. The complexity of the process combined with the expected uncertainty of the outcome indicates that management of innovation thereby represents a challenge. A prerequisite for a management system is the existence of the system to be managed. In order to fully comprehend the behaviour of a complex system, insight into elements of the system as well as the *emerging* properties of the system is essential. Insight into the system benefits from understanding the different levels of abstraction of various system elements, as well as interactions and dependencies among objects and agents, both within the system boundaries and between the system and its environment.

Systemism and a New Innovation Metamodel

Below we introduce a generic model approach to innovation systems that respects the vast knowledge we now have about the complexity of innovation processes and their diffusions. The model must be simple, flexible, and versatile, i.e., to be able to be applied in a variety of innovation management decision situations and contexts. Inspired by the quote by George Box (1976) "all models are wrong, but some are useful", we believe that there is a need for such a modelling exercise.

A *systemism approach* is used as a basis for formulating a model for an innovation system. This is centred in the following postulates as defined by Bunge (2000):

1. Everything, whether concrete or abstract, is a system or an actual or potential component of a system.
2. Systems have systemic (i.e. emergent) features that their components lack; hence, all problems should be approached in a systemic rather than in a sectoral fashion.

3. All ideas should be put together into systems (theories).
4. The testing of anything, whether idea or artifact, assumes the validity of other items, which are taken as reality benchmarks.

A system approach also implies not only the acknowledgement of a set of relationships and the interaction of different strength and direction between different system elements but also *that the system has emerging properties*—the whole is greater and qualitatively more complex than the sum of the parts.

In this paper, we adopt the definition of emergence as presented by Bunge, i.e. that an emergent property of a system is a global property not possessed by its elements (Bunge, 2003). The CESM metamodel developed by Bunge characterises a system in generic terms and within a framework consisting of the composition (C), environment (E), structure (S), and mechanisms (M) (Bunge, 2003, 2004). The CESM model of a concrete system σ states that any system σ may be modelled as $\mu(\sigma)$ at any instant, as a function of the quadruple:

$\mu(\sigma) = F(C(\sigma), E(\sigma), S(\sigma), M(\sigma))$, where

- σ denotes the specific system we need to model.
- Composition $C(\sigma)$ denotes the set of parts of σ. This will typically be represented by an ontological hierarchy of objects.
- Environment $E(\sigma)$ denotes the collection of environmental items that act on σ or are acted upon by σ. This will normally be represented by systems that are outside (excluded from) the target system but act upon, or are acted upon by, the target system.
- Structure S (σ) denotes the structure or set of bonds or ties that hold the components of σ together. This is often represented by hierarchy of authority, responsibility, and dependencies among system agents.
- Mechanism $M(\sigma)$ denotes the mechanisms or characteristic processes of σ.
- The function F represents a nonlinear dynamic system on the subfactors of σ: ($C(\sigma)$, $E(\sigma)$, $S(\sigma)$, and $M(\sigma)$). We assume that the interactions among the subfactors are usually represented by nonlinear differential or difference equations operated on by control parameters that *can* lead to different regimes of organisation known as "attractors". The intuition here is that it is not possible to derive a mathematical analytical expression to guide deterministic or probabilistic predictions about $\mu(\sigma)$.

Since the CESM system model is complex, the capacity for emergence is present. And the management of complex systems should be based on models and methods enabling the probing of desired emergent phenomena (i.e. beneficial innovations and positive innovation impact in the context of this paper). This is somehow a different—but not entirely different—managerial philosophy when compared to a linear managerial thinking, i.e. the management of inputs, throughputs, output processes in order to achieve predefined strategic objectives.

As the system behaviour $\mu(\sigma)$ can be understood and specified at different levels of abstraction, each of the elements in the CESM metamodel should also be addressed at different levels of abstraction. When modelling a system, the different levels of abstraction can be described by a hierarchy of objects, authorities, responsibilities, and functions and actions (DNV, 2022).

A high-level metamodel with some of the key characteristics may be defined as shown in Fig. 1.

