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A Systemic Approach to Evaluate Maturity in Data-Driven Human Resource Analytics: The Multi-Level Perspective Framework

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ABSTRACT

Many maturity models for Human Resource Analytics (HRA) do not capture how capabilities evolve across levels within and outside the organization. We use a systems-thinking framework to assess HRA maturity across five stages, from Initial to Optimized. The study combines the Fuzzy Analytic Hierarchy Process (FAHP) to weight nine key performance indicators (KPIs) and the Multi-Level Perspective (MLP) to interpret how change is shaped by outside pressures, current routines, and local innovations. The nine KPIs cover training, data security, system integration, budgeting, and related enablers. Results show a clear shift in priorities: early stages focus on funding, training, and basic safeguards, while later stages emphasize full integration and continuous improvement. MLP helps connect these internal shifts to wider forces of digitalization and policy. The work offers practical guidance for organizations in Iran that aim to build HRA in resource-constrained settings. We also outline next steps, including simple simulation tools and adaptive roadmaps, so leaders can test "what if" choices and plan long-term alignment between HR strategy and changing socio-technical conditions.

Keywords

Human resource analytics maturity model; Multi-level perspective; Systems thinking; Data-Driven human resource management.

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1. Introduction

Over the past two decades, organizations have faced increasingly volatile environments and complex, dynamic workforces (Khazaei et al., 2025a). These conditions have compelled organizations to adapt rapidly to external changes, exposing them to new challenges (Haseli, 2018; Bakhteri et al., 2022). In parallel, human resource departments have undergone significant transformation. They no longer serve merely administrative functions but are progressively taking on strategic and value-generating roles within organizations (Vargas et al., 2018; Levenson, 2018; Larsen and Edwards, 2021a). This evolution has been largely driven by the widespread adoption of digital technologies and the acceleration of digital transformation (Ghaedi et al, 2024), which have fundamentally altered how employees are managed and have provided managers with greater access to employee-related data and information (Gholian-Jouybari et al, 2024). Such data enables employers not only to better understand employee behavior and psychology but also to design more effective management strategies (Giermindl et al., 2022; Fernandez and Gallardo-Gallardo, 2020; McIver et al., 2018; McCartney and Fu, 2021; Huang et al., 2023).

These transformations, coupled with the growing emphasis on data-driven analysis, have created a need for new strategic decision-making capabilities within human resource management (HRM) (Ridgway et al, 2025), aimed at enhancing organizational competitiveness (Haseli, 2018; Levenson, 2018; Minbaeva, 2018). In particular, Human Resource Analytics (HRA) has gained traction as a tool for evidence-based decision-making, offering an alternative to intuition-based approaches (Lansford, 2019; Lushero and Bader, 2023). HRA facilitates performance improvement and reduces the risk of poor decisions, which is why many organizations are increasingly interested in developing these capabilities across their operations.

Despite this rising interest, many organizations continue to face serious challenges in the systematic implementation of HR analytics. These challenges include a shortage of specialized expertise, technological limitations, information management issues, and a lack of coordination among organizational units. Consequently, a significant proportion of HRA initiatives fail during early implementation stages, with approximately 42% of projects reported as unsuccessful (Bersin, 2021). Scholars have also warned that HR functions may struggle to successfully navigate the era of big data, risking failure to leverage its full potential for strategic decision-making if critical challenges are not addressed (Angrave et al., 2016). Organizations frequently cite a substantial gap between their current capabilities and the resources truly

required to fully leverage data-driven HR analytics, commonly referred to as the "capability gap" (Minbaeva, 2018). Much of this failure can be attributed to weak control over internal performance indicators; however, the growing need for clearly defined success and performance metrics in organizations is evident.

Figure 1 illustrates the global growth trajectory of the HRA market (in billion USD) across various regions, including North America, Europe, Asia-Pacific, the Middle East, and Latin America, from 2017 to 2024. While North America and Europe have seen dominant market shares, the Middle East has also shown stable and notable growth, signaling the increasing relevance of HRA in that region.

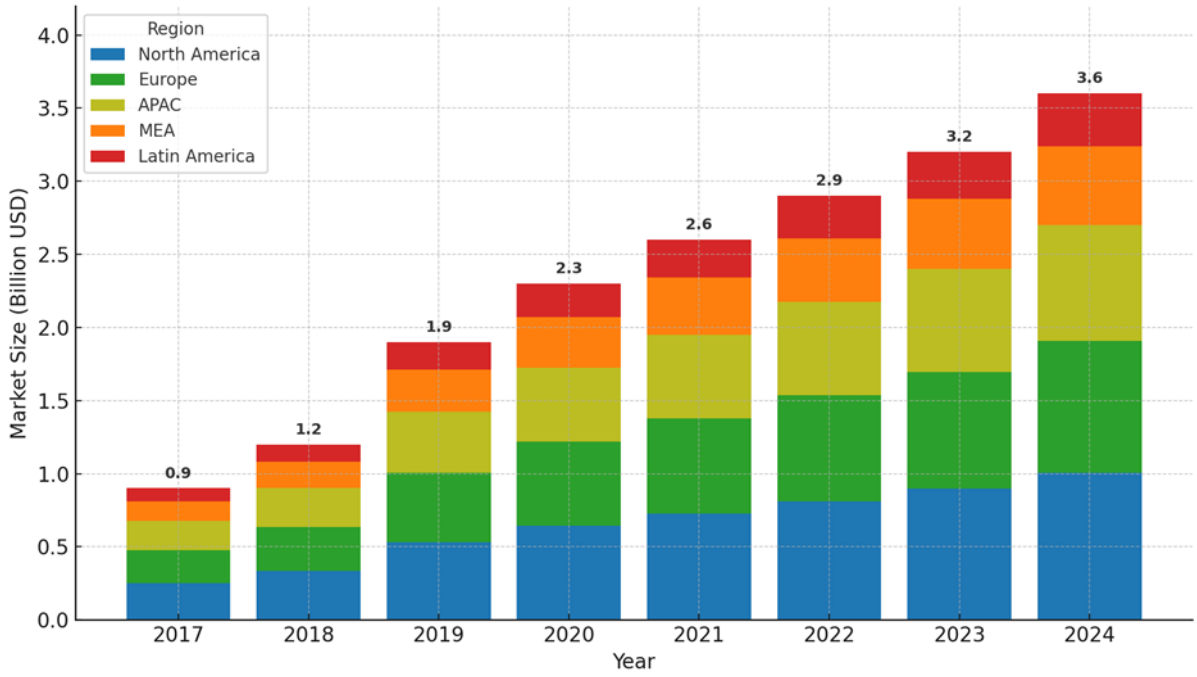

Figure 1. Market share of HRA by global regions over the past eight years (in Billion USD, Source: Global market insights, 2024).

In the Middle East, Iran, one of the region's largest and most populous countries, holds substantial potential to expand the HRA market. With the continued growth of diverse industries and the increasing need to optimize human resource processes, Iran is well positioned to play a significant role in advancing this market. The availability of an educated workforce and the increasing emphasis on optimizing organizational performance have positioned Iran as a key player in the Middle East's HRA landscape.

In this context, researchers view Human Resource Analytics as a multidimensional and multifaceted organizational capability, whose successful development requires coordination and integration of resources, skills, and technologies (Ramachandran et al., 2023; Wang et al.,

2024; Wirges and Nair, 2022; Cullen et al., 2023). Previous studies have shown that developing HRA in a way that enables integrated operation across all organizational dimensions is challenging, but essential for maximizing the value of data-driven insights (Marler and Boudreau, 2017; Levenson, 2018).

One of the most suitable tools to support the development and assessment of these capabilities is the Maturity Model (MM), which has been widely used in scientific research as a framework for evaluating the maturity of business analytics, business intelligence, and data analytics processes (Chen and Nath, 2018; Arunachalam et al., 2018). Research indicates that such models can help organizations systematically progress from initial to more advanced maturity levels, thereby enhancing their overall capabilities (Marks et al., 2012; Gokalp et al., 2021). However, the current academic literature lacks a dedicated maturity model tailored specifically to HRA, revealing a clear research gap (Bahuguna et al., 2023; Wang et al., 2024). Moreover, most existing models are static and overlook interdependencies across dimensions, which can adversely affect investment planning and prioritization (Meyer et al., 2009).

This study develops and evaluates a Human Resource Analytics Maturity Model (HRAMM) to guide progress in data-driven HR practices. The model defines five maturity levels and assigns weights to a focused set of KPIs at each stage. By considering the links among technology, organizational processes, and culture, the model provides a more comprehensive and practical picture of analytical capability. The framework is designed for use in Iranian organizations and similar contexts, helping decision makers improve strategy and day to day performance through structured use of HR data.

2. Literature review

In the theoretical background of the HRA maturity model, the literature is divided into three main sections. The first focuses on studies related to HRA, the second examines maturity model approaches, and the third synthesizes previous research in business analytics, business intelligence, and data analytics maturity frameworks.

In the academic literature, HRA has been defined in various ways (Marler and Boudreau, 2017; Margherita, 2021; Thakral et al., 2023). These definitions commonly refer to the use of statistical and mathematical techniques to support decisions related to an organization's people (Larsen and Edwards, 2021; Edwards et al., 2022; Cullen et al., 2023). In recent years, HRA has been conceptualized as an organizational capability (Levenson, 2018; Minbaeva, 2018; Falletta and Combs, 2021; Samson and Bhanugopan, 2022), reflecting its multidimensional

nature and its reliance on various internal resources and organizational factors (Minbaeva, 2018; Wirges and Nair, 2022). Organizational capability refers to the way an organization combines its resources, knowledge, and skills to systematically perform activities and generate specific outcomes (Salvato and Rerup, 2010). These capabilities should be developed using both internal and external assets and must be continuously maintained and enhanced (Helfat and Peteraf, 2003). Recent studies emphasize the need for integration across organizational assets and departments to develop HRA capabilities (Shet et al., 2021; Ramachandran et al., 2023; Wang et al., 2024), especially given that they operate across organizational boundaries and at multiple levels (Howell and Bondarouk, 2017; Minbaeva, 2018). Therefore, companies aiming to advance their HRA capabilities should transition from a purely HR-centric approach toward more integrated, organization-wide strategies (Andersen, 2017).

