How to Radically Innovate in Emerging Defense Ecosystems?

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Abstract

Radical innovation is the most critical driver for latecomers' catch-up. In this regard, while scholars doubt the emergence of radical innovations in the South, various success stories prove otherwise. On the other hand, the intensification of geo-strategic and geo-economic competition between great powers and the occurrence of the global technological revolution promises a fundamental transformation in the nature and distribution of global power, with radical innovation as an urgent priority for the world's military powers. Accordingly, this article first develops a radical innovation framework for emerging defense ecosystems based on the content analysis of 27 interviews with defense innovation experts. The drivers and sub-dimensions of the framework are then prioritized with fuzzy AHP, according to a survey answered by 67 experts. Culture (radical innovation importance, organizational culture, and collaboration culture), governance (policy framework, institutional framework, and organizational structure), resources (infrastructure, human capital, and financial resources), and processes (knowledge management, project management, and open innovation) are the proposed drivers for radical innovation in emerging defense ecosystems. Also, innovation resources are identified as the most crucial driver, with human capital, financial resources, policy framework, and institutional structure as the most critical sub-dimensions, respectively.

Keywords: radical innovation; innovation ecosystem; defense industry; emerging context

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Introduction

As the most critical driver of developed economies, innovation covers a broad spectrum, from minor improvements in goods to new businesses based on technological breakthroughs. Meanwhile, radical innovation includes introducing new products or services that lead to developing large businesses and new industries by creating new values (Gaynor, 2002). These innovations develop new territories and paradigms, create a capacity for grand transformations and are a vital driver for the growth, success and wealth of firms and countries (Norman, Verganti, 2014). However, reviewing innovation literature, few scholars have addressed radical innovation in latecomer countries as they suggest that these innovations probably do not develop in such a context. On the other hand, although latecomers can start the catch-up journey by imitating the leaders, replicating existing products or technologies can only be fruitful in the short run, as developing new technological pathways is vital later on (Malerba, Lee, 2021). Several successful firms in India, South Korea, South Africa, and Mexico moved up the learning hierarchy and even got ahead of the leaders using an ambidextrous strategy while investing in radical innovation (Forbes, Wield, 2002).

However, the analytical frameworks presented for radical innovation are unsuitable for analyzing and explaining such trends and processes because they have paid less attention to historical, social, external, and internal factors and the internal relationships affecting the dynamics of the radical innovation process (Uachotikoon, Utsahajit, 2019). Therefore, new approaches (e.g., open innovation and innovation networks) have studied innovation as a multiplayer and evolutionary phenomenon, with innovation ecosystems focusing on creating shared values (Gomes et al., 2016).

In the defense ecosystem, as a pioneer innovation ecosystem, the world is in the vortex of changes at the intersection of two transformative developments; intensified geostrategic and geoeconomic competition between the great powers - especially the United States and China - and the technological revolution promises a fundamental transformation in military power, resulting in global leaders prioritizing disruptive innovation (Cheung, 2021). Also, rapid development and convergence in robotics, information technology, and artificial intelligence will continue revolutionizing future battlefields (Billing et al., 2021). Technological innovations maintain armies' operational strength while reducing soldiers, thus transforming modern armies (Dyson, 2020). Furthermore, the relationship between technological innovations and military capacity dates back to the formation of the first armies, with various technological leaps resulting from military conflicts (Safdari Ranjbar, Fatemi, 2022). However, defense R&D has been widely criticized since the 1970s because of the opportunity cost, relative inefficiency compared to civilian R&D, and armies' focus on incremental innovations (Bellais, 2013). High-tech defense firms are eager to incrementally modify technologies they dominate to strengthen their position in the defense market, neglecting disruptive changes that compromise their technology portfolios or require additional investments. This conservative approach is also evident on the demand side, as armed forces promote established technologies, resisting new technologies that may alter their missions and organization (Bellais, 2009).

In addition, emerging defense ecosystems face more profound and multifaceted challenges. Emerging defense ecosystems are national defense innovation systems that are undergoing foundational development in institutional architecture, actor coordination, and policy coherence, typically marked by fragmented governance, underdeveloped innovation infrastructure, and limited experience in managing radical innovation processes within the defense sector.[1] These challenges are compounded by the sector's deep entanglement with national political and military agendas, where prioritizing defense innovation often diverts resources from other vital domains such as welfare. Moreover, international constraints severely restrict access to external expertise, as leading countries consistently refrain from transferring sensitive military technologies—even to close allies—forcing latecomers to rely primarily on domestic capacities for developing advanced capabilities (Lee, Park, 2019). In response, emerging defense ecosystems have historically pursued two divergent strategies: the "good enough" approach, which emphasizes affordable technologies tailored to regional threats, and the "golden" strategy, which aspires to match the technological sophistication of global powers through high-cost innovation initiatives (Cheung, 2014). Yet, the persistent dominance of traditional superpowers suggests the limited success of the latter approach, raising critical questions about the underlying barriers to radical innovation in the defense sectors of these countries.

As one of the emerging defense ecosystems, Iran's defense industry was founded by purchasing technology and importing production lines from foreign countries, especially Germany and the United States, before the 1979 revolution, within the framework of NATO's military doctrine. With foreign consultants as the primary knowledge workers, accumulated knowledge mainly included low learning and skill

[1] "Emerging defense ecosystems" is conceptually distinct from "emerging economies," which refers to a broader macroeconomic classification. For example, while countries like China and Russia are widely regarded as emerging economies, their defense innovation ecosystems are relatively mature.

capabilities. After the revolution, many foreign experts left Iran's defense industry, and the weak flow of defense innovations was interrupted by the start of the Iran-Iraq war and the resulting sanctions. As a result, the industry pursued a self-reliant approach, relying on domestic power, using limited opportunities for technological collaboration, and focusing on trial and error. Although defense R&D developed further in the post-war era, the technology gap with defense leaders is evident, especially in propulsion engines and advanced electronic systems (Ghazinoory, Vaziri, 2020).