When applying the CESM model to innovation processes, the new ISO 56000 standard for innovation management provides additional useful complementary terms and definitions, such as the following:

- Innovation—new or changed entity, realising or redistributing value.
- System—set of interrelated or interacting elements.
- Innovation system—system with regards to innovation. In a note to the definition, the standard states that an innovation system can be related to a country or nation, e.g. a national innovation system, a region, an industry sector, an entire or part of an organisation, a cluster or network of organisations, a community of practitioners, or any value network or ecosystem of various interested parties.
- Management—coordinated activities to direct and control an organisation.
- Organisation—person or group of people that has its own functions with responsibilities, authorities, and relationships to achieve its objectives.
- Open innovation—process for the management of information and knowledge sharing and flow across the boundaries of the organisation with regards to innovation.
- Process—set of interrelated or interacting activities that use inputs to deliver the intended result.
- Innovation activity—activity with regards to innovation.

Two intuitive descriptive elements of the innovation system are the *mechanisms* and the *composition of the network*. Mechanisms can be directly related to the term "innovation process". The process will include a set of interrelated or interacting activities aimed at innovation (the outcome). Innovation as such is an outcome implying interaction with networks and the social and technical environment; hence, the process element may be limited to the creation of a new or modified entity (e.g. solution). Elements on a lower level of system abstraction for the creation of the

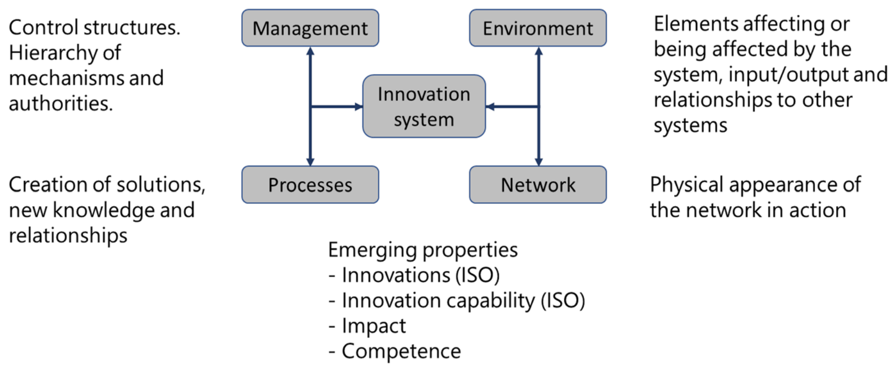

Fig. 1 Key characteristics of a metamodel of an innovation system based on Bunge (2003, 2004)

solution may be the eliciting of (innovation) ideas, concept development, development and validation of prototypes (products or services), etc.

The ISO definition of open innovation highlights the sharing and flow of knowledge across organisations. As an element of the mechanism (processes), knowledge building and network creation are therefore included as sub-processes in parallel to the process that delivers a solution, as the overall process will deliver change relative to defining the new entity creating value (innovation), change in knowledge base (outcome from research, experiments or development activities), as well as changed network relationships.

Innovation ecosystem or innovation networks (Tidd & Bessant, 2018) represents Bunge's *composition part* in our innovation system model. Innovation networks may be depicted as a hierarchy of hierarchies with different organisations on one level and contributing elements of each on a lower level of abstraction (e.g. researchers and laboratories for a university or production assets, operational assets, and operators for a commercial organisation). Typical elements of the network composition are academia, industry, public entities, investors, entrepreneurs, etc. Depending on the system considered, some typical network elements as listed may represent a part of the system or part of the environment, depending on whether the network element in question is directly affected by the structure elements of the system in question or not.

The metasystem we suggest allows for both coordination mechanisms and for gatekeepers; hence, the term system management is an appropriate node in our metamodel of an innovation system (Fig. 1). Innovation management encompasses a variety of possible elements (i.e. establishing vision, strategy, policy, and objectives) within different levels of system hierarchy. Three key tasks for management are the management of context(s), assets, and activities.

The *context* for an innovation system should be interpreted as defining the goals and priorities for the system, based on input from and conditions imposed by the environment and the ecosystem. This will guide the value or values to be pursued in the innovation process. Management of assets includes management of both the organisation/people and intellectual property. Innovation processes, as other temporary processes, benefits from project management. A project is defined as a temporary endeavour undertaken to create a unique product, service, or result (PMI, 2013); hence, an innovation process may be considered a project or a combination of activities. Key mechanisms in the management model are contracts and/or formal agreements regulating roles, responsibilities, and ownership and access to intellectual property emerging from the innovation process.