An MM is defined as "a structured collection of elements that describe characteristics of effective processes at different stages of development" (Pullen, 2007). Originally developed in software engineering, this approach significantly reduced development costs and improved process quality and efficiency (Gokalp et al., 2021). In recent years, management and operations research has increasingly adopted maturity models, as they offer a simple yet effective method for assessing the quality of organizational capabilities and systems (Lismont et al., 2017; Doctor et al., 2023) and for developing actionable improvement pathways (Wendler, 2012).

HR analytics has received increasing attention as organizations seek to make more evidence-based HR decisions. However, despite its growing popularity, many organizations still struggle to realize its full value due to limitations in organizational structure, analytical capabilities, and system support (Heuvel and Bondarouk, 2017).The key purpose of a maturity model is to identify gaps between a capability's current and desired states, thereby helping organizations build an effective roadmap for enhancing their maturity level (Becker et al., 2009; Stueber et al., 2023). Since the concept of maturity aligns with a stage-based development approach (Monteiro et al., 2020), the models typically propose incremental improvements through a series of intermediate stages (Sen et al., 2012). The main components of a maturity model include maturity levels, model dimensions, and evaluation tools (de Bruin et al., 2005). Each maturity level represents a stage to which the model's constituent dimensions can progress (Monteiro et al., 2020). These levels should be distinct, measurable, and logically connected to the previous and next levels (Becker et al., 2009).

Over the past few decades, researchers have proposed hundreds of maturity models for various organizational capabilities (Doctor et al., 2023), including business analytics (e.g.,

Cosic et al., 2012), data analytics (e.g., Carvalho et al., 2019), and business intelligence (e.g., Lahrmann et al., 2011; Lismont et al., 2017b). These terms are often used interchangeably in the literature (Arunachalam et al., 2018) to describe the organizational capability for the broad use of data, advanced analytics, and evidence-based management to support strategic decisions and actions (Davenport and Harris, 2007; Chen and Nath, 2018) (see Table 1).

Table 1. Categorized summary of prior studies.

Area	Study	Topic	Key findings
HRA	Marler and Boudreau (2017)	Definitions and terminology in HRA	HRA involves statistical techniques for decision-making related to people.
	Minbaeva (2018)	HRA as an organizational capability	HRA is defined as a multidimensional capability that requires the integration of resources and skills.
	Shet et al. (2021)	Role of integration across assets in HRA development	Successful HRA implementation requires collaboration across organizational units.
Maturity Model Approach	Pullen (2007)	Definition and components of maturity models	A maturity model is a structured framework describing the characteristics of process stages.
	Gokalp et al. (2021)	Maturity models for process cost efficiency	Maturity models improve productivity and quality by reducing process development costs.
	Boon et al. (2025)	Core elements of maturity models	Maturity levels, model dimensions, and evaluation tools are the foundational components.
Analytics and Maturity Models	Cosic et al. (2012)	Maturity models in business analytics	Maturity models contribute to higher-quality business analytics.
	Carvalho et al. (2019)	Maturity models in data analytics	These models support wide-ranging use of data for informed decision-making.
	Lismont et al. (2017)	Evidence-based management in business intelligence	Business intelligence is identified as a core component of data-driven decision-making maturity.

Although HR analytics enables organizations to utilize big data in human resource decision-making, scholars argue that organizations should not rely exclusively on date-driveninsights, and strategicHR decisions should also incorporate managerialexperience and contextual considerations (Opatha,2021). The literature reveals that while maturity models have been widely developed across domains such as data analytics, business intelligence, and HRA, they often treat organizational development as a linear, compartmentalized process. This overlooks the interdependent and dynamic nature of socio-technical systems, where progress in one area (e.g., data integration) is closely influenced by shifts in culture, policy, or technological infrastructure. Most existing models emphasize discrete elements such as standardization, security, or integration but fail to capture the feedback loops, cross-level interactions, and emergent behaviors that characterize real-world transitions.

To address this gap, the present study adopts the Fuzzy Analytic Hierarchy Process (FAHP) as a methodological foundation within a systems thinking framework. By systematically evaluating and weighting KPIs across five maturity levels, the model accounts for uncertainty, interconnection, and contextual variability. It is particularly tailored to the unique organizational and cultural structures of developing countries such as Iran, offering a more nuanced, adaptive, and systemic approach to assessing and enhancing HRA maturity. This enables organizations to better align their transformation strategies with both internal readiness and evolving external pressures.

3. Methodology

To conduct the research using a scoping review methodology, we followed the guidelines proposed by Arksey and O'Malley (2005) and later expanded by Levac et al. (2010). These methods were designed to ensure high levels of transparency and systematic rigor, thereby enhancing the accuracy, reliability, and credibility of the research process (Paré et al., 2016). Although scoping reviews are highly systematic, they should not be confused with traditional systematic reviews. Generally, systematic reviews, such as meta-analyses, aim to synthesize prior empirical findings in order to answer questions like "what works best?". In contrast, scoping reviews are more exploratory, aiming to provide an initial assessment of the volume and types of literature available on an emerging topic, identify existing gaps, and suggest directions for future research.

Our framework for conducting this scoping review aligns with the standards endorsed by systematic review advocates, emphasizing that each step of the process must be carried out with precision and transparency (Mays et al., 2001). The scoping review process should be sufficiently documented to allow for replication by other researchers. This level of clarity not only enhances the credibility of the findings but also protects the methodology from criticism of a lack of rigor (Mays et al., 2001) (see Figure 2).

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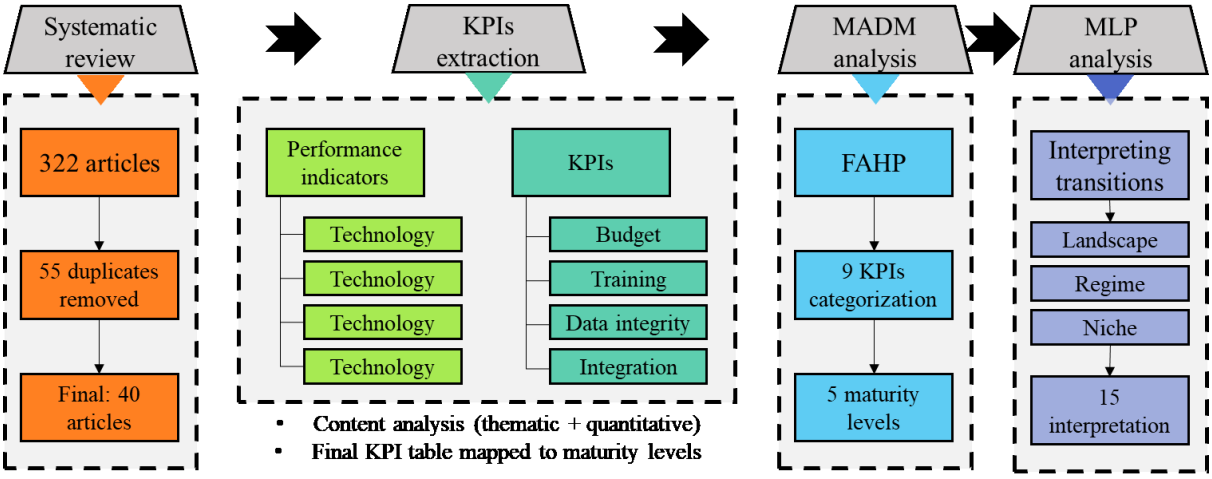

Figure 2. A five-phase research methodology framework integrating systematic review, KPI extraction, FAHP-based MADM analysis, and MLP interpretation.

The method used for identifying sources in this scoping review needed to provide both breadth and depth to comprehensively capture the domain. Unlike a narrowly focused research question that limits the investigator to a predefined set of studies (as in traditional systematic reviews), scoping reviews are not confined to a rigid protocol. This flexibility allows researchers to refine search terms and adjust sensitivity throughout the review process as their understanding of the literature evolves. At the outset, researchers may refrain from applying strict limitations on keywords, study identification, or source selection. The process is iterative and reflexive, allowing adjustments to ensure thorough coverage of the relevant literature.

Given these distinctions, the framework adopted in this study consists of five distinct phases: 1) Clear and focused research questions were formulated to define the scope and objectives of the review. These questions were designed to elicit a comprehensive perspective on the topic under investigation. 2) A wide-ranging search was conducted to identify all potentially relevant studies. This stage aimed to ensure inclusivity and diversity of viewpoints across the literature. 3) Identified studies were filtered to retain only those that directly addressed the research questions and met quality and methodological criteria. This ensured that only reliable and relevant studies proceeded to the analysis phase. 4) The selected studies were organized and categorized to extract key findings and structure them effectively. This helped streamline the data for deeper analysis. 5) The extracted data were synthesized and presented in a structured manner, offering a unified and in-depth understanding of the scoping review outcomes. This stage facilitates better comprehension for both researchers and practitioners (Oliver, 2001).

3.1. Protocol development

As a foundational step, a detailed research protocol was designed to guide the scoping review process. This included defining core research questions, search strategies, inclusion/exclusion criteria, and data extraction procedures. Additionally, the protocol specified team responsibilities, the conceptual framework, data analysis techniques, and a project timeline. Aligned with best-practice recommendations from methodological experts, the protocol served as a systematic yet flexible roadmap that could be updated as needed (Ebrahimi et al., 2025). The guiding research questions were:

- What key indicators and metrics are used to measure data-driven HRM maturity?
- What maturity levels are typically proposed for assessing HRM analytics?
- What are the promising and practical research directions for future studies in HRM maturity assessment?

These questions were designed to provide a comprehensive understanding of performance measurement indicators in data-driven human resource maturity and to highlight future research opportunities in this evolving domain.

