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Technology Component System Framework (TCSF) as an Ex-Ante Assessment of Science and Technology Parks: An Integrative Review

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***Abstract*—*Science and Technology Parks (STPs) are crucial parts of the national innovation system in developing countries such as Indonesia. Many challenges have arisen in the vision of developing 100 STPs, one of which is the overemphasis on physical infrastructure. Existing evaluation models largely rely on ex-post "black box" output metrics, such as patents and spin-offs, which are inappropriate for early-stage STPs that are not yet operational and possess complete technology. To address this challenge, this study conducts a structured integrative review to integrate the Technology Component System Framework (TCSF) as an ex-ante assessment framework for STPs. This approach is based on the Resource-Based View (RBV) and represents a different perspective from output-based performance assessment. The conventional synthesis produced a conceptual summary of the components of an STP technology system. These results are expected to be useful for STP managers to balance the utilization of complex technology components and guide further research on ex-ante STP assessment.*

***Keywords*—*Science and Technology Parks, Ex-Ante Assessment, TCSF, Technological Capability, and Resource-Based View*.**

I. INTRODUCTION

Innovation is the prime driver of national competitiveness and regional economic growth . It improves productivity and accelerates gross domestic product (GDP) growth . Over the past few decades, technological innovation has become central to sustainable development strategies across governments, academia, and industry . For developing countries, it serves as a key mechanism to bridge the prosperity gap with developed countries . Consequently, the development of national innovation systems has become an essential priority for long-term economic resilience.

As the largest developing economy in Southeast Asia, Indonesia has prioritized industrial advancement using an innovation-driven strategy. In this context, the government has committed to developing 100 science and technology parks (STPs) in various regions . STPs, as innovation ecosystems, are intended to encourage knowledge transfer and research output commercialization among triple helix stakeholders. They are positioned as the backbone of the national innovation system . However, the implementation of STP development is currently in its early stages and faces a long development trajectory in the future.

Significant bottlenecks arise when STP development initiatives are implemented on a large scale. Most STPs fail to achieve sustained growth towards high maturity stages despite receiving substantial funding . Government-initiated STPs are also at risk of failure due to a lack of management competencies . In addition, developing countries have limited resources that make it difficult to build a massive number of STPs simultaneously .

In Indonesia, these challenges are compounded by a variety of systemic issues, including bureaucratic rigidity, human capital scarcities, technology sources, and policy misalignment in Indonesia's STPs . These constraints have resulted in a limited number of STPs reaching core maturity. To date, only one STP has reached core maturity. Most STPs in Indonesia are still in the early stages of development, despite having received investment and been developed over a long period. Kegiatan operasional STP masih bergantung pada pendanaan eksternal dan kementerian lembaga yang menaungi. This condition was severely impacted during the COVID-19 pandemic, which led to reduced funding for STPs and consequently disrupted their operations and development . These constraints hinder STPs from performing their functions and producing outputs. Crucially, this widespread failure suggests that the core problem lies not in the lack of physical infrastructure, but in gaps in optimizing technology utilization and internal operations. This blind spot highlights the need to understand the internal resource dynamics necessary for the development of STPs towards high maturity and their impact on the national innovation system.

Current Indonesian practices evaluate STP progress through standardized performance levels that reflect operational compliance with master plans . STPs that are still in the early stages of maturity remain focused on preparation and are not yet fully operational to provide services. This condition causes the majority of STPs in Indonesia to still lack consistent technological capabilities, services, and outputs. With a focus on preparation, what managers need is how the costly development of STPs can be carried out effectively. By

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measuring STP only through its performance level ex-post in a "black-box" paradigm , we lose sight of the dynamic and qualitative nature of technological capabilities.

Previous research has largely focused on outcome metrics (e.g., number of patents and spin-offs) without examining the internal resource configurations that enable those outcomes, thus leaving a theoretical void in understanding capability development trajectories. This creates an evaluative mismatch: early-stage STPs cannot produce mature output without first developing their capabilities. Existing frameworks fail to resolve the contradiction between high infrastructure investment and low innovation output because they ignore internal technology system readiness, a key construct governing an institution's capacity to absorb, develop, and commercialize technology.