Few scholars have studied radical innovation ecosystems, especially in the defense context, which has unique features. Also, as emerging defense ecosystems mostly have limited resources to invest, presenting a guideline for prioritizing required actions for developing radical innovation in their defense ecosystems is vital. Therefore, this article aims to develop a conceptual model for radical innovation in emerging defense ecosystems and then prioritizes its drivers and sub-dimensions with fuzzy AHP. Respectively, the research questions are: 1) What are the drivers and sub-dimensions of developing radical innovation in emerging defense ecosystems? and 2) Which drivers and sub-dimensions are most critical in developing radical innovation in emerging defense ecosystems? For this purpose, the article reviews radical innovation, innovation ecosystem, and innovation in the defense context to identify the research gap. Then, it discusses the qualitative-quantitative research methodology, presents the conceptual framework with the prioritization of drivers and sub-dimensions. Finally, the article discusses the findings while comparing them with previous studies, and concludes by presenting policy implications and possible research directions.

Literature review

Radical innovation

There are various dichotomies for categorizing innovation, including competence-developing versus competence-destroying innovation, modular innovation versus architectural innovation, and identity-challenging versus identity-sustaining innovation (Ansari, Krop, 2019). Among these dichotomies, administrative versus technical innovation, product versus process innovation, and radical versus incremental innovation are more beneficial (Costa, Monteiro, 2016).

Radical innovation is commercializing products and technologies that strongly impact the market and the firm through a simultaneous change in business model and technology, resulting in a fundamental transformation in the industry's competitive environment (Sarkar et al., 2018). Radical innovation is vital for the growth of firms and economies as it deals with creating new markets and integrating or destroying old markets. Therefore, it can push small followers toward the industry's leadership position when incumbents are locked in the current technological trajectory (Bao et al., 2019). Although scholars identify radical innovation as a strategic driver for firms' growth and renewal, empirical evidence indicates that they fail to develop strategies tailored to its complex and challenging nature (Hill, Rothaermel, 2003).

Innovation ecosystem

An innovation ecosystem is a network of actors producing or exploiting products and services focused on a shared value (Autio,Thomas, 2014). The approach combines open innovation, strategic management, organizational studies, evolutionary economics, and industrial ecology knowledge fields and has gained popularity among strategy and policy scholars (Rinkinen, Harmaakorpi, 2018). Various definitions and concepts are presented to analyze innovation ecosystems from different perspectives, the most important of which are focal (hub) ecosystems (Nambisan, Baron, 2013), open innovation ecosystems (Chesbrough, Bogers, 2014) platform ecosystems (Gawer, Cusumano, 2014), and innovation ecotones (Ghazinoory et al., 2021). While such conceptualizations indicate the flexibility of the concept, they can lead to conflicts and divergence. Also, the distinction between the innovation ecosystem and supply chain, network, and business model is vague, making knowledge integration difficult (Gomes et al., 2018). Finally, the culture, subsystems and institutions play a vital role in analyzing innovation ecosystems (Durst, Poutanen, 2013); therefore, developing a radical innovation ecosystem requires attention to the context.

Innovation in defense industries

Defense innovation varies from similar concepts, including military innovation and national security innovation. Defense innovation develops complex, high-value solutions by integrating multiple technologies and complementary skills (Barbaroux, 2019). While military innovation focuses on enhancing armies' capabilities, defense innovation also encompasses the civilian domain, particularly the dual industrial base (Cheung, 2021).

Defense innovation has unique characteristics compared to civilian innovation. Defense R&D has a lower rate of social return and higher uncertainty than civilian R&D projects. Also, defense programs are frequently postponed, their costs increase quickly, and the expected results are sometimes not obtained (Bellais, 2009). On the other hand, while commercial enterprises should pay special attention to financial efficiency, distribution and logistics, market studies, pricing and marketing to ensure their survival in the competitive environment, defense innovation focuses primarily on technical and operational efficiency (Safdari Ranjbar, Fatemi, 2022). Therefore, defense innovation requires a specific policy and management model.

Research gap

Emerging defense ecosystems face a strategic imperative to develop indigenous capabilities, and radical innovation plays a pivotal role in this pursuit. For countries lacking access to advanced military technologies due to geopolitical tensions or embargoes, the capacity to innovate radically is not merely a developmental goal but a matter of national security. By moving beyond incremental upgrades and investing in high-risk, long-horizon technological development, such states seek to reduce dependency, close capability gaps, and signal deterrent strength (Bitzinger, 2014; Irfan et al., 2023). Asymmetric innovation trajectories further enable weaker actors to challenge dominant power structures through disruptive means (Mehta, 2021), while spillovers from defense R&D can stimulate wider industrial upgrading (Safdari Ranjbar, Fatemi, 2022).

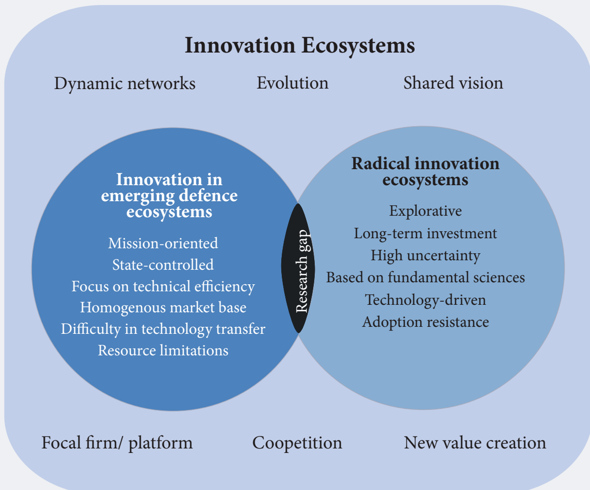
However, while the motivation is clear, the conceptual understanding of how radical innovation might unfold in these settings remains underdeveloped. Much of the literature focuses on advanced defense ecosystems in the United States (Gholz, Sapolsky, 2021), Russia (Kashin, 2018), or NATO countries (Efthymiopoulos, 2019; Fiott, 2017), where innovation is supported by mature industrial bases, stable alliances, and large-scale procurement mechanisms. A few studies examine non-Western cases — such as China (Yuan et al., 2016) and South Korea (Moon, Paek, 2010) — but these are typically framed as exceptional trajectories and do not yield a transferable framework for less resourced contexts. Moreover, existing research tends to emphasize descriptive system mapping or normative policy guidance, while neglecting the analytical tensions that arise when attempting to integrate radical innovation dynamics into politically centralized, resource-constrained defense environments.