3.2. Systematic review and screening

To ensure comprehensive coverage of performance indicators and maturity assessment in data-driven HRM, six major databases were searched: Emerald, Springer, ProQuest, Taylor and Francis, ScienceDirect, WILEY, and Web of Science. Additionally, one article was manually added from Scopus. These databases were chosen for their diverse collections and broad publisher coverage, minimizing selection bias. Each team member independently performed trial searches to refine the keywords. After multiple rounds of discussion, a final set of keywords was agreed upon (see Table 2). No publication-year restriction was applied; only articles in English or Persian were included. Searches were conducted uniformly across all databases, and results were cross-validated among team members. The process took place in Fall 2024, yielding 322 articles.

Table 2. Summary of literature search results

Database	Keywords	Articles
Taylor and Francis	Data-driven HRM maturity; HR performance indicators	22
Emerald	Data-driven HR analytics; HR performance	34
WILEY	Data analytics maturity models; HRM and analytics maturity	37
Springer	HR analytics and competitive advantage; data capabilities	68
Web of Science	Data-driven analysis and HRM; analytical capabilities	87
ProQuest	Maturity measurement and human data management; employee performance	11
ScienceDirect	HR analytics and optimization; maturity and efficiency indicators	73

A multi-stage screening process was conducted to ensure relevance. Of the 322 initial articles, 55 duplicates were removed. Subsequently, 237 articles were excluded for lacking a focus on KPI-based maturity assessment in HR analytics, according to predefined inclusion/exclusion criteria. One manually identified article from Scopus was added, bringing the total to 40 final articles, as shown in Figure 2. A structured coding form was developed to extract data from each article, including publication year, journal name, article title, type, authors, research questions, key findings, and future research directions. This step aimed to map out the intellectual landscape of KPI-based maturity assessment in HRM. Key concepts were also extracted to develop a conceptual map of relevant performance indicators. This map supports a comprehensive understanding of how data-driven HR maturity has evolved and highlights gaps for future research.

3.3. Fuzzy analytic hierarchy process

The FAHP used in this study is based on Chang's method (1992), which integrates classical AHP with fuzzy logic to handle multi-criteria decision-making (MCDM) under uncertainty. In modern complex and uncertain environments, especially in HR contexts where subjective judgments are common, traditional decision-making tools like cost-benefit analysis are often insufficient. FAHP offers a flexible and robust framework that improves decision accuracy by incorporating triangular fuzzy numbers to model expert opinions.

This method was applied to evaluate the relative importance of KPIs in data-driven HRM maturity models. FAHP is particularly useful for incorporating diverse stakeholder perspectives and addressing ambiguities in HR assessment. Triangular fuzzy numbers convert linguistic terms (e.g., "more important," "much more important") into numerical values, enabling structured pairwise comparisons (see Table 3).

Table 3. Triangular fuzzy numbers and their reciprocals

Linguistic term	**Fuzzy number (*l*, *m*, *u*)**	**Reciprocal (l^{-1}, m^{-1}, u^{-1})**
Equal importance	(1.0, 1.0, 1.0)	(1.0, 1.0, 1.0)
Slightly more important	(0.5, 1.0, 1.5)	(1.5, 1.0, 2.0)
More important	(1.0, 1.5, 2.0)	(0.5, 1.5, 1.0)
Strongly more important	(1.5, 2.0, 2.5)	(0.4, 0.5, 1.5)
Very strongly important	(2.0, 2.5, 3.0)	(0.3, 1.5, 0.5)
Absolutely more important	(2.5, 3.0, 3.5)	(0.3, 0.3, 1.5)

Pairwise comparisons were conducted using expert judgments aligned with the KPI hierarchy. Consistency of the fuzzy pairwise matrices was verified using Gogus and Boucher's inconsistency index. While Chang's FAHP is simpler and easier to compute (based on

arithmetic means), Buckley's FAHP offers more accuracy in resolving inconsistency using geometric means but requires advanced software tools. In this study, Chang's method was selected for its simplicity and interpretability, making it suitable for initial modeling and practical implementation in data-driven HR environments (Kubler et al, 2016).

If $M_1 = (a_1, b_1, c_1)$ and $M_2 = (a_2, b_2, c_2)$ are two triangular fuzzy numbers, the arithmetic operations on them are defined as follows:

$$M_1 \oplus M_2 = (a_1, b_1, c_1) \oplus (a_2, b_2, c_3) = (a_1 + a_2, b_1 + b_2, c_1 + c_2)$$
$$M_1 \otimes M_2 = (a_1, b_1, c_1) \otimes (a_2, b_2, c_2) = (a_1 \times a_2, b_1 \times b_2, c_1 \times c_2) \quad (1)$$

Various FAHP methods have been proposed by researchers. However, they all share a common foundation: combining fuzzy theory with hierarchical structure analysis. Most studies have applied the method introduced by Chang (1992). The steps of implementing and computing FAHP from Chang's perspective are as follows:

Step 1: Construct the pairwise comparison matrix based on triangular fuzzy numbers M_{gi}^{j}, where i=1,2,…,n, refers to the row number and j=1,2,…,m, refers to the column number.

$$(M_{gi}^{j})_{m*n} = \begin{bmatrix} M_{g1}^{1} & \cdots & M_{g1}^{m} \\ \vdots & \ddots & \vdots \\ M_{gn}^{1} & \cdots & M_{gn}^{m} \end{bmatrix} = \begin{bmatrix} (1,1,1) & (a_{12}, b_{12}, c_{12}) & \cdots & (a_{1m}, b_{1m}, c_{1m}) \\ \vdots & \ldots & \ddots & \vdots \\ (a_{n1}, b_{n1}, c_{n1}) & (a_{n2}, b_{n2}, c_{n2}) & \cdots & (1,1,1) \end{bmatrix} \quad (2)$$

Step 2: Calculate the fuzzy synthetic extent value (S_i) for each row of the pairwise comparison matrix.

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \otimes \left(\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right)^{-1} \quad (3)$$

Step 3: Determine the degree of possibility that s_i is greater than s_k, using a defined formula based on the comparison of fuzzy numbers.

$$V(S_i > S_k) = \begin{cases} 1 & m_i \geq m_k \\ 0 & l_k \geq u_i \\ \left(\dfrac{l_k - u_i}{(m_i - u_i) - (m_k - l_k)}\right) & othermise \end{cases} \quad (4)$$

Step 4: Calculate the degree of possibility for each S being greater than the rest of the fuzzy numbers (n−1), by taking the minimum value among them.

$$V(S \geq S_1, S_2, \ldots, S_k) = V[(S \geq S_1), (S \geq S_2), \ldots, (S \geq S_k)] = Min\, V(S \geq S_i), \quad i = , \ldots, k \quad (5)$$

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Step 5: Compute the weight vector $W = (W_1, W_2, \dots, W_n)^T$ of the pairwise comparison matrix using the minimum degrees of possibility. Normalize the resulting weights using a normalization formula to determine the relative importance of each criterion.

$$W_i' = Min\, V(S_i \geq S_j \mid \mathrm{j} = 1, \dots, \mathrm{m}\ , \mathrm{i} \neq \mathrm{j})$$

$$W_i = \frac{W_i'}{\sum_{i=1}^{n} W_i'} \tag{6}$$

3.4. Multi-Level perspective: A systemic method

The Multi-Level Perspective (MLP) is a systems thinking methodology designed to understand complex, long-term transitions in socio-technical systems. It conceptualizes change not as a linear or isolated process, but as the outcome of dynamic interactions across different structural levels. This holistic view aligns with systems thinking principles, in which elements are interrelated (Khazaei et al., 2025b) and feedback loops play a critical role in shaping system behavior over time (Safaie et al., 2023). In this study, MLP is used to examine how KPIs evolve within the broader maturity of data-driven HRA (Geels, 2019) (see Figure 3).

At the niche level (the foundation of the system), innovations and experimental practices emerge in protected environments. These may include pilot programs, start-ups, or research-driven initiatives in HR analytics, such as predictive modeling for employee engagement or machine learning in recruitment. Niches represent the seeds of systemic change, nurtured by supportive actors who shield them from immediate competitive pressures. They serve as testbeds for new ideas, enabling trial-and-error learning that might not be possible within mainstream settings (Geels, 2002).

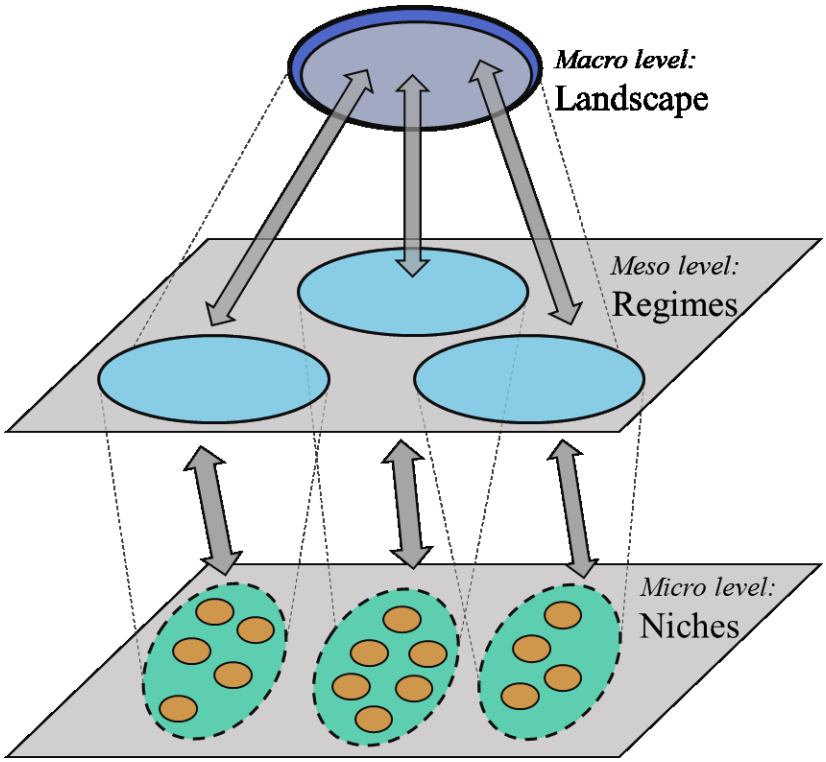

Figure 3. The MLP framework as a systems thinking approach, illustrating the interplay between three levels of socio-technical systems (Geels, 2002, 2019).