Finally, the environment node in our metamodel includes a collection of items that act upon or are acted upon by the innovation system. From a "system of systems" perspective, the environment may also be described by a CESM metamodel on its own, e.g. a national innovation system. Elements that clearly will influence the innovation system we want to model are funding sources, market mechanisms, and demand/trends/preferences but also regulations such as within a domain or legislation related to intellectual property, market competition, data privacy, etc. On the other hand, the degree of adoption/diffusion of the output (innovations) from the innovation system will have an influence on the economic and social environment, that is, it will have an *innovation impact* (Fig. 2).

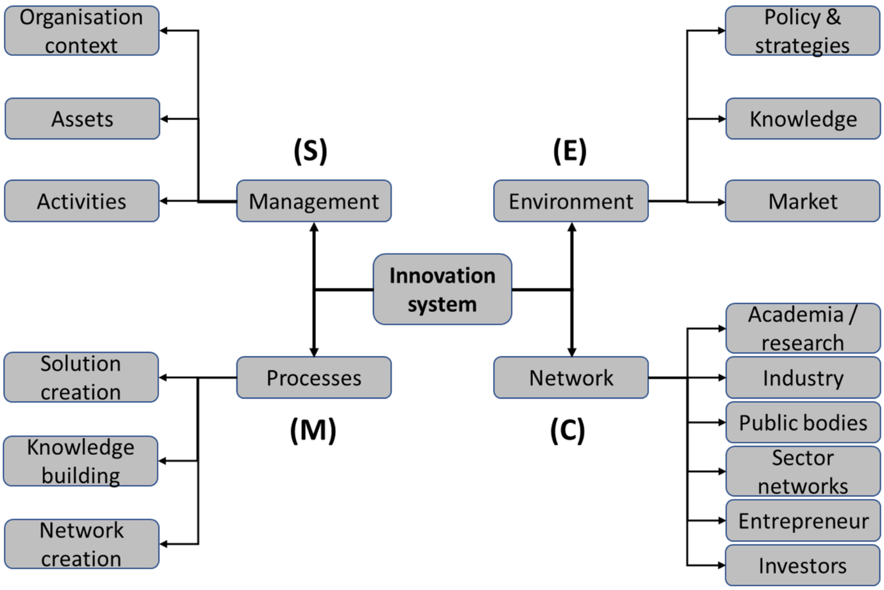

Fig. 2 An illustrative model of an innovation system for a network of organisations on two levels of abstraction

The Emergence Properties of the Metamodel

The CEMS-model may be applied not only at different levels of abstraction but also as subsystems of larger systems. A research centre or a company may represent one complex innovation system in its own right. Concurrently, it is also connected to several other larger innovation systems (system of systems). The point here is that the complexity of the overall innovation global, national, and regional systems is echoed within a single (sub)system and vice versa, the complexity of individual subsystems contributes to the emergence of complexity in the higher order systems. However, these system-subsystem interactions are not active and significant all the time and in all circumstances. The role of a good model is precisely to single out the most salient elements of the four systemic components and flesh them out in a sufficient degree of detail in such a way that enables strategic awareness and accurate and timely action.

Hence, complex systems can be characterised in different ways and with varying degree of precision when people refer to "emergent properties" of the system, reinforced by a variation in perspectives, e.g. in philosophy and engineering (Johnson, 2006). In this study, emergence is considered properties of a system that is not a property of any single element of the system but is still a feature of the system as a whole, i.e. the system is qualitatively more and different when compared with the sum of its parts.

We argue that it is useful to understand innovation as *a weak emergent property* of the innovation system in which it is embedded, as it emerges from the interaction and interdependencies of the system and its environment. This can best be understood on lower levels of abstraction, e.g. the sum of activities combined in an innovation process (as a sub-level of the mechanism) is not sufficient on its own to result in an innovation. Combining the innovation process with, e.g. management (structure) and value creation by interaction with the network and environment, innovation may be treated as an emerging property of the innovation system. Knowledge creation, competence development, and innovation capability may also be understood as emergent properties in a similar manner.

The ISO 56000 standard states that "the resulting impact of innovations is generally both the realization of value and the redistribution or even destruction of value across a chain, network or ecosystem of interested parties" (ISO, 2020). Consequently, innovation impact may be perceived as a *strong emergent property* since it is not dependent only on innovation (sub)system, but it is also shaped by the mechanisms and pressures within higher-order systems, e.g. it depends on policy mechanisms, market responses, or international regulations, in order to reinforce a wider adoption of the innovation in question.