The present research responds to this gap by conceptualizing the intersection of three theoretical domains: innovation ecosystems, radical innovation, and emerging defense systems (Figure 1). These domains rest on fundamentally different assumptions. Innovation ecosystems emphasize distributed interaction, evolving networks, and value co-creation among heterogeneous actors. Radical innovation entails long-term exploration, institutional flexibility, and openness to failure, making it highly dependent on absorptive capacity, interdisciplinary integration, and learning loops. Emerging defense ecosystems, in contrast, tend to be mission-oriented, state-controlled, inward-looking, and governed by formal hierarchies, secrecy norms, and budgetary inflexibility. This misalignment is not incidental but structural as the conceptual space in which these three domains intersect is marked not by synergy but by tension. The juxtaposition reveals that many of the conditions considered essential for radical innovation are not only absent in emerging defense ecosystems but are directly obstructed by their institutional logic.

Three interlocking tensions are central to this problem. First, there is a fundamental contradiction between the openness required for exploratory innovation and the closed nature of defense environments. Knowledge flows that fuel innovation ecosystems—through user feedback, cross-sector collaboration, and academic–industry exchange—are frequently constrained by classification, compartmentalization, and national security restrictions. Second, radical innovation depends on the capacity to absorb uncertainty and pursue untested technological paths, yet defense institutions often operate under risk-averse procurement regimes designed to ensure operational continuity. The result is a structural preference for incremental improvement over technological discontinuity. Third, whereas innovation ecosystems rely on decentralized initiative and horizontal coordination, emerging defense ecosystems are typically organized through vertical chains of command that limit agency at the organizational periphery. In such systems, entrepreneurial actors lack both institutional legitimacy and resource autonomy, reducing the potential for bottom-up innovation.

These tensions challenge the applicability of conventional innovation models in such settings. The

Figure 1. **Theoretical Framework**



Source: authors.

constraints involved are not merely technical bottlenecks or capability deficits that can be addressed through targeted policy, but deeper contradictions between innovation logic and governance logic. Attempts to apply mainstream innovation frameworks to these ecosystems without accounting for these contradictions risk overlooking the mechanisms through which innovation is filtered, slowed, or redirected. As such, the question is not how to replicate radical innovation systems under ideal conditions, but how to understand the partial, constrained, and adaptive forms innovation may take in structurally misaligned environments. This requires a conceptual approach that begins not from the assumption of functionality but from an inquiry into the points of friction where competing institutional logic collides. This research adopts such stance as it treats emerging defense ecosystems not as incomplete versions of advanced systems, but as analytically distinct fields in which innovation emerges under tension. By placing the structural contradictions at the center of analysis, this article aims to clarify the conditions under which radical innovation becomes possible, unlikely, or redirected—and to offer a basis for theorizing innovation under constraint.

Research methodology

In the qualitative research phase, data are collected through interviews to design a model for radical innovation in emerging defense ecosystems. The statistical population included three groups of experts: 1) senior managers active in defense innovation policymaking, 2) managers and researchers from organizations focused on defense radical innovation (e.g., Organization for Defensive Innovation and Research), and 3) Defense R&D project specialists with previous participation in advanced technology development projects (e.g., satellites, guided missiles, advanced materials, radar systems, and drones). As the knowledge and experience of the research subject were more crucial than the number of participants, judgmental and snowball sampling methods were combined to identify suitable interviewees. As a result, the interviews started with the participation of a group of identified experts, who then suggested other experts while paying attention to the selection criteria. Sampling considered five critical criteria: 1) critical role in radical innovation development, 2) reputation among other experts, 3) theoretical understanding of the topic, 4) diversity of interviewees, and 5) their willingness to participate. The sampling process was extended to 27 interviews to ensure theoretical saturation. The final pool of interviewees consisted of 9 policymakers, 11 institutional managers and researchers, and 7 R&D project specialists.

The interviews started with presenting radical innovation and innovation ecosystems to the interviewees, as some had engineering backgrounds and were unfamiliar with the terminology. Then, the actors, roles, strategies, and culture of defense innovation ecosystems were discussed throughout their lifecycle. Finally, the interview focused on the unique characteristics of radical innovation and its prerequisites to fully address the research question. In addition to structured probes, participants were encouraged to elaborate on their experiences and perspectives. Key lines of inquiry included: the distinction between systems and ecosystems; institutional and cultural features enabling radical innovation; stakeholder incentives and necessary reforms in defense innovation governance; and the differences between radical and incremental innovation strategies. Interviewees also provided concrete examples of radical innovation, described perceived barriers and catalysts to such innovation, and reflected on the types of collaborative arrangements required. Finally, they shared perspectives on how national innovation systems can evolve to better support breakthrough defense technologies. These interviews were meticulously recorded and subsequently transcribed for import into MAXQDA. The analysis phase included three steps: initial coding, where the data was broken down into discrete parts; axial coding, which focused on establishing connections between these codes; and selective coding, where a central category capturing the essence of the research was selected from the analyzed codes. Finally, the validity of this phase was confirmed by holding a follow-up focus group, external reviewing, and recoding of data samples through MAXQDA's intercoder agreement.