To address this constraint, research must shift from traditional ex-post output assessments to an ex-ante approach. Implementing ex-ante assessments facilitates the elimination of ineffective development projects through pre-evaluation . This is important because technological upgrading constitutes a substantial capital investment and is essential for institutional sustainability . This study applies the Technology Component System Framework (TCSF) as an assessment tool to identify internal capability gaps before development projects are implemented. This multi-level technology-based development framework has been developed by for decades. The TCSF provides a resource-centric perspective that decomposes a technology system into measurable components, focusing on the balance of components' sophistication and contribution . This decomposition overcomes the limitations of the black box by making the internal capability configuration observable and measurable to identify resource gaps that hinder STP maturation. By shifting the focus to ex-ante assessment, this framework provides a non-black-box, technology-based pathway for STP development.

This study conducts an integrative review to address the following research question: How can the Technology Component System Framework (TCSF) be conceptually integrated into the ex-ante assessment of STPs to identify internal technological capability gaps? This study contributes a resource-based diagnostic framework that operationalizes TCSF components (Technoware, Humanware, Inforware, Orgaware, and Cysnetware) as ex-ante assessment criteria for STP capability readiness, enabling policymakers to identify resource gaps before capital allocation and researchers to test propositions about component interdependencies and maturation trajectories. While the existing literature establishes STPs as important drivers of regional innovation, this study advances prior proximity research by introducing an alternative conceptual framework that aligns ex-ante assessment with internal technological capabilities. The remainder of this paper is structured as follows: Section 2 establishes the theoretical foundations of technology-based STP development and the TCSF; Section 3 outlines the integrative review methodology, including the literature search and selection strategy; Section 4 presents the conceptual synthesis and the integrated ex-ante diagnostic framework; and Section 5 discusses the proposed research agenda, policy implications, limitations, and conclusions.

II. LITERATURE REVIEW

Historically, the concept of innovation has evolved from Schumpeter's classic focus on novel factor combinations ward a systemic process aimed at integrating knowledge-based technologies into commercial value streams. However, definitions of technology have focused on emphasizing the transformation of ideas into physical reality . However, this concept of technology is insufficient for modern innovation ecosystems such as STPs, which require a broader perspective. Technology is an integrated system consisting of human capabilities, information flows, organizational structures, and digital connectivity. This systemic nature makes evaluating STP technology readiness necessary to boost regional competitiveness.

A. Science and Technology Parks (STPs) in National Innovation Systems

In recent years, there has been increasing interest in building science and technology parks as conduits for innovation processes that lead to research commercialization . Classically, a science park is defined as a location of a cluster of new technology industrial companies or research units located in a park-like environment, with close proximity and interaction with a research university and its staff, resources, and common facilities .

In many countries, STPs are part of national plans or strategies for boosting the development of science, technology, and innovation, and/or moving products from the laboratory to the market . In the context of an innovation ecosystem, STPs aim to promote knowledge transfer through interactions between the government, universities, and industry (GUI) . STPs are important instruments for connecting research outputs in higher education with industry . In addition, STPs have several other roles in building a culture of innovation .

Currently, STPs in Indonesia are categorized into three maturity levels: beginner, intermediate, and major. An STP is considered mature when it can conduct research sustainably, successfully grow start-up companies, and is effective in attracting industrial interest to locate in the area and utilize the technology services offered in the development of technology-based companies and start-up companies based on university research . In addition, the Indonesian government regulates the documents and studies required to establish and build an STP .

B. Existing STP Evaluation Models: The "Black-Box" Paradigm

Much of the literature on STP development is characterized by a reliance on ex-post evaluation models that prioritize end-point performance metrics. STP success is often measured through aggregate output indicators, such as the number of patent applications, formation of university spin-off companies, and overall contribution to regional economic stimulation . These metrics provide a measurable measure of regional impact, but tend to focus on the end-state of the innovation process. also explains that this approach is more appropriate for STPs that have been functioning and producing stable outputs. Consequently, the existing evaluative literature often fails to account for the internal institutional capabilities necessary to sustain long-term innovation performance. Current models measure outcomes (patents, spin-offs) but do not diagnose the foundational capacities required to produce those

outcomes. This is a weakness of the ex-post model of service availability and impact (economic based) of STPs, as described by and, much earlier, by .

This limitation is exacerbated by broader structural gaps in existing knowledge. Research in this field has grown rapidly since its inception in the 1950s , but the existing literature remains highly fragmented across disciplines , narrowly focused, non-comprehensive. , and heavily reliant on isolated case studies . These characteristics mean that current evaluative frameworks lack an integrative approach to bridge the internal levels of STP components. Despite the recognized importance of STPs as resource providers, no existing framework systematically evaluates their internal resource readiness—the foundational capabilities required before output generation. A resource-based perspective is essential for evaluating the fundamental capacity of STPs as key resource providers within innovation ecosystems .