Applications of the Metamodel

The innovation system metamodel presented above is generic and needs to be developed in order to inform decision making in a specific organisational and systemic context. In this section, let us assume the perspective of an academic institution. We shall demonstrate possible adaptations of our metamodel in order to enlighten organisational decision making within a range of diverse areas and tasks such as knowledge management, management of intellectual property, and development of new projects, as well of assess how to monitor innovation contributions from the system.

Application 1—Knowledge Management and Competence Building in Collaborative Research Schemes

$\mu(\sigma)$ as shown in Fig. 2 above only represents a model of a system, hence a reduction and simplification of reality (real world). However, models are valuable means to, and source of, knowledge and have a function as mediators of such knowledge. Morgan and Morrison (2010) describe how models serve a number of functions such as serving as instruments for the exploration of theory, allowing us to represent a system and offering us the ability to enhance learning through construction and manipulation. For an innovation system, knowledge management is relevant both regarding the knowledge of the innovation system itself and the knowledge required to successfully capture the new entity and value required for innovation (i.e. ISO-standard requirements for an innovation). According to ISO 9000, competence is defined as the ability to apply knowledge and skills to achieve intended results. From a complex innovation system perspective, competence represents a long-term emerging property of an innovation system, which in turn it supports multiple possible innovations emerging from the same innovation system.

In collaboration between an academic institution and other stakeholders from industry and public entities, there are large variations in incentives, perspectives, and level on knowledge and understanding of what an innovation system is. A depiction of a system model is often useful tool to identify differences in perspective with respect to what competencies are needed and how is best to develop them. In any innovation process, there are several types of knowledge interactions that occur between the elements of the system:

- The evolution of a new solution (innovation process) based on input from the environment (e.g. trends or demand) and network (current solutions).
- The interaction between change in knowledge (learning, e.g. through research and development, with relationships to the larger research system) and application in the innovation process towards a defined goal.
- The increased system knowledge by the combination of the new conceptual knowledge, manufacturing knowledge, and utilisation knowledge—key elements in system knowledge and learning curve theories (Neij et al., 2003), dependent on the process, network, and environment.

This may help developing a deeper understanding of the need for diversity and competence within the various knowledge elements in a well-functioning innovation system (Table 1).

Application 2. Management of Intellectual Property in Collaborative Research

There is an increasing expectation from modern universities to engage with research-based innovation activities through research collaboration activities with the industry. Knowledge and experience with management of intellectual property (IP), however, vary among the members of the faculty; in fact, to a large extent such experience is missing (WIPO, 2020). Evidence shows that there may be large differences between governing principles for management of intellectual property as defined in the contractual framework for the co-creation and the preferred operational solutions between academics and the industry partners (Gorbatyuk, 2020). Value capture from an innovation process may partly be

Table 1 Example of innovation system competence elements.

System element	Relevant competence and knowledge elements
Management	Strategies and policies, project management, innovation management, intellectual property management, basic contract law
Process	Innovation process, methods and tools in innovation activities, intellectual property management, utilisation mechanisms, business models and valuation, assurance case/validation, communication
Network	Industry value chains, regulatory governance, manufacturing, operational practice, service models
Environment	National policies and funding mechanisms, business models, trends, legislation and regulation, state of the art in a specific domain

embodied in IP and IP rights, and the value created from IP rights is an emergent property that cannot be predicted by examining the elements alone. A system model may contribute to illustrating both some of the elements contributing to this complexity, and the need to understand the interactions at a lower level of abstraction in order to identify and follow up good practices in managing the contentious area of intellectual property rights.

Figure 3 provides an example of complexity related to the management of intellectual property in open innovation:

- The legal framework, based on a structure of overarching regulation by laws in combination with employee and project contracts.
- Management of intellectual assets, including control of background intellectual property, combination of background and foreground intellectual property, as well as ensuring non-violation of already registered rights (pre-existing intellectual property such as patents or copyright).
- Allocation of ownership and access rights between network actors which typically may involve negotiations of allocation of ownership and access rights for different purposes (e.g. research or commercialization) or market segments.