After extracting the drivers and sub-dimensions of radical innovation in the defense industry from the interviews, they were prioritized with fuzzy AHP. Although AHP is widely practiced in mathematical optimization and operational research (Liu et al., 2020), its weakness in fully reflecting the human thinking style through crisp numbers resulted in the development of fuzzy AHP (Coffey, Claudio, 2021). Comparing Fuzzy AHP with Fuzzy ANP, Fuzzy AHP emphasizes pairwise comparisons and crisp linguistic terms, simplifying the decision-making process under fuzzy conditions and enhancing clarity and interpretability. When contrasting Fuzzy AHP with Fuzzy TOPSIS, Fuzzy AHP allows the inclusion of sub-dimensions into a hierarchy and is also more agile in prioritizing a few drivers and sub-dimensions (Junior et al., 2014). Compared to Fuzzy VIKOR, Fuzzy AHP's structure enables decision-makers to systematically evaluate criteria and alternatives under fuzzy conditions, leading to more coherent and reliable decision outcomes. Lastly, in contrast with Fuzzy PROMETHEE, Fuzzy AHP's logical integration provides a more robust and transparent methodology for deriving priority weights and rankings in fuzzy decision contexts (Macharis et al., 2004). Overall, Fuzzy AHP is preferred over other MCDM techniques for this particular research as it can reflect experts' qualitative responses through fuzziness, organize a three-level hierarchical framework, and analyze and interpret a small hierarchy (with only four drivers and twelve sub-dimensions) with more agility and transparency. To implement Fuzzy AHP, a researcher-made questionnaire was designed to compare the drivers and sub-dimensions extracted in the qualitative phase. The questionnaire was distributed among 67 experts purposefully selected from participants in innovative projects within the defense industry. These individuals were national elites actively collaborating with the defense innovation ecosystem and had expressed willingness to contribute to the study. The authors had access to a curated pool of these experts and distributed the survey online to facilitate access and participation. The disciplinary backgrounds of the respondents included engineering and technical sciences (44), humanities and social sciences (18), basic sciences (1), medical sciences (3), and other fields (1). In terms of academic qualification, the sample comprised 2 B.Sc., 37 M.Sc., 8 Ph.D. candidates, and 20 Ph.D. holders, ensuring the analytical sophistication required for pairwise comparisons under fuzzy conditions. Consistent with the fuzzy AHP methodology, the respondents were asked to perform pairwise comparisons of the four main drivers and their twelve associated sub-dimensions. After validating the consistency of responses—achieving an inconsistency rate below 0.1—the data were analyzed. Based on the Chang methodology (1996), the initial matrix was constructed using fuzzy triangular scales (Samouei et al., 2016) and the geometric mean of each pairwise judgment. Subsequently, the fuzzy values of matrix elements were calculated to derive the final prioritization.

$$S_i = \sum_{j=1}^{m} M_{g_i}^{j} \odot [\sum_{i=1}^{n}\sum_{j=1}^{m} M_{g_i}^{j}]^{-1} \quad (1)$$

Then, the relative magnitude of drivers and sub-dimensions is calculated according to Equation 2, where l, m, and u are the lower, middle, and upper values of fuzzy triangles, respectively.

$$V(M_2 \geq M_1) = \begin{cases} 1 & if \;\; m_2 \geq m_1 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & if \;\; m_2 < m_1 \end{cases} \quad (2)$$

Finally, each driver and sub-dimension's weight and relative importance are calculated according to Equation 3.

$$V(M \geq M1, M2,\ldots, Mk) = minV(M \geq Mi), i = 1,\ldots,k. \quad (3)$$

Radical innovation model for defense ecosystem

After extracting and classifying primary codes from 27 interviews, twelve sub-dimensions and four main drivers were identified. These include: (1) developing radical innovation culture, (2) developing radical innovation governance, (3) developing radical innovation resources, and (4) developing radical innovation processes.

Developing radical innovation culture

Cultural transformation is widely perceived as the most foundational shift needed to support radical innovation. It involves not only modifying behaviors but challenging legacy assumptions about how innovation is conceived, implemented, and legitimized. Developing radical innovation culture includes "promoting radical innovation", "developing organizational culture", and "developing collaboration culture."

Promoting radical innovation. Organizations lock in their paradigms, capabilities, and previous investments, which act as critical obstacles to radical innovation development. Therefore, encouraging a risk-taking culture, supporting innovative activities with high uncertainty, and nurturing an alternative defense innovation discourse promote radical defense innovation. A recurring challenge is the institutional ambiguity surrounding what qualifies as radical innovation. This ambiguity often leads to conflation with incremental efforts and dilutes organizational focus. Developing formal classification systems and assessment criteria to distinguish between types of innovation would sharpen strategic alignment and reduce resource dispersion. Additionally, building legitimacy for radical innovation requires reframing it not as an occasional disruption but as an ongoing strategic necessity — one that safeguards national security through anticipatory capability development.

Developing organizational culture. Radical innovation in defense ecosystems requires more than technical breakthroughs; it depends on a flexible organizational culture that encourages learning, leadership-driven exploration, and a tolerance for failure. A rigid culture can stifle this progress, limiting the discovery of new values that often extend beyond economic benefits. Innovation environments benefit from cultivating individualism, leadership support, and shared language among stakeholders to reduce misalignment and build innovation momentum. Organizational learning mechanisms — such as after-action reviews and structured reflection — help transform both setbacks and breakthroughs into durable institutional capacity. Moreover, the cultural norms of many defense organizations remain dominated by procedural correctness rather than adaptive experimentation. Overcoming this requires not only managerial support but symbolic acts — such as awarding internal prizes for discontinued but instructive projects — to change perceptions about productive failure. Building internal narrative tools that reframe failure as "mission knowledge" rather than "error" can gradually displace the existing aversion to risk.

Developing collaboration culture. Cross-functional knowledge sharing is essential, especially in defense ecosystems where fields such as AI, robotics, and materials science intersect. Interdisciplinary teams that break down silos and foster real-time collaboration accelerate innovation. Collaborative platforms and flexible scheduling practices enhance integration, especially when innovators are granted sufficient autonomy. Moreover, recognizing innovators' contributions and securing long-term economic rights through tailored incentive systems—especially non-financial rewards — was seen as essential for sustaining high-level talent. Persistent inter-agency mistrust and rigid clearance boundaries often inhibit the formation of such collaborations. Delineating fast-track protocols for trusted partnerships and modular information-sharing agreements can reduce these friction points while maintaining operational security. In addition, the absence of shared digital environments for synchronous collaboration makes real-time problem-solving nearly impossible across organizations. Deploying secure multi-organizational platforms could streamline collaboration without compromising confidentiality. Building alliances through temporary task forces that include both internal and external innovators can also accelerate high-risk experimentation under time constraints.