The regime level encompasses dominant organizational structures, norms, and policies that guide current practices. In the HRA context, this includes established HR processes, legal frameworks, and cultural expectations. Regimes tend to be stable and self-reinforcing, making them resistant to abrupt transformation. However, as niche innovations mature and gain legitimacy, they begin to challenge the regime, particularly when existing structures face performance gaps or external pressures. Understanding the regime's rigidity and its potential levers for change is essential in systems thinking to identify where interventions can be most effective (Genus and Coles, 2008).

At the top of the framework lies the landscape level, representing external macro-trends such as demographic shifts, technological advancements, regulatory changes, or global crises. These factors evolve independently of actors at the regime or niche levels but exert significant influence on them. For instance, increasing global emphasis on data governance or digital transformation creates landscape pressure that accelerates the need for mature HRA capabilities. Systems thinking highlights how these pressures cascade through the system, creating windows of opportunity for innovation to scale up (Shahroodi et al., 2024).

By applying MLP as a systems-thinking tool, this study identifies 15 distinct transition patterns across the three levels. These patterns help interpret how organizations progress

through different stages of maturity in adopting data-driven HR practices. Rather than viewing KPI evolution as a series of isolated upgrades, the MLP perspective frames it as an emergent property of systemic interactions in which innovation, institutional inertia, and contextual pressures intersect. This approach not only explains the past trajectory of HRA development but also guides strategic planning for future transformation.

4. Results

To build a comprehensive maturity model for HRA, clear research questions and objectives were first established. These questions aimed to identify the key dimensions and performance indicators across different maturity levels, focusing on technology, organizational structure, performance, and data-driven culture. The goals included identifying existing technological standards, organizational capabilities, and performance attributes essential for successful HRA implementation. In addition, an empirical expert validation was conducted to ground the KPI weights and maturity transitions in practice. We recruited nine experts using purposive sampling, including five senior HR practitioners from large Iranian organizations, two data and HRIS specialists, and two academics with publications in HRA and analytics. All experts had at least seven years of relevant experience. Evidence was collected in two steps. First, each expert completed a structured FAHP instrument, in which pairwise comparisons were made for the nine KPIs across the five maturity levels, using triangular fuzzy numbers. Second, a 90-minute online workshop was held to clarify definitions and resolve outliers. Individual judgments were aggregated using the fuzzy arithmetic mean consistent with Chang's FAHP procedure. Consistency was examined with the Gogus and Boucher inconsistency index. Kendall's W was also computed to assess agreement among experts. All responses were anonymized, participation was voluntary, and consent was obtained prior to data collection.

The literature search was then conducted using a range of academic sources, including peer-reviewed articles, books, and theses. Databases such as Web of Science, ScienceDirect, and others were searched to identify relevant materials on HR analytics, organizational maturity models, and key performance indicators. Sources were selected based on their relevance to topics like system integration, data management, organizational support structures, and data-driven decision-making. These materials provided both conceptual and empirical foundations for identifying HRA maturity dimensions.

Following this, key data were extracted and coded from the selected studies. Core components and performance indicators were identified across four categories: technological

architecture, organizational processes, performance characteristics, and cultural alignment. Data were coded separately for each dimension to ensure structured, consistent integration into the final maturity model. This process enabled the development of a well-defined framework, offering specific indicators for each maturity level within data-driven HR analytics. Table 4 summarizes the domains, dimensions, and KPI definitions of the proposed data-driven HRA maturity model.

Table 4. Domains, dimensions, and KPI definitions in data-driven HRA.

Domain	Dimension	Definition	Components	Component definition	KPIs
Technology	HRA Architecture	Describes the technological architecture of HRA	Technology Standards	Reference standards for system interoperability and data modeling	% Compliance with technology standards
			System Integration	Description of internal and external HRA integration	% of system integration
	Data Management	Managing data collection elements	Data Storage	Capacity to store and retain essential data	Volume of stored data
			Data Modeling	Structuring data for analysis and access	Quality of data structuring
Organizational	HRA Strategy	Long-term planning for HRA	Allocated Budget	Organizational budget allocated to HRA	% of allocated budget
			Executive Support	Level of executive support for HRA initiatives	% of managerial support
Functional	Data Governance	Ensuring input data quality	Data Completeness	Validation of data integrity and completeness	% of complete data
			Data Security	Ensuring authorized access and privacy	Number of security incidents
Dissemination	Analytical Culture	Promoting an analytical mindset within the organization	Analytical Awareness	Fostering a data-driven decision-making culture	Number of training sessions

In the data analysis phase, findings extracted from the reviewed articles were assigned to specific KPIs. For example, under the technology dimension, indicators such as alignment with technology standards and system integration were identified as key performance metrics. For each KPI, five maturity levels were defined, ranging from "Initial" to "Optimized." These levels indicate an organization’s progress in adopting HRA and its organizational maturity in this area. Each level is associated with specific characteristics and benchmarks that help determine the current stage of maturity and the targets the organization should aim to achieve. Table 5 presents the key performance indicators and their corresponding maturity levels in data-driven HR analytics.

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Table 5. Key performance indicators and maturity levels in data-driven HR analytics

#	KPI	Level 1: Initial	Level 2: Repeatable	Level 3: Defined	Level 4: Managed	Level 5: Optimized
A	% Compliance with technology standards	No standards applied	Partial compliance with some standards	Compliance with common standards	Full compliance with global standards	Optimized and updated use of standards
B	% of system integration	Systems work independently	Limited integration	Full internal integration	Full internal and external integration	Integration with automated interactions
C	Volume of stored data	Limited and manual storage	Partial data storage	Systematic data storage	Effective data storage methods	Continuous and optimized storage
D	Quality of data structuring	Unstructured data	Limited structuring for some data	Fully structured for basic analytics	Optimized structuring and accessibility	Highest quality data structuring
E	% of allocated budget	No specific budget	Limited budget for specific areas	Adequate budget for HRA strategies	Budget aligned with management priorities	Flexible and optimized budgeting
F	% of managerial support for HRA	Limited and partial support	Support for some objectives	Systematic support in decision-making	Strategic executive support	Full and strategic top-level support
G	% of complete data	Data is incomplete	Partial data completion	Systematic data completion	Completion with validation	Full data completeness guaranteed
H	Number of security incidents	Security breaches not identified	Partial security monitoring	Systematic security oversight	Reduced number of incidents	Maximum and continuous security
I	Number of training sessions	Limited and sporadic training	Training for select teams	Broad training across departments	Continuous and systematic training	Extensive training and cultural integration

4.1. Fuzzy-AHP analysis of KPI importance across maturity levels

To make the FAHP procedure transparent and reproducible, we provide a brief example of how linguistic inputs were encoded. During elicitation, experts compared KPI pairs using a six-point linguistic scale: equal, slightly more important, more important, strongly more important, very strongly important, and absolutely more important. Each phrase corresponds to a triangular fuzzy number listed in Table 3. For instance, when comparing System integration with Budget allocation at the Managed level, seven of nine experts rated integration as strongly more important, and two rated it more important. We converted these selections to the corresponding fuzzy numbers from Table 3, averaged the resulting triples to obtain the group judgment for that pair, and recorded the reciprocal term for the reverse comparison. As a second illustration, at the Initial level, most experts rated Training over Data structuring as very strongly important, given the need to build basic literacy before technical refinement. All pairwise judgments were then synthesized using Chang's FAHP steps, and matrix quality was checked using the Gogus and Boucher inconsistency index along with Kendall's W for agreement. This example reflects the typical workflow used across all maturity levels and KPI pairs.

Table 6 illustrates the evolution of KPI importance weights across five maturity levels, as assessed using the FAHP. This integrated table offers a consolidated view of how each KPI's relative weight changes as organizations progress through different stages of data-driven HR maturity, from Initial (Level 1) to Optimizing (Level 5).

Table 6. Consolidated FAHP results showing the relative importance (BNP and normalized weights) of nine KPIs across five maturity levels in data-driven human resource analytics.

KPIs	Level 1		Level 2		Level 3		Level 4		Level 5	
	BNP	Weights	BNP	Weights	BNP	Weights	BNP	Weights	BNP	Weights
A	0.101	0.0968	0.135	0.1296	0.13	0.1245	0.116	0.1105	0.116	0.1105
B	0.109	0.1039	0.117	0.1121	0.099	0.0944	0.148	0.1409	0.137	0.1306
C	0.127	0.1213	0.093	0.089	0.163	0.1556	0.105	0.1003	0.119	0.1138
D	0.077	0.0732	0.075	0.0715	0.085	0.0811	0.073	0.0691	0.075	0.0715
E	0.132	0.1257	0.12	0.1153	0.095	0.0911	0.125	0.1191	0.143	0.1364
F	0.114	0.1089	0.106	0.1014	0.11	0.1052	0.087	0.0834	0.109	0.1037
G	0.125	0.1195	0.124	0.1185	0.133	0.1273	0.127	0.121	0.125	0.1195
H	0.129	0.1231	0.135	0.1299	0.111	0.1062	0.146	0.1392	0.123	0.117
I	0.133	0.1276	0.138	0.1327	0.12	0.1145	0.122	0.1163	0.101	0.0968

At the Initial level (Level 1), the highest weights are assigned to KPIs such as budget allocation (E), training efforts (I), and data security (H) (see Figure 4). These priorities reflect the foundational needs of organizations initiating a data-driven transformation, in which establishing a secure, well-funded, and well-educated environment is crucial. Conversely, lower weights for indicators such as data structure quality (D) and technical standard alignment (A) suggest that technical refinement and integration are not yet a major concern at this early stage.

At the Repeatable level (Level 2), training (I) and security (H) remain dominant, indicating a focus on process stabilization through consistent learning and protective measures. Notably, the weight of the budget (E) slightly declines, suggesting that financial structure is now more established, while low emphasis continues on technical quality (C, D).