C. Shift to Resource-Centric and Ex-Ante Capability Assessment

Recent scholarship advocates a strategic trantowards toward ex-ante capability assessments to mitigate the limitations of ex-post evaluations. Identifying internal resource gaps before significant capital allocation is fundamental to minimizing failure risks in technology-driven initiatives . This proactive diagnostic approach ensures that infrastructure investments are precisely aligned with institutional readiness for STP, thereby preventing evaluative mismatches in which nascent organizations are subjected to mature output expectations.

This paradigm shift is based on the Resource-Based View (RBV), which posits that an institution's viability is determined by the configuration of its capabilities. The Technology Component System Framework (TCSF) operationalizes this view by providing a non-black-box lens for auditing the sophistication of internal technology systems. This perspective is resource-centric and prioritizes "technology system readiness" as a system that builds an institution's capacity. Furthermore, prioritizing the accumulation of knowledge stocks in the form of infoware and orgaware can explain how physical facilities and human resources operate. Organizations need to focus on these two components as they transition to higher maturity. Consequently, the transition to a resource-centric assessment model provides an analytical foundation for optimizing internal assets and guiding innovation stowards toward sustainable economic impact.

D. The Technology Component System Framework (TCSF)

Technology is fundamentally systemic, functioning as part of a system and having objects within which it operates . In line with this rationale, the Technology Component System Framework (TCSF) serves as a technometric model based on benchmarking, capability assessment, and multi-criteria decision-making . This approach breaks down a technology system into five main components categorized as THIO+C:

1) Technoware: Object-embodied physical facilities in the form of objects, including tools, machines, and materials, designed to enhance human work capacity and represent the operational core of an organization's tasks.

2) Humanware: Person-embodied human abilities in the form of individuals, encompassing the skills, intelligence, and tacit knowledge required to effectively utilize physical assets.

3) Inforware: Document-embodied codified facts and procedures in documents, such as technical manuals and specifications, that govern the effective implementation of technology.

4) Orgaware: Institution-embodied operational frameworks that integrate organizational resources and coordinate activities through standardized routines and structures.

5) Cysnetware: Cyberspace-embodied digital connectivity that facilitates Internet-based collaboration and virtual integration of innovation processes.

The effective utilization of technology components requires the fulfillment of certain minimum conditions. There are interdependencies between components, necessitating the management of the gaps between the levels of technological contribution . Therefore, the development of STP requires holistic planning that encompasses all components. Therefore, mapping the components of STP technology is crucial.

III. METHODOLOGY

To explore the decomposition of the internal technology system of an STP, this study applied an integrative literature review methodology. This approach provides a new understanding and future research agenda of the current literature. We refer to the explanation of the methodology mentioned by , which divides the methodology into seven stages.

In the preparation phase, we identified the problem as explained in Section I, namely the evaluative mismatch in the STP measurement system. Next, we discussed the variables of interest and the research objectives, focusing on the decomposition of the STP technology system using TCSF. Articles for the review were searched in the Scopus database, focusing on the STP modeling literature. We used a search query covering publications from 2000 to 2025 based on the terms of STP explained in , as follows: TITLE-ABS-KEY (Technology) AND TITLE-ABS-KEY ("Science and technology Park" OR "Science Technology Park" OR "Science Park" OR "Technology Park" OR "High Tech Park" OR Technopole OR Technopolis OR "Kawasan Sains Teknologi"). We prioritized the synthesis of articles that developed STP assessment models and explained technology components. Out of 1,909 articles retrieved from the search results, we conducted an in-depth review of 68 articles. However, we also studied articles with other focuses in the STP literature. Finally, we conducted a qualitative content analysis to achieve conventional synthesis, which is documented in this paper and other supporting documents. Table I describes the steps of the research methodology.

IV. FINDINGS AND DISCUSSION

A thematic synthesis of the constituent elements of Science and Technology Parks (STPs) reveals a multidimensional technology system categorized through the Technology Component System Framework (TCSF). This section presents empirical findings derived from the systematic decomposition of the STP ecosystem

into its key components: Technoware, Humanware, Inforware, Orgaware, and Cysnetware. By shifting the evaluation's focus toward these internal resource dynamics, the following analysis explains how each component catalyzes institutional maturation and addresses the development barriers identified in the emerging innovation landscape.