Developing radical innovation governance

Governance was described as both the engine and the bottleneck of radical innovation. Current decision-making models were often mismatched with the dynamism required for high-risk innovation. Radical innovation governance includes developing "policy framework," "institutional framework," and "organizational structure".

Developing policy framework. Radical innovation typically originates from foresight-oriented visions and roadmaps that guide development. Leaders should define specific but evolving goals aligned with strategic advantage. Although goals cannot be crystal clear due to inherent uncertainty, excessive ambiguity can also hinder progress. A more structured approach to long-term policy integration would involve embedding radical innovation goals into national security doctrines and creating annual cross-sector foresight summits. These summits can serve as formal spaces to recalibrate vision documents based on emerging technological and geopolitical developments. Moreover, policies should institutionalize periodic reallocation of funds from low-impact projects to emerging high-potential areas, guided by predefined indicators of novelty, risk appetite, and ecosystem impact. Regular policy audits can ensure alignment between operational practices and the evolving innovation mandate.

Developing institutional framework. Institutional contexts must match environmental requirements for radical innovation. Collaboration among stakeholders must be redefined to facilitate open innovation in the defense ecosystem. Top-level agreements between defense organizations support decision-making and provide full backing for radical innovation. The lack of coordination among research units, procurement bodies, and regulatory authorities often leads to sequential instead of concurrent innovation cycles. This temporal misalignment slows the entire ecosystem. Establishing a tri-sector coordination council with legislative status can synchronize regulatory adaptation, procurement responsiveness, and research trajectories. Additionally, cultivating cross-institutional leadership exchange programs can foster shared mental models and strengthen informal communication lines. Furthermore, political interference was seen as a recurring disruptor that undermines consistency in innovation strategies. The institutional framework must thus shield key innovation functions from external volatility while enabling coordinated action across actors.

Developing organizational structure. Rigid defense protocols hamper creativity. Flat structures enhance participation and facilitate decision-making. To develop radical innovations, revising manager appointment criteria, removing unnecessary restrictions, and encouraging centralized, mission-oriented institutions are necessary. It is also essential to build differentiated career tracks for innovation-oriented professionals. These tracks should reward technical creativity, project ambidexterity, and cross-domain leadership, allowing personnel to alternate between R&D, policy, and field roles. This flexibility would better match the emergent needs of radical innovation initiatives and build cumulative innovation expertise within institutions. Encouraging "dual ladder" promotion models—where managerial and technical tracks are equally rewarded—can also reduce the attrition of high-potential innovators.

Developing radical innovation resources

Resource limitations were frequently cited as both structural and self-inflicted. Underuse of existing capacities and fragmentation of strategic investments often outweigh absolute scarcity. Expanding radical innovation resources includes developing "infrastructure," "human capital," and "financial resources".

Developing infrastructure. Radical innovation infrastructure, including user-participatory prototyping labs and test environments, is vital for adapting technologies to battlefield requirements. A network of integrated labs, national research centers, and Fab Labs enables faster testing and adaptation. Several facilities operate in silos with overlapping missions and capabilities. Developing a centralized infrastructure roadmap with cross-institutional access rights and real-time equipment availability databases would significantly optimize capacity usage. Furthermore, innovation infrastructure must be paired with simulation environments for scenario-based testing, especially for dual-use technologies. The lack of such simulation infrastructure often results in premature scaling or misalignment with operational realities. Embedding evaluation metrics into infrastructure usage — not just project outcomes — can improve accountability and enable strategic renewal of assets.

Developing human capital. Human capital transformation is central to radical innovation. Technology champions, guardians, and inspirational leaders drive ideas into action. Succession planning and internal knowledge transfer mechanisms help prevent critical capability loss. Leader-centered team design, backed by tailored incentives, supports motivation and performance. The current overreliance on formal degrees and traditional career progression models hinders the infusion of diverse innovation capacities. Recognizing informal learning trajectories—such as hands-on technical portfolios and hackathon performance — can diversify the talent pipeline. Additionally, the ecosystem would benefit from establishing multi-generational mentorship programs, where seasoned experts engage with emerging professionals in experimental projects. This would create continuous loops of tacit knowledge transfer and role modeling. Formalizing lateral mobility within innovation units can also help prevent the compartmentalization of expertise and distribute high performers across priority areas. It is also essential to build differentiated career tracks for innovation-oriented professionals. These tracks should reward technical creativity, project ambidexterity, and cross-domain leadership, allowing personnel to alternate between R&D, policy, and field roles. This flexibility would better match the emergent needs of radical innovation initiatives and build cumulative innovation expertise within institutions. Encouraging "dual ladder" promotion models — where managerial and technical tracks are equally rewarded — can also reduce the attrition of high-potential innovators.

Developing financial resources. Financial constraints remain a central barrier to radical innovation. A stable and independent financial base, supported by diversified research sources, ensures resilience. It is also important to distinguish between core funding for infrastructure and contestable project-specific funding. The latter must include failure-tolerant provisions and flexible reallocation mechanisms. Funding instruments such as rolling horizon grants and milestone-triggered bonuses can improve responsiveness and encourage continuous learning across projects. Moreover, innovation accounting systems must shift from fixed-output tracking to learning-based metrics—capturing adaptability, portfolio synergy, and exploratory traction. This would recalibrate incentives toward long-term ecosystem development. Developing an ecosystem-wide fund that allows resource pooling across defense and dual-use actors may also resolve duplication and allow for riskier bets.

Developing radical innovation processes

Processes are not just operational tools but the connective tissue through which ideas gain traction. Process deficiencies act as both symptoms and sources of institutional rigidity. Radical innovation processes include "knowledge management", "project management," and "open innovation".