A success factor for open innovation, and in particular where co-creation between research institutions and commercial actors takes place, is to achieve a successful knowledge transfer. A premise for this is a common understanding of the goal (context) for the cooperation, though it is also imperative to meet expectations from different actors for utilization of results, and the implication this has for management of intellectual properties as described with different perspectives by Chesbrough et al. (2018) and Egelie (2019).

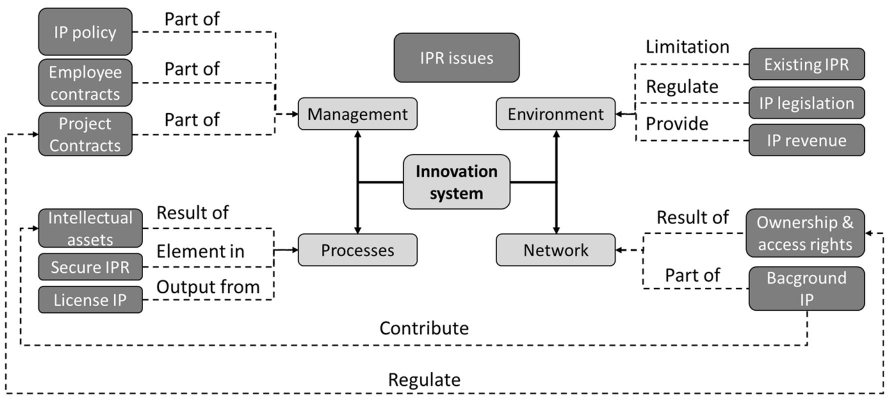

Fig. 3 Example of interactions and relationships related to intellectual property

Application 3. Risk Assessment of New Projects

Collaborative innovation projects represent an innovation system on micro-level. During development of the project, the innovation model is useful assistance in assessing and predicting unwanted or unanticipated emergence (project risk as a weak emergent property) (Fig. 4). If we adopt the ISO definition of risk as the "effect of uncertainties on the expected result", uncertainty may be reduced by ensuring that the project definition is consistent with key elements of the proposed system model, e.g.,

- Goals and objectives, i.e. expectations, are aligned between the elements of the network as well as sources of external funding.
- Composition of the network is aligned with the knowledge and resources required for the solution sought as motivated by market relevance.
- Control mechanisms are aligned with the processes planned as well as funding and resources allocated.

Discussion

The innovation system metamodel presented above is not a "silver bullet". It is rather—we believe—a step in the right direction, and it is to a large extent complementary to other innovation system models. The advantage of our model is that it enables a synthesis of an "in-house" and open system approach to assist increased understanding of innovation processes from different perspectives within the innovation system of systems. The model can be deployed and developed in as much detail and level of abstraction as needed, depending on the analytical and managerial needs of its user. An extended example of levels of abstraction is shown in Appendix. The model is illustrated in the perspective of the ISO standard on innovation management, as the standard is relevant for individual stakeholder in an innovation system.

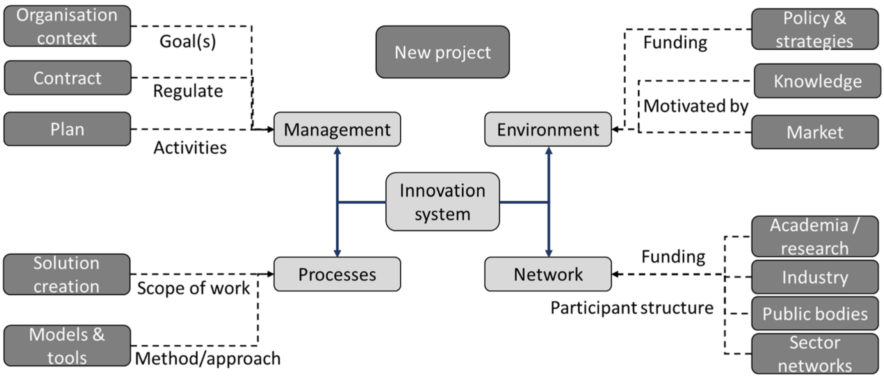

Fig. 4 Example of elements to be managed in the design of a new collaborative project

ISO defines a management system as the "way in which an organization manages the interrelated parts of its business in order to achieve its objectives". The metamodel for an innovation system presented here may represent a useful complementary model to understand the position and role of an individual organisation in a larger innovation system, and hence the strength and weaknesses of applying the management principles offered by the new ISO 56000 management standard. Relevant elements not included as examples are aspects related to roles and responsibilities as well as monitoring and measurements.