A. STP Technoware Component

Physical facilities are essential for the successful implementation of STP operations and play a role in creating spatial proximity between stakeholders and fostering a creative climate . In the context of the innovation ecosystem, physical facilities are needed to implement the innovation process from ideas to commercialization. STP physical facilities also serve as a space for technology and knowledge transfer activities between universities, companies, and the market to improve research quality and carry out innovation processes .

This explanation explains the need for STP physical facilities for several roles. STPs need to provide modern laboratory facilities and equipment that are accessible to relevant stakeholders . As the landlord , STPs need to provide offices and utilities for tenant business operations that are integrated with other stakeholders, especially universities . As the village , STPs need to provide supporting facilities that complement work and research functions within the STP through physical proximity for interaction and the exchange of ideas .

B. STP Humanware Component

Strengthening human resources is necessary for the innovation ecosystem to function and develop sustainably . In the STP context, this component is divided into several parts based on the level in the organizational structure. This division based on hierarchy is done because the scope of work is diverse, ranging from the operational technical level to the multi-stakeholder ecosystem.

STP-level managers must be able to manage stakeholders' roles in a balanced manner and create an environment that supports the transfer of knowledge between elements within the STP. This part of humanware also serves as the orchestrator for various stakeholders' roles as the sub-systems of the ecosystem. At a more specific level, STPs need to have knowledge-based service managers, who vary based on the STP's strategy, from basic research to startup incubation and product commercialization . This level of human resources is necessary to meet the needs of the ecosystem for innovation-related services. Another important aspect is the human resources provided by the STP for tenants and stakeholders in the area . This section explains the STP's role in the talent supply of the ecosystem innovation, channeling developed human capital from universities and experts in the region.

C. STP Inforware Component

Tenants/users of STP benefit from the knowledge of the information provided and obtained at the STP . Several types of information need to be managed by the STP. Information on developments in knowledge and technology, including access to ideas and information related to research, technology, production equipment, and intellectual property, including patents , needs to be utilized by tenants to develop technology-based organizations. In terms of area management, the required information includes mapping member capabilities , laboratory collaboration opportunities , and startup growth . The STP also needs to disseminate information to the public to promote services, facilities, and tenants .

D. STP Orgaware Component

In the context of the STP, Orgaware is the institutional governance framework, interaction mechanisms, and formal regulations that govern the relationships between stakeholders and available facilities. This component plays a role in integrating other technological components into a holistic innovation ecosystem, regional sustainability, and downstreaming research results into the market . Therefore, this component is divided into various parts from strategic management to operational standardization.

In managing the area, STP must have a comprehensive strategy to improve strategic outcomes that bridge interactions and communication between stakeholders, the government, and universities . This part of orgaware is important because STP's strategic direction is the part that binds stakeholders together. Service governance is realized through the development and optimization of a park's organizational infrastructure, which includes the provision of public, technical, and specialized, and educational consulting services . This part ensures the utilization of existing technologies to support the ecosystem. Good financial governance is expected to directly impact tenants' cost efficiency . This part needs to be managed because it is the fuel source of STP activities through appropriate budget utilization and innovation investment.

E. STP Cysnetware Component

Cysnetware is the newest component in TCSF. In the context of STPs, cysnetware is needed to provide a shared platform that supports the flow of information within the system . This component serves as a strategic conduit for tenant internationalization by establishing formal and informal linkages with international communities and professional associations. Furthermore, this criterion is oriented towards easy access to customers and support for distribution channels . Tenants at STPs can actively utilize facilities that connect them with academics to obtain critical information related to the business challenges they face . In addition, in terms of incubation, digital platforms enable online discussions to share problems and challenges faced by startups .

F. Technological System of STP

The conventional synthesis method identified the components of technology in STP. All components can be divided into several parts with a broad focus, allowing for further detail. Furthermore, some of the synthesized components overlap with STP problem areas, such as bureaucracy (organware), human capital scarcities (humanware), technology sources (technoware), and inforware (information asymmetry). The decomposition of the technological system is shown in Figure 1. This demonstrates the effectiveness of this approach in STP as an innovation ecosystem.