Developing knowledge management. Radical innovation depends on dynamic knowledge ecosystems. Beyond formal documentation, the integration of tacit and explicit knowledge supports sustained exploration. To address this, defense organizations need structured knowledge repositories, idea generation systems, and thematic learning hubs. The inconsistent categorization of knowledge across units creates retrieval barriers. Developing a shared ontology — classifying innovation knowledge under unified taxonomies — would streamline access and accelerate reuse. In parallel, incentives for real-time documentation and codification must be institutionalized so that knowledge does not remain locked within individual projects. Integrating codification into performance metrics could align documentation with professional recognition. Establishing communities of practice within and across organizations would support live problem-solving and break isolation around emerging knowledge areas.

Developing project management. Projects aimed at radical innovation must account for both market and technological uncertainties. Milestone-based evaluation frameworks, rather than traditional fixed-output models, allow for more realistic performance tracking. Managers with both academic and industrial credentials are essential for navigating frontier projects. The ecosystem lacks standardized templates for adaptive project scoping. Developing a repository of project charters, risk registers, and pivot logic models from past radical projects would inform better upfront design. Moreover, embedding project historians — professionals responsible for narrating and preserving the evolution of projects — could enhance institutional learning and provide context for retrospective evaluation. Advanced scenario-planning tools and postmortem protocols can also help refine future strategies and avoid repeating avoidable failures.

Developing open innovation. Despite high security requirements, selective openness can amplify defense innovation. Collaboration with academia, startups, and specialized communities broadens the solution space. Developing strategic openness guidelines — specifying domains, timeframes, and collaboration modes that can safely engage external actors — would remove ambiguity and encourage more frequent partnerships. Public innovation campaigns on non-sensitive problem statements can help identify unconventional solutions and signal the defense ecosystem's openness to external ideas. Finally, creating a classified version of a technology readiness level (TRL) framework would allow defense organizations to communicate innovation maturity across different actors while respecting security constraints. Bridging institutions — such as defense-linked accelerators—can act as buffers between external partners and core security assets.

Accordingly, several persistent obstacles continue to constrain the effectiveness and coherence of radical innovation efforts within the defense ecosystem. These challenges reveal deep-seated structural rigidities that undermine the strategic intent of innovation policies (Table 1). In the cultural domain, organizational behavior remains shaped by bureaucratic inertia and a strong preference for continuity over disruption. This deeply embedded conservatism often favors legacy platforms and established technological pathways, leading to a pervasive emphasis on incremental refinement rather than high-risk exploration. Risk aversion, both at the institutional and individual levels, further weakens the pursuit of radical trajectories. Failures are treated as reputational liabilities rather than as essential feedback mechanisms, stifling the experimental learning loops necessary for innovation maturity. A particularly limiting condition is the lack of a shared discourse between innovators and operational units; engineers, scientists, and commanders frequently operate within separate conceptual frameworks, resulting in breakdowns in communication, misaligned priorities, and limited absorptive capacity for novel technologies.

At the level of governance, the absence of a bold, future-oriented vision has led to fragmented policy agendas and inconsistent leadership support. Innovation strategies are rarely tied to battlefield needs or broader defense transformation goals, leading to a proliferation of isolated initiatives with low cumulative impact. Strategic ambiguity is compounded by an absence of consensus at the macro level, with key stakeholders often pursuing conflicting priorities. Institutional arrangements tend to reinforce siloed behavior, while excessive centralization and procedural rigidity reduce the operational autonomy of R&D teams. The dominance of security-centric considerations — while understandable in a defense context — often creates additional delays in coordination, limits inter-agency collaboration, and discourages openness to external knowledge sources.

Deficiencies in resource capabilities further constrain innovation potential. Infrastructure for advanced experimentation, especially prototyping laboratories and simulation facilities, remains fragmented and outdated. Long-term employment structures prioritize loyalty and continuity over flexibility and expertise renewal, making it difficult to attract or retain personnel capable of operating across emerging technical domains. Many organizational actors lack the interdisciplinary mindset and agility needed to manage radical innovation processes. Motivation is undermined by the absence of competitive incentives, dynamic career pathways, or opportunities for visible impact. On the financial side, the ecosystem remains overly reliant on short-term, state-sponsored funding cycles, with minimal engagement from commercial or hybrid capital sources. This dependency restricts risk appetite and discourages sustained investment in radical, long-horizon initiatives.

Finally, procedural failures reflect weaknesses in how innovation processes are designed, executed, and evaluated. Closed innovation norms continue to dominate, limiting the inflow of ideas and reducing engagement with academia, startups, or dual-use technology developers. The boundary between theoretical research and field-adaptable technology remains blurry, resulting in misaligned outputs and underutilized capabilities. Codification and documentation practices are generally underdeveloped, leading to poor institutional learning and limited knowledge transfer across projects. The system also lacks mechanisms to accumulate critical mass in strategic knowledge areas, particularly in interdis-

Table 1. **Failure Factors for Radical Innovation in Emerging Defense Ecosystems**

Dimension	Factors
Culture	• Organizations› bureaucratic culture • Defense industry›s tendency toward old technologies • Desire for incremental innovations • Risk aversion and resistance toward accepting failures • Lack of common language between innovators and operational teams
Governance	• Lack of bold vision and roadmap • Lack of prioritization based on defense needs • Lack of agreement at the macro level • Lack of independence and autonomy in R&D teams • Too much focus on security aspects
Resources	• Lack of laboratory infrastructure • Conflict between long-term employment patterns and intellectual flow dynamics • Employees› inherent weakness in radical innovation • Lack of motivation for radical innovation • Dependence on limited public resources
Processes	• Closed approach toward innovation • Lack of distinction between academic and technical knowledge • Inadequacy of documented scientific resources for reaching knowledge edges • Lacking the critical mass of knowledge • Ignoring interdisciplinary knowledge

Source: authors.

Table 2. **Hierarchical Structure of the Framework**

Dimensions	Components
Culture	• Collaboration culture • Radical innovation importance • Organizational culture
Governance	• Policy framework • Institutional structure • Organizational structure
Resources	• Human capital • Financial resources • Infrastructure
Processes	• Knowledge management • Open innovation • Project management

Source: authors.

ciplinary and fast-moving fields where defense relevance is emerging but not yet fully institutionalized. Collectively, these structural and procedural failures underscore the fragility of the current ecosystem and the need for deliberate interventions to remove institutional bottlenecks, recalibrate priorities, and unlock latent innovation capacity.