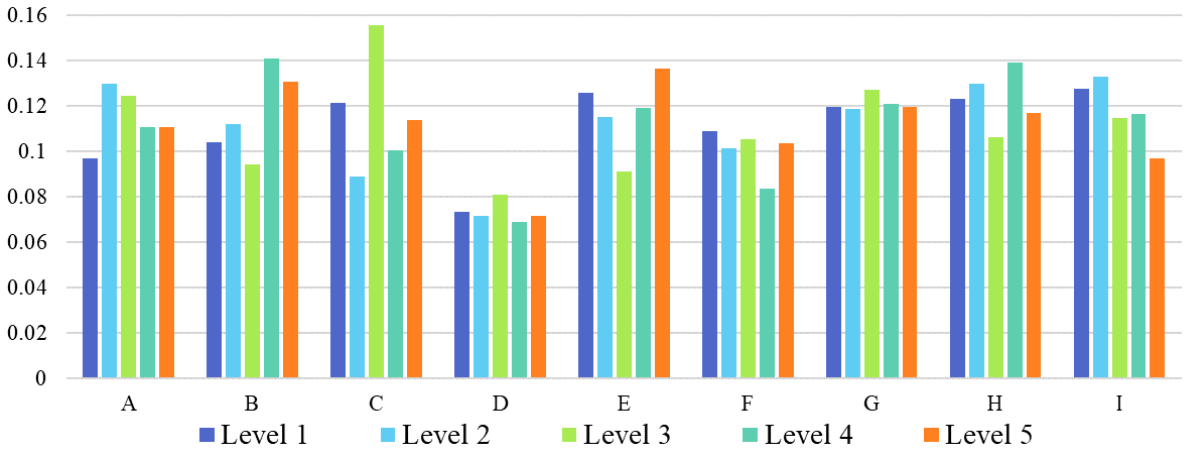

Figure 4. Comparison of normalized weights for nine KPIs across five organizational maturity levels in HRA.

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At the Defined level (Level 3), KPIs related to data structure (C) and data modeling (A) receive the highest weights, indicating a transition toward the development of systematic, optimized data architectures. This indicates that organizations at this level are consolidating their infrastructure to support future scalability, thereby shifting focus from governance and training to core data readiness.

The Managed level (Level 4) represents a peak in integration (B) and security (H), underscoring the need for full-system coordination and strict control of data access as organizational complexity increases. In contrast, the importance of managerial support (F) and data structure quality (D) declines, indicating they have likely reached a satisfactory baseline relative to prior levels.

Finally, in the Optimizing level (Level 5), budget flexibility (E) and system integration (B) become the most critical KPIs. These reflect the organization's shift toward strategic refinement, efficient resource allocation, and continuous optimization of inter-system functionality. Meanwhile, early-stage enablers such as training (I) and basic data structuring (D) are de-prioritized, signaling maturity in foundational capabilities.

In summary, the FAHP analysis reveals a logical and sequential shift in KPI importance, beginning with foundational enablers such as funding and training and progressing to system integration and optimization. This pattern underscores the need for organizations to align their maturity journey with evolving performance priorities at each stage.

Transition analysis of HRA systems using MLP

As organizations progress from initial stages toward full maturity in data-driven human resource analytics, merely identifying and weighting key performance indicators is insufficient. To gain a deeper understanding of the barriers and enablers of this transformation, the MLP framework can be employed. MLP analyzes the transformation of socio-technical systems across three analytical layers: the macro level (landscape), the meso level (regimes), and the micro level (niches). This framework enables a dynamic, multidimensional interpretation of the maturity transition, rather than treating it as a linear process.

In this study, the use of MLP helps contextualize the FAHP results within a broader socio-technical framework, allowing us to interpret why certain indicators are prioritized in lower maturity levels and how shifts in policy, technology, or organizational culture influence changes in priority at more advanced stages. According to this framework, external drivers such as global pressures toward digitalization (landscape), the current administrative and structural setup of organizations (regimes), and emerging pilot innovations or successful experimental

projects (niches) simultaneously shape the organizational maturity journey. The following MLP-based interpretation for each maturity level explores the dynamics of transition and systematically identifies barriers and enablers of transformation.

Level 1 – Initial: MLP-based analysis

At the initial level of HRA maturity, organizations are in the early stages of adopting data-driven practices. From an MLP lens, transformation is minimal because the pressures from the broader landscape remain weak or unrecognized. External factors such as national digital transformation policies or global data governance standards may exist, but are often not internalized by the organization. At the regime level, traditional HR practices dominate, characterized by manual data entry, fragmented reporting, and a lack of digital integration. Institutional resistance, limited digital competencies, and the absence of strategic support act as strong barriers. At the niche level, however, small-scale initiatives may emerge: isolated training sessions on HR analytics, pilot dashboards for monitoring simple KPIs, or individual efforts to digitize HR records. These niches, while not yet structurally disruptive, can serve as seeds for systemic transition, but only if they are supported by policy incentives and aligned with broader regime reforms. Table 7 provides an MLP-based analysis of Level 1 (Initial) maturity in HRA.

Table 7. MLP-based analysis of Level 1 (Initial) maturity in HRA.

MLP#	Observed state at level 1	Examples in Iranian organizations	Barriers and leverage points
Landscape	Weak external pressure for transformation; digitalization not fully enforced	National documents on IT modernization exist, but lack enforcement mechanisms	Opportunity: leverage public-sector digitalization plans or regulatory frameworks to stimulate movement
Regime	Manual, isolated, and reactive HR processes; no integrated systems	Paper-based employee files, non-standardized reports, and fragmented HR systems	Barrier: Institutional inertia, limited budget, cultural resistance to technology
Niche	Sporadic pilot efforts with limited institutional impact	HR managers using Excel-based KPI dashboards; ad hoc training in HR analytics	Potential: Early adopters can become champions of change if connected to a formal strategy or policy-level encouragement

Level 2 – Repeatable: MLP-based analysis

At the repeatable level, organizations begin to systematize certain HR processes and embed them into organizational routines. From an MLP perspective, the landscape pressure becomes slightly more visible: governmental calls for digital reporting, industry benchmarks, and increasing regional competition create a soft but growing push for modernization. However, these forces are often perceived as optional rather than imperative. At the regime level,

organizations start to codify processes, but systemic inertia remains strong. Most changes are operational rather than structural; for example, HR units may automate attendance tracking or introduce performance monitoring tools, but these remain loosely connected. At the niche level, we observe clearer experimentation: internal training modules on data literacy, the use of KPI dashboards by select departments, or the implementation of pilot digital HR systems without full institutional integration. The regime still isolates these efforts rather than scaling them, but the shift toward repeatability shows that some niches are gaining traction. The organization stands at a tipping point where landscape forces and niche innovation must converge to overcome regime rigidity. Table 8 presents the MLP-based analysis of Level 2 maturity in HRA.

Table 8. MLP-based analysis of Level 2 maturity in HRA.

MLP#	Observed state at level 2	Examples in Iranian organizations	Barriers and leverage points
Landscape	Emerging pressure from policymakers and market dynamics	Ministry-level reporting requirements, regional competitors adopting HR tech	Leverage point: Frame compliance and modernization as strategic imperatives rather than optional upgrades
Regime	Early automation and formalization of HR tasks without systemic integration	Attendance tracking systems, isolated HR analytics tools	Barrier: Siloed digitalization, lack of cross-functional alignment, short-term thinking
Niche	Training programs and pilot technologies are tested by mid-level HR professionals	Departmental-level KPI dashboards, Excel-to-web migration of HR records	Potential: Institutionalize successful pilots through HR strategy alignment and budgeted expansion plans

Level 3 – Defined: MLP-based analysis

At the defined level of HRA maturity, organizations exhibit a noticeable shift from isolated experimentation toward structured, organization-wide practices. From the MLP lens, pressures at the landscape level, such as national digital transformation roadmaps, cross-sector success stories, and investor expectations for transparency, are now more actively acknowledged. Organizations begin to align internal goals with external expectations. At the regime level, formal frameworks and digital standards are introduced across departments: organizations adopt organization-wide KPI systems, develop centralized data repositories, and integrate multiple data sources. However, legacy systems and cultural inertia may still constrain full harmonization. At the niche level, we see advanced experimentation: predictive analytics pilots, cross-functional HR analytics teams, and early use of AI in candidate screening or workforce planning. These innovations are increasingly aligned with regime goals and, if nurtured properly, can form the basis for regime transformation. At this point, the organization is in a critical phase, sophisticated enough to define and test, but still fragile if external pressure or leadership support wavers. Table 9 presents the MLP-based analysis of Level 3 maturity in HRA.

Table 9. MLP-based analysis of Level 3 maturity in HRA.

MLP#	Observed state at level 3	Examples in Iranian organizations	Barriers and leverage points
Landscape	Institutional pressure for modernization and accountability is growing	Digital governance guidelines, data ethics codes, and stakeholder demand for reporting	Leverage point: Use landscape shifts to justify strategic data integration and system investment
Regime	Organization-wide frameworks for HR analytics begin forming	Centralized HRIS systems, integrated KPI dashboards, and defined analytic workflows	Barrier: Resistance to de-siloing, inconsistent data quality, and lack of interdepartmental coordination
Niche	Advanced pilot initiatives are increasingly structured and aligned with strategy	Predictive models for attrition, talent analytics platforms, and internal HR data science labs	Potential: Embed niche teams into core HR functions; align their success with regime KPIs and long-term strategic planning

Level 4 – Managed: MLP-based analysis

At the managed level of HRA maturity, organizations move beyond defining analytics processes to controlling and optimizing them across departments. From an MLP standpoint, landscape pressures become more directive: legal compliance mandates, investor scrutiny, regional benchmarking, and competitive positioning drive organizations to formalize data-driven practices. The regime begins to transform: digital infrastructures are not only established but governed through policies, performance standards, and integrated platforms. HR systems are connected to finance, operations, and strategic planning. Cultural alignment improves, though resistance may persist when automation challenges power structures or entrenched norms. At the niche level, experimentation gives rise to institutional capability. What were once test pilots (e.g., data dashboards or predictive tools) have now become embedded systems, maintained by trained analysts or internal data teams. The boundary between niche and regime begins to blur. However, sustaining this transition demands leadership commitment, real-time feedback mechanisms, and alignment with changing landscape expectations. Table 10 presents the MLP-based analysis of Level 4 maturity in HRA.