Understanding STP within an innovation system requires an understanding of its complexity to consider the innovation process as a whole . Based on the analysis, each technology component in the STP consists of several parts or subcomponents. This confirms the complexity of STP technology systems compared to case studies in a single industry, making the approach used in this study relevant for application to STP. One framework that explains this lengthy innovation process

is the stage-gate process, which explains the progression from idea to launch across 5 gates . Each stage requires specific technologies to support it. In this regard, industrial capacity does not necessarily encompass the entire innovation process. STPs need to step in to provide services so that the innovation process runs smoothly, based on the triple-helix concept . The goal of STPs for the development of technology-based companies and faculty-based spin-offs is expected to carry out this series of processes sustainably.

This study also aligns with the statement of that successful innovation requires a deep understanding of innovation dynamics, the development of an innovation strategy, and a well-developed process for its implementation. In general, the dynamics of technology utilization occur as explained by . Advanced technoware is needed to meet the needs of research and innovation activities, as well as tenant operations. Humanware with specialized skills is needed to operate the advanced technoware effectively. In addition, humanware with specialized competencies is also needed to deliver knowledge-based services, ranging from technical to strategic as innovation intermediaries. Inforware is needed for the foundation of organizational capabilities, recording innovation achievements, progress in the roadmap, monitoring tenant maturity, and promotion. Cysnetware complements by providing digital infrastructure to accompany physical infrastructure. Finally, orgaware is required to organize the other four components with strategic direction, service arrangements, and funding or financial policies. Humanware with capable leadership abilities is also needed to organize the STP. Furthermore, the full use of the TCSF will allow for filling gaps in technology development by benchmarking best practices as the ideal desired level, as described by . Ultimately, the journey of the STP from a minimal technology system to a state-of-the-art system can be modeled.

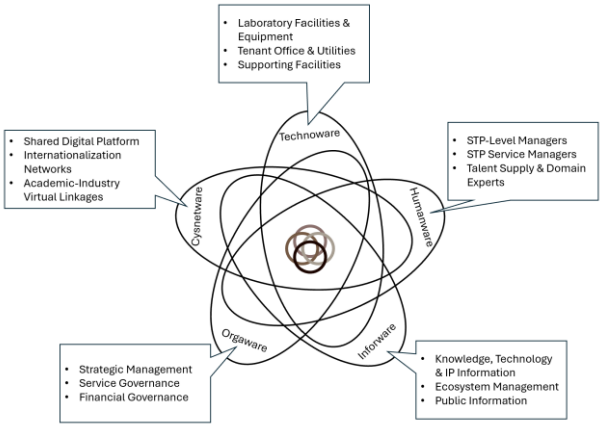


Fig. 1.
Decomposition of STP Technological System based on the TCSF Framework.

From a practical perspective, these findings can serve as strategic guidance for STP managers, university leaders, and regional policymakers. A common pitfall in STP development is the disproportionate allocation of financial capital to physical infrastructure (Technoware) while neglecting the intangible technological components. This analysis demonstrates that physical facilities alone cannot drive innovation without supporting a dynamic ecosystem. STP leaders need to have a strategy for managing all technological components and invest in their development proportionately. Ultimately, transforming STPs from basic physical spaces into cutting-edge innovation hubs requires harmonizing technological sophistication with organizational, human, and digital capabilities.

Although this study successfully identified the components of technology, further research on the extent to which the TCSF can address the issues in STP is still needed. Furthermore, the synthesized components also encompass intangible technology, an advantage of the TCSF, which uses a broad definition of technology. Furthermore, this study only identified the parts/subcomponents that make up the technology components. These results are an initial step toward further understanding the dynamics of utilization relationships between technology components within STP.

V. CONCLUSION

This study integrates the Technology Component System Framework (TCSF) as an ex-ante assessment to analyze the complex technology ecosystem of Science and Technology Parks (STPs). This research offers a different perspective from the output-based performance evaluation of STPs, which is already widely available in the literature. It decomposes the STP technology system into five distinct components: Technoware (physical infrastructure and dedicated spaces), Humanware (human capital quality, expertise availability, and talent supply), Inforware (knowledge dissemination, capability mapping, and IP management), Orgaware (institutional governance and strategic alignment), and Cysnetware (digital platforms and global networking capabilities).

The primary contribution of this study lies in explaining that STPs are technological systems that need to be managed for optimal utilization. This component decomposition provides a diagnostic framework for park managers, universities, and policymakers to map the dynamics of technology as an internal resource, identify gaps, and determine development directions based on state-of-the-art technology benchmarks.

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