Prioritizing drivers and sub-dimensions

The hierarchical structure is developed on two levels according to the theoretical framework extracted in the qualitative section (Table 2) to prioritize drivers and sub-dimensions with fuzzy AHP.

In the following, radical innovation resources are prioritized as an example. Considering the fuzzy values and calculating the geometric mean of experts' opinions, Table 3 presents the matrix of pairwise comparisons of resources.

Then, the fuzzy value of the matrix cells is calculated as follows.

$$S_I = (2.48, 2.67, 2.88) \odot \left(\frac{1}{9.91}, \frac{1}{9.11}, \frac{1}{8.40}\right) = (0.25, 0.29, 0.34)$$

$$S_{HC} = (3.00, 3.27, 3.58) \odot \left(\frac{1}{9.91}, \frac{1}{9.11}, \frac{1}{8.40}\right) = (0.30, 0.36, 0.43)$$

$$S_{FR} = (2.92, 3.17, 3.45) \odot \left(\frac{1}{9.91}, \frac{1}{9.11}, \frac{1}{8.40}\right) = (0.29, 0.35, 0.41)$$

Next, the relative magnitude degree of sub-dimensions is calculated.

$$V(M_I \geq M_{HC}) = \frac{0.30 - 0.34}{(0.29 - 0.34) - (0.36 - 0.30)} = 0.38$$

$$V(M_I \geq M_{FR}) = \frac{0.29 - 0.34}{(0.29 - 0.34) - (0.35 - 0.29)} = 0.46$$

$$V(M_{HC} \geq M_I) = 1;\ V(M_{HC} \geq M_{FR}) = 1;\ V(M_{FR} \geq M_I) = 1$$

$$V(M_{FR} \geq M_{HC}) = \frac{0.30 - 0.41}{(0.35 - 0.41) - (0.36 - 0.30)} = 0.91$$

Finally, the minimum magnitude degree of each sub-dimension is considered as its weight, which is later normalized (Table 4).

Table 3. **Fuzzy Matrix of Pairwise Comparisons of Radical Innovation Resources**

	Infrastructure (I)	Human Capital (HC)	Financial resources (FR)
Infrastructure (I)	(1, 1, 1)	(0.8, 0.9, 1.02)	(0.68, 0.76, 0.86)
Human Capital (HC)	(0.98, 1.11, 1.25)	(1, 1, 1)	(1.02, 1.17, 1.33)
Financial Resources (FR)	(1.17, 1.31, 1.47)	(0.68, 0.76, 0.86)	(1, 1, 1)

Source: authors.

Table 4. **Weight of Resources' Sub-dimensions**

	I	HC	FR	Weight	Normalized weight
Infrastructure (I)	–	0.38	0.46	0.38	0.16
Human Capital (HC)	1	–	1	1	0.44
Financial Resources (FR)	1	0.91	–	0.91	0.40

Source: authors.

Therefore, human capital and financial resources are the most critical radical innovation resources, respectively. Other sub-dimensions are also prioritized with similar calculations, resulting in Table 5.

Discussion

The innovation systems approach has helped fulfill strategic objectives in defense industries. However, the complexity, uncertainty, and systemic interdependencies inherent in radical innovation demand a more ecosystem-oriented perspective — especially in contexts constrained by geopolitical pressures and resource limitations (Khotbesara et al., 2023). This article contributes by proposing and prioritizing a model tailored for radical innovation in Iran's defense sector, highlighting four key drivers and twelve sub-dimensions (Figure 2, table 6).

The combined attention to radical innovation sources, culture, process, and governance indicates a comprehensive ecosystem lens. Promoting fundamental research, adopting a long-term orientation, and fostering a tolerance for failure exemplify core characteristics of radical innovation within the model. Defense-specific conditions are reflected in efforts to relax excessive ideological restrictions and enhance commercial translation of defense technologies. Similarly, reversing skilled labor outflows exemplifies how emerging country contexts shape innovation capabilities. Accordingly, the findings both resonate with and depart from existing research on innovation ecosystems. While many conceptual foundations—such as the role of leadership, openness, and network-based governance—are shared, the defense setting imposes structural constraints

Table 5. **Priorities of Drivers and Sub-Dimensions of Radical Innovation in Defense Industries**

Drivers (weight)	Dimensions	Drivers' weights	Dimensions' relative weights	Dimensions' weights
Culture (0.05)	Radical innovation importance	0.3	0.001	11
	Organizational culture	0.2	0.001	12
	Collaboration culture	0.49	0.002	10
Governance (0.23)	Policy framework	0.48	0.110	3
	Institutional structure	0.41	0.094	4
	Organizational structure	0.11	0.025	9
Resources (0.49)	Infrastructure	0.16	0.078	6
	Human capital	0.44	0.216	1
	Financial resources	0.4	0.196	2
Processes (0.23)	Knowledge management	0.38	0.087	5
	Project management	0.29	0.067	8
	Open innovation	0.34	0.078	7

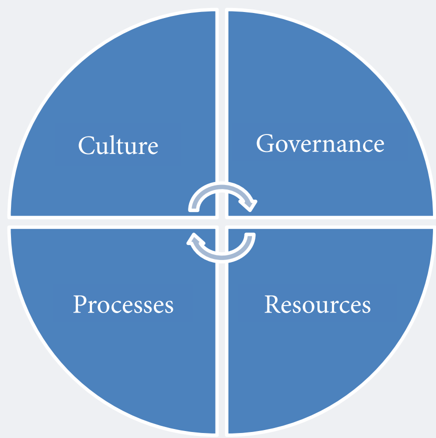
Source: authors.

and distinctive priorities. For instance, although ecosystem theory emphasizes agility and horizontal coordination, defense innovation often unfolds within rigid hierarchies. Rather than replicating commercial templates, the model favors sector-specific adaptations like semi-autonomous R&D units or dual-ladder institutional configurations.