Table 10. MLP-based analysis of Level 4 maturity in HRA.

MLP#	Observed state at level 4	Examples in Iranian organizations	Barriers and leverage points
Landscape	External forces increasingly prescriptive and measurable	HR technology adoption KPIs in national plans, ESG reporting standards, and sector-wide audits	Leverage point: Position HR analytics as a strategic enabler of compliance and competitiveness
Regime	Formalized governance and cross-functional integration of HRA systems	Integration of HRIS with ERP, automated reporting dashboards, and performance governance layers	Barrier: Mid-level resistance to analytics-based decision-making; challenges in maintaining interoperability and data governance
Niche	Embedded capabilities; pilots become routine, sustained by trained personnel	Internal HR analytics units, HR-data fusion with BI tools, and AI-enhanced recruitment platforms	Potential: Niche teams can drive continuous improvement loops; potential for feedback systems and adaptive HR decision support models

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Level 5 – Optimized: MLP-based analysis

At the optimized level, the organization has achieved full integration and strategic alignment of its HR analytics systems. Through the MLP lens, the relationship between landscape, regime, and niche is no longer one-directional; the organization begins to shape its environment rather than merely adapt to it. At the landscape level, the organization participates in shaping national and sectoral standards, contributes to data governance discussions, and positions itself as a digital leader in HR transformation. At the regime level, systems are agile, continuously learning, and equipped for real-time optimization. Processes are data-driven, automated, and deeply embedded across all organizational functions. HR analytics informs strategic forecasting, workforce modeling, and cross-organizational decision-making. At the niche level, the distinction with the regime effectively disappears. Innovation becomes an ongoing, institutionalized process, with internal R&D, AI-enhanced models, and predictive simulations constantly refining operations. The organization not only responds to external pressures but also co-creates future expectations, serving as a benchmark for others. Table 11 presents the MLP-based analysis of Level 5 maturity in HRA.

Table 11. MLP-based analysis of Level 5 maturity in HRA.

MLP#	Observed state at level 5	Examples in Iranian organizations	Barriers and leverage points
Landscape	Organization becomes an active shaper of external expectations	Participation in HR-tech policymaking forums; exporting best practices to peer institutions	Leverage point: Institutional legitimacy allows shaping national standards and influencing regulatory evolution
Regime	Fully adaptive, data-driven HR architecture integrated with strategic management	Real-time dashboards, simulation-based workforce planning, and AI-supported decision environments	Barrier: Sustaining innovation pace; risk of stagnation if feedback systems are not maintained; need for strong ethical governance around employee data usage
Niche	Continuous, embedded innovation as part of daily operations	HR innovation labs; embedded AI models for retention, wellbeing, inclusion	Potential: Niche thinking institutionalized as a permanent innovation engine; agile experimentation accelerates long-term resilience and strategic foresight capability

The layered interpretation offered by the MLP highlights that organizational transformation toward advanced HRA maturity is neither linear nor internally driven alone. Rather, it emerges from a dynamic interplay between external macro pressures, entrenched internal practices, and bottom-up innovations. The alignment, or misalignment, among these levels fundamentally shapes the speed and depth of organizational change. With this in mind, the following discussion synthesizes the FAHP-based findings within this socio-technical transition framework and identifies practical implications for HR leaders, policymakers, and system designers seeking to foster sustainable, data-driven HR ecosystems.

5. Discussion

The evolution of HR analytics maturity is not only a matter of weighted KPIs across five levels but also a reflection of dynamic socio-technical transitions across landscape, regime, and niche layers. Figure 5 illustrates the maturity of HR analytics through the multi-level perspective (MLP), highlighting the interaction between macro-level pressures (landscape), organizational structures (regimes), and innovations (niches) across five maturity levels. This systems-thinking approach reveals how innovation scales and embeds within an organization over time.

At the initial stage, key priorities include training initiatives, budget allocation, and basic data security measures. These reflect the organization's need to build foundational capabilities. In the MLP framework, this aligns with isolated, experimental efforts (niches) and minimal pressure from the landscape. In contexts such as Iran, this suggests the necessity of investing in employee training for basic tech and data awareness, alongside minimal infrastructure funding to initiate digital transformation.

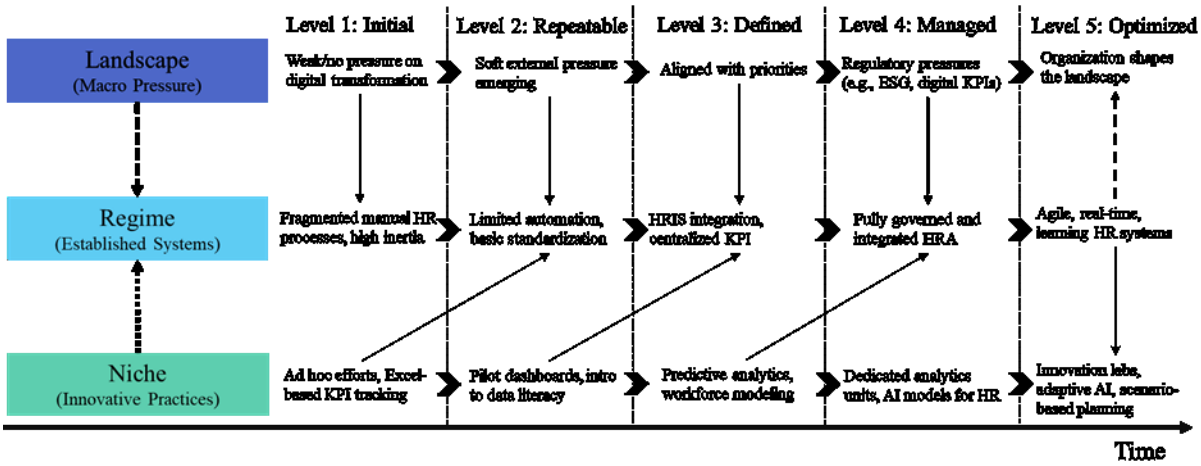

Figure 5. Multi-level perspective (MLP) of HR analytics maturity across five levels.

In the repeatable level, integration becomes essential. Regimes, partially automated systems, basic KPI tracking, and managerial support evolve from pilot innovations. Increasing budget flexibility and standardized training help overcome systemic inertia. For large Iranian organizations with siloed structures, developing integrated data systems is crucial to improve efficiency and coordination.

By the defined level, data systems are formalized. Organizations begin to develop centralized storage and structured access. Regimes stabilize, and predictive capabilities emerge. This stage benefits from strong managerial sponsorship and full systematization of data architecture. Iranian firms managing fragmented data ecosystems must prioritize storage standardization and stakeholder alignment to move beyond local optimizations.

At the managed level, pressures from the landscape (e.g., regulatory frameworks and ESG reporting standards) intensify. The regime becomes governed, and data systems are integrated across functions. Security incidents can be reduced through advanced protocols, and sustained managerial commitment is critical. In the Iranian context, attention to data protection and regulatory alignment will be key to building resilient systems.

Finally, in the optimized level, the boundary between niche and regime fades. Organizations adopt agile, real-time analytics systems and co-shape industry landscapes through innovation. Investment efficiency, standards harmonization, and a wide-scale data-driven culture become core capabilities. For organizations operating in rapidly evolving environments such as Iran, adapting to global technological standards and fostering an analytics-driven workforce can provide a critical competitive advantage.

This study underscores the critical role of HRA in shaping data-driven decision-making across various stages of organizational maturity. Through the prioritization and evaluation of KPIs, we observe that organizations transition from foundational concerns, such as training and data security, toward advanced capabilities like system integration, predictive modeling, and strategic resource allocation. Importantly, HRA maturity is not merely a technical upgrade but a strategic transformation in how human capital is understood, managed, and optimized. The shifting weight of KPIs across maturity levels reflects the evolving needs of organizations as they align HR functions with broader institutional goals. For countries like Iran and similar developing contexts, this progression offers a roadmap for scaling HRA adoption from isolated efforts to institutionalized intelligence.

Methodologically, the study adopts a systems-thinking lens, integrating the MLP to understand the nonlinear and dynamic nature of maturity transitions in HR analytics. Rather than viewing the maturity journey as a staged checklist, MLP allows us to contextualize each stage within the interaction of landscape-level pressures, regime-level organizational structures, and niche-level innovations. This layered framework highlights how external regulatory changes, internal managerial shifts, and localized pilot efforts collectively shape the path toward data-driven maturity. The use of FAHP to weight KPIs complements the MLP by quantifying priorities while acknowledging uncertainty and complexity. Ultimately, this combined approach offers both depth and structure to HRA research, enabling a more realistic, adaptive, and forward-looking assessment of organizational readiness.

6. Conclusion

This study demonstrates the strategic value of HRA as a maturity-building tool that enables organizations to shift from reactive HR management to integrated, predictive, and optimization-oriented practices. Through the identification and fuzzy prioritization of nine KPIs, the findings reveal a structured path from foundational capabilities, such as training and data security, to advanced dimensions, including real-time system integration and budget optimization. The distribution of KPI weights across maturity levels not only offers diagnostic insight but also highlights the evolving competencies required at each stage. For Iranian organizations operating in transitional economies, these insights provide a scalable roadmap for maturing HRA practices in alignment with resource availability and institutional readiness.

More importantly, by applying a systems-thinking lens through the MLP, the study reframes HRA development as a dynamic socio-technical transition rather than merely a set of technical upgrades. This approach clarifies how broader environmental pressures (landscape), entrenched organizational systems (regime), and bottom-up innovations (niches) interact to influence the pace and success of HRA adoption. The integration of FAHP with MLP reveals that KPI prioritization results from ongoing co-evolution across these levels, and that meaningful transformation requires alignment across strategic, operational, and experimental domains. This layered interpretation deepens our understanding of organizational maturity and serves as a practical planning framework for institutions seeking resilience amid digital transformation.