Roles and Responsibilities

Based on the examples above, the system model may assist in a common understanding of the need and relevance of various roles and responsibilities for a well-functioning innovation system. In any management system, allocation of responsibilities and the roles ensuring process control and execution of plans are essential. In Table 2, examples of such roles and responsibilities, based on the metamodel presented, are defined.

Monitoring and Measuring

Monitoring and measuring innovation represents a challenging task. In an ISO management system, such as the ISO 56000, performance evaluation serves as an important part of the plan-do-check-act continuous improvement cycle. The model will provide limited contribution on the challenging question of how to measure innovation, but the model contributes to the understanding of innovation as an emerging property of a complex system. If we accept that innovation represents an emerging property, the acceptance of the complexity of measuring it will be easier. NTNU has assessed alternative potential indicators for university contributions to innovation (NTNU, 2023). In the pilot, innovation indicators representing four fundamental dimensions of academic innovation system was applied:

(a) Direct commercialization results (patents, IPR-licensing, spin-offs) including non-pecuniary agreements for licensing of IPRs.

Table 2 Aspects related to roles and responsibilities in an innovation system

System element	Aspects related to roles and responsibilities
Management	Management (strategies and policies, goals, priorities), project manager (managing activities), innovation manager (managing innovation process), legal and HR support (contracts)
Process	Research staff (covering different disciplines), technical staff (operation of infrastructure), designers (ensure fit-for-purpose), software engineers (delivering digitalisation), technology transfer office (execution of knowledge transfer)
Network	Project board (supervision of project), activity management (responsible for execution of activities), research staff (contribution to innovation process), operations, sales, and aftermarket experience
Environment	Authorities (policies, regulations, and RDI funding), customers (demand), market regulators (competition rules), NGOs (group interests), public at large (acceptance)

(b) Funding: the ability to attract innovation funding.
(c) People: the complex interactions of people engaged, e.g. in HEI innovation activities.
(d) Networking: the number and the reach of the networking activities between the academic environment, economic actors, and the broader society.

Although some of the indicators investigated by NTNU are procedural innovation indicators most relevant for an academic actor in the innovation system, the majority of indicators are relevant for the new system model. These include the following:

(a) Commercialization results—as an element of the management of intellectual property registration of patents, license agreement may be recorded over time.
(b) Funding—as all activities in the innovation process will require funding, and typically are formalised through contract, the volume of funding of the system may be recorded.
(c) People—this is a set of indicators relevant for a university and includes cooperation with network partners on student thesis and recruitment of students to network partners at end of education; in a system model, this would represent an element of knowledge transfer.
(d) Networking—indicators here may represent both the size and composition of the network and the quantitative number of network activities in during the innovation processes.

Conclusions

In order to manage an innovation system, as when adopting the ISO 56000 management standard, the system being managed should be understood and defined. The most important reason being that stakeholders of an innovation system need a common system description as a powerful internal communication and coordination tool for decision making and for culture building.

This paper suggests a new model approach for managing innovation processes. This approach has been inspired by the systemism philosophy of Mario Bunge. Our CESM-model contributes to explicitly model relevant interactions among stakeholders in the innovation system as a means to address and capture the systemic and emergent nature of innovation processes. The point with this (meta)model is that it can intersect (sub)systemic levels of abstraction when this is relevant in guiding management of innovation processes and actions. From the perspective of an academic institution, the CESM-model can be utilised in practical management decision making by taking into account interactions within academic ecosystems (that also encompass organisations in public and private sectors) and relevant interactions with higher systemic level policy organisations outside these ecosystems. We also demonstrate the usefulness of our model by highlighting typical management aspects relevant for innovation processes.

This discussion invites also to a critical scrutiny of all CESM-models as abstractions and begs the question of what types of data, measurements, and qualitative information are needed to improve model designs in the future. In other words, a useful model of a specific innovation system (e.g. a research centre) must provide the possibility to assess potential risks and opportunities and key success factors related to any management decision alternatives. In the case of the NTNU, the CESM-model seems to provide insights regarding actions needed to support and ameliorate the local innovation system of a university centre or a university department. It is in this sense that indicators of how universities contribute to innovations, as recently developed by NTNU (Kaloudis et al., 2019; NTNU, 2023), enables a systematic data collection on how actions and decisions impact the environment and vice versa. Other current innovation policy work at NTNU includes research on possible formats for measurement of impact (emerging properties and impact on the larger environment), and establishment of operational decision support for managers (management of knowledge transfer of outcomes of the solution creation process). All these actions are aligned with the systemism model approach and contribute to identify the most relevant interactions in the CESM-models for various types of underlying innovation management decisions.