Organizational dynamics offer a useful entry point for comparison. In both defense and non-defense settings, small and flexible structures promote creativity by reducing bureaucratic inertia (Diederiks, Hoonhout, 2007). However, changes to structure or workflows in defense contexts face heightened resistance due to security protocols, mission criticality, and entrenched administrative norms. Therefore, change management should be pursued with special precautions, focusing on a fundamental change in thinking patterns (Bao et al., 2019). Ambidextrous leadership also plays a nuanced role in radical innovation. In defense, this ambidexterity must also reconcile compliance with risk tolerance, blending procedural discipline with adaptive responsiveness. Accordingly, leaders solve the agility-discipline conflict as accumulating decision-making power in the leader leads to agile and accountable decisions. They must balance the various demands of stakeholders and team members while supporting the creation of new ideas and focusing on selected ideas with an ambidextrous approach (Alexander, Van Knippenberg, 2014). An innovative leader should have the soft skills to interact with human resources and the hard skills to manage complex technological projects (Robbins, O'Gorman, 2015). Also, leaders' forgiveness encourages radical innovation by promoting self-sacrifice among the team (Mallén-Broch, Domínguez-Escrig, 2021).

This ambivalence stems from the fact that open innovation in radical ecosystems can increase imitation risks. As a result, knowledge governance exhibits structural similarities with broader innovation ecosystems, but its operationalization diverges significantly. In general contexts, open innovation enhances absorptive capacity and accelerates knowledge flow. However, in defense, the stakes of knowl-

Figure 2. **Cyclic Scheme of Radical Innovation Model for Emerging Defense Ecosystems**



Source: authors.

Table 6. **Components of the Radical Innovation Model for Emerging Defence Ecosystems and Their Weights**

Dimensions	Components (weight values)
Culture	• Collaboration culture (0.02) • Radical innovation importance (0.01) • Organizational culture (0.01)
Governance	• Policy framework (0.110) • Institutional structure (0.094) • Organizational structure (0.025)
Resources	• Human capital (0.216) • Financial resources (0.196) • Infrastructure (0.078)
Processes	• Knowledge management (0.087) • Open innovation (0.078) • Project management (0.067)

Source: authors.

edge leakage are higher. While firms benefit from open source strategies in the short term — given the wide use of technology, rapid adaptations, and the variety of contributors — they risk long-term erosion of competitiveness. Patenting becomes vital for technology and knowledge protection (Holgersson, Granstrand, 2017). Moreover, whereas general ecosystems promote openness across all stages, defense settings require calibrated openness. Given the ambiguity in goals, difficulty in valuation, and other collaboration conflicts, idea generation and technical and commercial evaluation fit better with a closed innovation framework. In defense ecosystems, selective openness tends to occur only at the integration or application stage, when the risk of leakage has diminished and regulatory clarity improves. Selective integration of external knowledge under regulated conditions becomes feasible only at later stages (Domínguez-Escrig, 2018).

Network structures and actor roles within the ecosystem also evolve differently. General ecosystem literature favors decentralized orchestration and peer-based learning, whereas defense systems rely more on centralized leadership. In radical innovation collaborations, paradoxes — such as formality versus flexibility, long-term commitment versus costly termination, and co-creation versus knowledge conservation — must be managed (Sadovnikova et al., 2016). Structured networks governed by formal rules and aligned objectives are more effective for radical innovation than loosely governed bilateral relationships. This insight is particularly applicable to defense systems where trust must be formalized, and intellectual breadth is often lacking (Czakon et al., 2020).

Beyond organizational and governance structures, user engagement also diverges across ecosystems. Although resistance from end-users is common due to complexity and switching costs, in defense contexts, this reluctance is amplified by risk aversion, operational doctrine, and psychological burden (Lettl, 2007). Consequently, team-driven innovation often outpaces user-generated input (Robbins, O'Gorman, 2015), though involving select lead users with cross-disciplinary backgrounds can still support institutional learning (Scaringella et al., 2017). These comparisons reveal that many ecosystem principles remain relevant but require recalibration to defense-specific institutional logics. Accordingly, radical defense innovation ecosystems should be understood as adaptive, semi-open systems governed by strategic constraint. While general ecosystem theories offer valuable starting points, their application in defense settings must contend with sectoral legacies, institutional rigidity, and national security imperatives. The concept of innovation champions, for instance, is less about entrepreneurial freedom and more about navigating political and bureaucratic constraints with mission-driven resolve. Likewise, adaptability in defense ecosystems is not merely institutional agility but also strategic ambiguity management — ensuring long-term continuity while absorbing shocks and constraints.

These theoretical insights link directly to practical implications. Fundamental research undergirds technological breakthroughs but suffers from valuation challenges, time delays, and political interference. Policy frameworks must avoid blue-sky inefficiencies while sustaining long-horizon initiatives. Defense innovations with commercial spillover potential should be supported through dual-use pathways that secure IP while encouraging diffusion. Open innovation protocols, if carefully designed, can promote collaboration without compromising confidentiality. Likewise, rigid HR models in the public defense sector limit the inflow of creative talent. Reforms must prioritize cross-functional mobility, innovation-aligned recruitment, and cultural renewal. Furthermore, among the four main drivers, resource development — especially in human capital and finance — emerged as the most influential. Meanwhile, macro-level governance and political structure had stronger shaping effects than internal organizational features. These patterns underscore the importance of structural enablers over tactical adjustments. A recurrent gap in defense innovation culture is the absence of systemic thinking — reflected in fragmented governance, siloed expertise, and underdeveloped feedback loops.

Addressing various aspects of the research can direct future studies. Scholars could compare radical and incremental innovation dynamics in defense to refine context-specific strategies. Multi-case studies comparing defense and civilian ecosystems could clarify the generalizability of key findings. Further exploration of defense-sector catch-up strategies and science diplomacy would enrich policy relevance. From a methodological standpoint, alternatives to Fuzzy AHP—such as Fuzzy ANP or combined VIKOR models — could improve scenario robustness and account for interdependencies. Comparative testing using Fuzzy TOPSIS might also offer empirical validation across contexts.

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