This study has several limitations that inform cautious interpretation of the results. First, the context is Iran. Institutional settings, regulatory structures, and digital readiness in Iran differ from those in many countries, which may limit generalizability. The maturity pathways and KPI priorities we report should be viewed as a context-informed baseline that requires local calibration elsewhere. Second, the evidence base for KPI identification relies on a scoping review. Scoping reviews emphasize breadth over exhaustive appraisal, which can introduce selection bias and publication bias. Although we searched multiple databases and applied explicit inclusion criteria, some relevant studies may have been missed, particularly non-indexed or practice-oriented sources. Third, expert elicitation for FAHP introduces subjectivity. Despite using structured pairwise comparisons, consensus procedures, and consistency checks, judgments reflect the perspectives of a limited panel. The FAHP variant adopted here, Chang's method, prioritizes simplicity and transparency, yet it is sensitive to the mapping of linguistic terms to triangular fuzzy numbers and to the aggregation scheme. Fourth, the design is cross-

sectional. We infer maturity transitions using MLP interpretation and expert knowledge rather than tracking organizations longitudinally. As a result, causal dynamics and the timing of transitions remain to be validated with panel data, case studies, or field experiments. These limitations motivate future work. Replication in other developing and developed contexts, mixed-method validation using organizational case studies, longitudinal measurement of maturity change, and comparison of FAHP variants or alternative MCDMs can strengthen external validity and methodological robustness.

Looking ahead, this study paves the way for the development of adaptive, systems-oriented decision-making tools in HR analytics. Future research should build on the MLP framework to develop simulation models that map multiple transition pathways across various policy and technological scenarios. Such models can help organizations identify leverage points, such as regulatory shifts, scaling pilot programs, or strategic reinvestment, that accelerate progress toward maturity. These simulations, embedded in system dynamics or agent-based modeling techniques, enable practitioners to test "what-if" scenarios and anticipate resistance points within their HR infrastructure. This direction holds particular promise in volatile and uncertain environments where agility and foresight are indispensable. In addition, several concrete directions can extend the model's scope and validity. First, adapt the maturity framework to sector-specific contexts, for example, healthcare, manufacturing, and financial services, with tailored KPI taxonomies and process maps. Second, conduct cross-cultural validation across developing and developed economies to examine contextual transferability and to recalibrate KPI weights where needed. Third, implement longitudinal field studies that track organizations across maturity stages and compare simulated trajectories with observed transitions. Fourth, triangulate FAHP with complementary MCDM approaches and qualitative case studies to test robustness, refine constructs, and capture socio-technical nuances. Furthermore, the methodological integration of MLP with other soft systems and MCDMs, such as DEMATEL, system dynamics, or scenario-based fuzzy cognitive mapping, can provide richer diagnostic and prescriptive capabilities. These hybrid frameworks can explore non-linear feedback loops, cross-domain interdependencies, and cultural adaptation challenges that often hinder HR transformation. Particularly in developing contexts like Iran, where institutional inertia and policy fragmentation are common, systems thinking-based approaches can bridge the gap between strategic intent and practical execution. By institutionalizing these tools within HR departments, organizations will be better equipped to design data strategies that are not only technically sound but also socially and contextually embedded.

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From Senge to Silicon: A Critical Review of Learning Organizations Theory in an AI-Driven World

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ABSTRACT

This paper critically examines Peter Senge's learning organization theory and its relevance in today's complex, AI-driven world. Employing a mixed-methods approach to analyze the theory's core assumptions, concepts, and prescriptive elements. The research aims to assess the theory's strengths and limitations in the face of contemporary challenges, specifically the impact of rapid technological advancements, globalization, and increasing uncertainty. While the learning organization framework offers a valuable paradigm for organizational development, research identifies gaps in addressing contemporary realities. Specifically, the paper explores the theory's adaptability to the rise of artificial intelligence and its impact on organizational learning processes, revealing how AI integration both facilitates and challenges traditional learning dynamics. By highlighting these limitations and presenting empirical findings on AI's influence, the study proposes avenues for theoretical refinement to enhance the learning organization concept for scholars and practitioners navigating the complexities of the modern organizational landscape. It contributes to a more nuanced understanding of how organizations can effectively learn and adapt in the 21st century.

Keywords

Learning organizations theory, Mixed-methods research, Critical theory, Theoretical refinement.

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1. Introduction

The rapid proliferation of artificial intelligence (AI) has fundamentally altered the business landscape, introducing unprecedented opportunities and challenges for organizational learning. While AI enables data-driven insights, predictive analytics, and automated decision-making, it also demands agility and redefined learning paradigms. Peter Senge's theory of learning organizations, a long-standing cornerstone for understanding organizational adaptation through systemic learning, may not fully address these new realities. Specifically, the increasing integration of AI into organizational processes raises a critical question: to what extent does Senge's foundational framework remain relevant and sufficient in guiding organizational learning in this AI-dominated era? This study critically evaluates the enduring relevance of Senge's theory in this context. It interrogates whether core concepts such as "systems thinking" and "shared vision" retain their utility when AI reshapes knowledge acquisition, collaboration, and adaptability. Critics like Hsu and Lamb (2020) argue that Senge's model risks reducing learning to a superficial, process-oriented ideal, ill-equipped to navigate the complexities of AI-driven systems, including algorithmic bias and real-time data flux. Similarly, Caldwell (2012) highlights gaps in the explanations of modern organizational structures—now increasingly decentralized and AI-integrated—that challenge Senge's original prescriptions. Therefore, the central concern of this research is to examine the continued applicability and limitations of Senge's theory amid pervasive AI adoption and to explore how it might be adapted or supplemented to effectively guide organizational learning in this evolving landscape. This research aims to provide a comprehensive and critical evaluation of Peter Senge's theory of learning organizations. The study not only identifies the theory's strengths and weaknesses and determines the barriers to its implementation but also offers practical recommendations for improving and developing the theory. The findings of this research can assist researchers, managers, and policymakers in management and organizational development in gaining a deeper understanding of learning organizations and in using them to enhance organizational performance. The study concludes with actionable recommendations for evolving Senge's framework, advocating for hybrid models that integrate AI's analytical strengths while preserving human creativity and ethical governance. By bridging decades-old theory with Silicon Valley innovation, this work equips researchers and practitioners to reimagine learning organizations as adaptive, ethically grounded entities in the AI age.

2. Literature review

2.1. Theoretical foundations of the research

Critique, a powerful tool for analyzing and evaluating ideas and theories, has deep roots in the history of human thought. From antiquity to the present, critique has played a pivotal role in fields such as philosophy, literature, and the social sciences. Philosophers like Kant, Feuerbach, and Marx have significantly contributed to the development and deepening of this concept. Critique has always been recognized as a dynamic and multifaceted process that not only evaluates but also recreates and transforms knowledge (Adler et al., 2007).

The critique of management theories is not limited to examining theoretical aspects but also assesses their practical and applied dimensions. In fact, critique is used to evaluate and improve management theories and models. Critiquing research theories based on their ontological, epistemological, and methodological foundations is a complex issue that has been explored in various disciplines. It is referred to as paradigmatic critique .

Given the widespread influence of the learning organization theory in management and the emergence of new technologies such as artificial intelligence and machine learning, this theory has been selected as a key topic for in-depth critique and analysis. This research aims to examine the alignment of this theory with contemporary organizations' needs and to identify strategies to strengthen organizational learning in the digital age.

2.2. Evaluating theories through the lens of Bacharach

Bacharach (1989) offers a framework for evaluating theories, structured as a matrix. This matrix (table 1) is organized around two primary criteria: falsifiability and utility. Falsifiability, the capacity of a theory to be disproven through empirical testing, is assessed via measurement issues, construct validity, and logical and empirical adequacy, applied across variables, constructs, and relationships. Utility, the practical value and applicability of a theory, is evaluated through variable and construct scope, and explanatory and predictive adequacy.

Table 1. Criteria for evaluating theory

	Falsifiability	**Utility**
Variables	Measurement Issues	Variable scope
Constructs	Construct validity	Construct scope
Relationships	Logical adequacy Empirical adequacy	Explanatory potential Predictive adequacy

- Measurement Issues: Concerns the accurate and reliable measurement of variables. Addresses how variables are operationalized and whether they truly reflect the intended construct.
- Construct Validity: Focuses on whether the constructs themselves are valid. It includes convergent validity (different measures of the same construct correlate) and discriminant validity (the construct is distinct from other constructs).
- Logical Adequacy, Empirical Adequacy: These relate to the relationships between constructs and variables. Logical adequacy assesses the clarity and non-tautological nature of the propositions. Empirical adequacy assesses whether the relationships can be operationalized and empirically tested.
- Variable Scope: Concerns the breadth of the variables used. Do they adequately capture the full domain of the construct they are intended to measure? A variable with limited scope may not fully represent the construct, thus limiting the explanatory power of the theory.
- Construct Scope: Similar to variable scope, but at the construct level. Does the construct adequately capture the phenomenon it's intended to represent? A construct with limited scope will restrict the theory's ability to explain the broader phenomenon.
- Explanatory Potential, Predictive Adequacy: These relate to the utility of the theory. Explanatory potential concerns the theory's ability to account for the existence of relationships. Predictive adequacy concerns the theory's ability to accurately predict outcomes. A useful theory should both explain and predict.