An important insight from the CESM examples presented is the modelling complexity when applying the CESM model in innovation, both on selecting the depiction of relevant systemic levels and interactions between system elements. The CESM model highlights the interactions between the different elements of the innovation system and their impact on the emergent properties and behaviours of the system as a whole. This can help to identify areas of improvement and to manage the innovation process more effectively. Expanding the system understanding by assessing dynamic system properties such as system constraints, capabilities, and resilience (Meadows, 2008) may further increase the usefulness of the model for innovation management purposes.

The social characteristics of the innovation system is an aspect that needs to be at the front of the CESM-research agenda, and they should be properly addressed in many of the bonds/relationships within the innovation system. It is an unfortunate limitation of the work presented here that we do not have the space for a more comprehensive reference to these social aspects. We do believe the model itself presents a new viewpoint for research on social characteristics shaping the strength and the direction of systemic knowledge interactions in the model design of management mechanisms.

As an example, we can contemplate briefly one key social factor, that is power relations. These can be complex, and we know that innovation processes are shaped by power relations in knowledge networks (Avelino, 2021). For example, power relations may directly affect the capacity to achieve common objectives (typical precondition for a successful intended system change) and they should be more carefully investigated. Key power relationships that could be on the forefront of the analysis are the following:

– governance mechanisms in knowledge management such as influence over research and rights to results (consensual or conflictual, contractual versus trust based, power balance, and motivation to contribute to common objectives and influence on actual change);
– reward and incentives in universities for knowledge co-creation processes with industry, e.g. researchers incentives and motivation to co-innovate, such as gold, ribbon, and puzzle (Lam, 2011).

Having said that, a generic and management-oriented model should always allow for many possible and different configurations of social arrangements within a specific innovation system design. The modelling challenges consist of the following: a) to select a relevant system ontology; b) design and capture all interactions between systemic levels that are relevant to the concrete management situation the model shall be applied for (e.g. develop an innovation strategy for a university department); c) decide the role of social aspects that are likely to shape the strength and the direction of the interactions depicted in the model. In this paper we concentrated our analysis on the necessary properties a model must have to accomplish task (a). An analysis of the task (b) implies adjusting and detailing the (generic) model to fit the structure of the local social fabric of the system under scrutiny. As Lundvall (2007) points out, special attention must be "given to institutions and capabilities supporting learning. I point to the need to give more emphasis to the distribution of power, to institution building, and to the openness of innovation systems".

We believe that the systemism approach to the innovation system as presented represents a relevant approach for designing features of systems with respect to specific management decision making tasks. We need concrete case studies to assess how versatile and how useful the systemism CESM-model actually is. In the future, therefore, we intend to further develop and extend the systemism metamodel approach, through a series of concrete case studies of innovation management processes and competence building, starting with the case of Norwegian centre for research-based innovation (SFI).

For a university, models of its multitude of innovation ecosystems together with a comprehensive (and perhaps qualitative) analysis of key CESM bonds should be of particular interest. For example, an understanding of the mechanisms that render universities to provide "solution creation", the coexistence of parallel knowledge dynamic mechanisms exist, such as mode 1 and mode 2 research as well as doing-using-interacting (DUI) approaches. Within mode 2, alternatives as science and technology innovation (STI) and research design science (RDS) processes co-exists, where, e.g. in academia-industry cooperations all such processes will at some stage face a technology transfer subprocess and alternative external innovation and stage gate models (Carayannis & Campell, 2010).

Finally, the design process of a system model is a type of learning that can be coined as "learning by modelling" (Morgan & Morrison, 2010). A good CESM model is a forecasting tool, it is a decision-management tool, a coordination tool, and a communication tool between stakeholders in the innovation system. To quote Mario Bunge (2004), "The systemic approach advocated here is not a theory to replace other theories. It is, instead, a viewpoint or strategy for designing research projects whose aim is to discover some of the features of systems of a particular kind."

Appendix: Example of extended CESM model of an innovation system

The CESM metamodel may be developed to different levels of abstraction, each level with increasing level of detail and number of elements. An example of possible elements on a lower level of abstraction is illustrated in Fig. 5. The figure is an example only and not intended to describe a complete model of this complex system. As an indication, the box "Science and technology-based" process element may be further refined in the ISO 56002 (2019) sub elements/activities of such a process by expansion to identify opportunities + create concepts + validate concepts + develop solutions + deploy solutions.

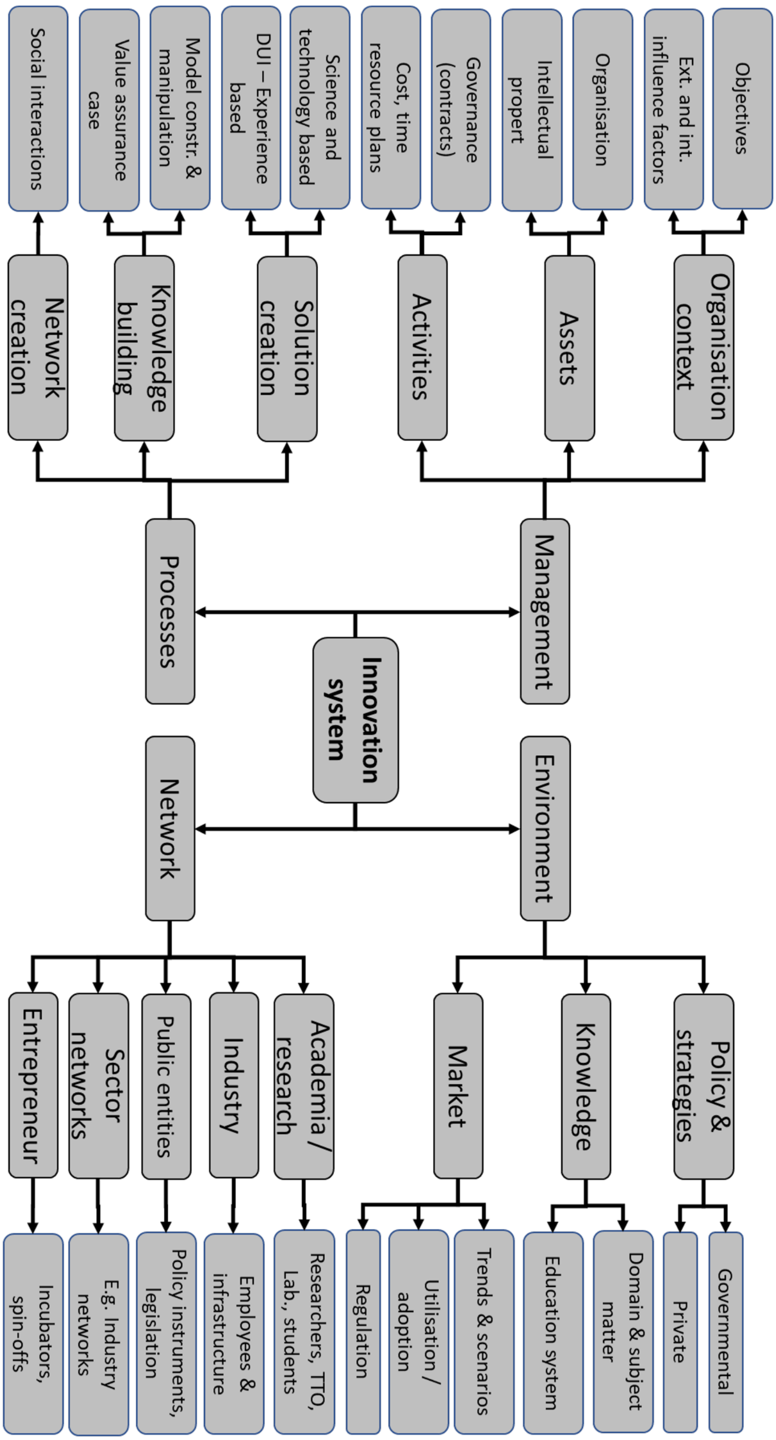

Fig. 5 An illustrative model with multiple levels of abstraction

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Declarations

Conflict of Interest The authors declare no competing interests.

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