2.3. Evaluating theories through the lens of Thomas and Tymon

Thomas and Tymon (1982) proposed a framework for evaluating management theories that encompasses the following criteria:

- Descriptive Relevance: A sound theory should accurately and comprehensively describe phenomena within organizations. In other words, it should be able explaining the fundamental characteristics and nature of the phenomenon under investigation.
- Goal Relevance: A theory should be designed to enable the prediction and creation of desirable organizational changes. That is, the theory's dependent variables should align with managerial objectives.
- Operational Validity: A robust theory should be practically applicable and can guide decision-making and the design of organizational interventions. In essence, it should be transformable into practical tools and methods.
- Non-obviousness: A theory should present novel ideas and insights that extend beyond existing knowledge in the field. In other words, it should answer unanswered questions and deepen our understanding of the phenomenon under study. Moreover, it should effectively explain the complexities inherent in organizational environments.
- Timeliness: A sound theory should be relevant to contemporary organizational issues and challenges and applicable to addressing problems and opportunities in the dynamic business environment.

2.4. Evaluating theories through the lens of Weick

Weick (1989) proposed a set of criteria for evaluating theories that emphasize their cognitive and philosophical aspects. This approach includes the following criteria:

- Cognizance of the Subject Matter: A robust theory should define the subject matter precisely and clearly, delineating the boundaries of the research.
- Non-linear and Iterative Progress: The development of theories is not necessarily linear and often involves revisiting and refining previous ideas. Strong theories account for this complexity in the development process.
- Creativity and Systematicity: A good theory should not only be innovative and address new questions but also possess a logical and coherent structure

2.5. Evaluating theories through the lens of Klimoski

Klimoski (1991) introduced a comprehensive framework for assessing the quality of organizational theories. This framework comprises 14 primary criteria that any theory must meet to establish scientific credibility. These criteria can be examined as follows:

- Phenomenon of Interest: Clearly and concisely define the research focus, capturing the reader's attention within the domain of interest.
- Units of Analysis: Explicitly state the relevant units of analysis (e.g., individuals, groups, organizations).
- Boundary Conditions: Identify the limitations and scope of the theory.
  - Temporal: Specify the time frame within which the theory is expected to hold.
  - Contextual: Define the specific contexts or situations where the theory is applicable.
  - Unit-specific: Clarify the types of units to which the theory applies.
- Assumptions: Clearly articulate the theory’s underlying assumptions and provide logical or empirical justification for each.
- Theoretical Constructs:
  - Clearly define all central constructs (causes, processes, outcomes).
  - Provide comprehensive and unambiguous definitions for each construct.
  - Offer evidence (empirical or logical) for the validity of each construct.
  - Specify criteria for falsifying the validity of each construct.
  - Justify the scope and boundaries of each construct's domain.
- Theoretical Variables: Identify observable indicators (variables) for each construct facilitate operationalization and empirical testing.
- Propositions:
  - Explicitly state the relationships between constructs, including the direction and strength of these relationships.
  - Clearly indicate whether relationships are contingent upon specific conditions.
- Propositions Illustrated: Utilize examples, diagrams, or other visual aids to enhance understanding and clarify the relationships between constructs.
- Logical Adequacy:
  - Ensure propositions are not tautological (self-evident).
  - Clearly specify whether antecedent conditions are necessary, sufficient, or both, for the predicted consequences.
- Underlying Processes: Explain the mechanisms and processes that link constructs, providing a deeper understanding of the "why" behind the proposed relationships.
- Hypotheses: Derive testable hypotheses from the propositions, stating the expected relationships between variables.
- Value of New Theory:

- Demonstrate the unique contribution of the theory by comparing it to existing theories in the literature.
- Clearly articulate how the new theory advances knowledge and addresses existing limitations.

- Overall Quality:
  - Ensure flawless internal logic and consistency throughout the theory.
  - Acknowledge and incorporate relevant literature.
  - Verify the accuracy and currency of all factual statements.
  - Maintain high standards of writing and presentation.
- Criteria for Retention:
  - Interesting: The theory should challenge existing assumptions and offer novel insights.
  - Relevant: The theory should address the concerns and interests of the intended audience.
  - Useful: The theory should have practical implications and guide meaningful action for researchers and practitioners.
  - Market Test: The theory should undergo iterative refinement through feedback and critical evaluation from the relevant scholarly community.

2.6. Learning organizations theory

The concept of learning organizations has been widely discussed but lacks a singular, universally agreed-upon definition (Örtenblad, 2019). Researchers have proposed various interpretations, emphasizing supportive learning cultures, continuous transformation, and sustainable development. As Dodgson (1993) notes, learning organizations are those that consciously adopt structures and strategies to foster learning at all levels (Ellinger et al., 1999). Flexible and dynamic structures, entrepreneurial cultures, and supportive leadership characterize these organizations.

Many researchers underscore the significance of systems thinking in learning organizations. Senge (2006), and Marquandt and Reynolds (1994) argue that learning in these organizations occurs not merely at the individual level but throughout the entire organizational system. Gerard (2008) offers a comprehensive view, describing learning organizations as environments that embrace change, encourage experimentation, learn from mistakes, and reward learning at all levels.

Table 2. Definition of a learning organization

Definition of a learning organization	Author(s)
A learning organization possesses a supportive culture and structure that enable learning systems throughout the organization to continuously adapt and innovate, fostering sustainable development in complex and uncertain environments.	(Bui, 2019)
Emphasizes the role of collective employee learning in enhancing organizational performance.	(Yeo, 2006)
Organizations that consciously adopt structures and strategies to encourage learning at all levels.	(Okeeffe, 2002)
An organization where people continually expand their capacity to create the results, they truly desire, where new and expansive patterns of thinking are nurtured, where collective aspirations1 are set free, and where people2 learn continuously how to learn together.	(Senge, 2006)
Where learning is ongoing and embedded, changing the very nature of the organization itself.	(Reynolds and Ablett, 1998)
A learning organization must acquire, share, and use knowledge so that its members can work together to change how the organization responds to challenges. Individuals must question old, socialized, and entrenched ways of thinking. Learning must occur and be supported in larger teams and groups where individuals can co-create new knowledge. And this process must be ongoing as becoming a learning organization is an endless journey.	(Marsick and Watkins, 1996)
An organization that continuously becomes more intelligent in an endless cycle. Organizational intelligence is constantly increasing.	(Hitt, 1995)
Learning organizations are those in which the entire organizational system focuses on learning.	(Marquardt and Reynolds, 1994)
Learning organizations are generally described as those that continuously learn, grow, and share knowledge about markets, products, technologies, and business processes.	(Slater and Narver, 1994)
Organizations that purposefully adopt structures and strategies that encourage learning.	(Dodgson, 1993)
A learning organization is skilled at creating, acquiring, and transferring knowledge, and modifying its behavior to reflect new knowledge 1 and insights.	(Garvin, 1993)

As shown in Table 2, definitions of the learning organization vary considerably, emphasizing different aspects such as knowledge creation, collective learning, and supportive organizational structures.

The concept of a learning organization has been defined in various ways. While some definitions emphasize the organization's ability to create, acquire, and transfer knowledge, others underscore the importance of individual and collective learning. Still others focus on the organizational structures and cultures that facilitate learning. A significant portion of the discourse on organizational learning and the construction of learning organizations is essentially descriptive, with authors more inclined to provide metaphorical descriptions of learning organizations than to offer operational details (Talbot et al., 2015). Consequently, there has been limited attention to how to create a learning organization in terms of a framework for action or practical steps. Except Ellinger and others (1999), the literature has tended to be highly abstract in explaining the importance of learning, without providing experience-based guidance on how leaders can develop learning capabilities in organizations (Thomas and Allen, 2006).

Learning organizations, as a new generation of organizations with a distinct approach to learning and innovation, are transforming the business landscape. The table 3 systematically compares learning and traditional organizations across various dimensions.

Table 3. Comparative characteristics of learning organizations and traditional organizations

Feature	Learning organization	Traditional organization	Reference
Leadership and management	Leaders act as teachers, coaches, and facilitators, fostering autonomy and trust.	Leaders often employ autocratic and command-and-control styles that hinder learning and innovation.	(Andjelkovic and Boolaky, 2015)
Organizational structure	Flat, decentralized structures that facilitate open communication and information flow.	Hierarchical, bureaucratic structures can impede knowledge transfer and learning.	(Andjelkovic and Boolaky, 2015)
Culture and environment	A highly caring environment characterized by trust and respect, allowing flexibility and the free expression of ideas.	Competitive and power-oriented cultures that hinder collaboration and knowledge sharing.	(Andjelkovic and Boolaky, 2015)
Barriers to learning	Actively seeks to remove structural barriers to learning.	Often has structural barriers that impede the transfer and application of knowledge.	(Andjelkovic and Boolaky, 2015)
Innovation and adaptability	Continuously seeks innovative solutions and adapts rapidly to change.	May struggle with change due to entrenched practices and resistance to new ideas.	(Anttila and Jussila, 2018; Armstrong, 2016)
Knowledge management	Actively manages competencies and fosters a dynamic cycle of knowledge creation and application.	Less active in knowledge management and may rely on tacit knowledge and informal learning.	(King and Ko, 2001)

2.7. Five disciplines of learning organizations

Peter Senge identified five key disciplines that transform organizations into learning environments. These interconnected disciplines are: personal mastery, mental models, shared vision, team learning, and systems thinking.

1. Personal Mastery: As defined by Senge (2006), personal mastery is an ongoing process of self-assessment, goal setting, and skill development. This concept underscores the importance of individual responsibility for learning and growth. By focusing on personal mastery, individuals can enhance their abilities to contribute to organizational learning and innovation.
2. Mental Models: As internal cognitive structures, mental models play a pivotal role in shaping individuals' perceptions, thoughts, and actions. These models, comprising beliefs, assumptions, and interpretations, provide a framework for understanding the world. To foster learning and innovation within organizations, it is essential to examine existing mental models and revise them as needed. Cultivating a culture of open dialogue and critical thinking is crucial for identifying and challenging limiting mental models. Furthermore, developing the capacity for inquiry and the pursuit of new knowledge can help organizational members update their mental models and adapt to changing environments.
3. Shared Vision: A shared vision is a collective picture of the future that motivates rather than imposes commitment. In this process, leaders facilitate rather than dictate, encouraging collective decision-making about the vision. This participatory approach fosters a sense of ownership among organizational members, motivating them to strive toward its realization.
4. Team Learning: In contemporary organizations, teams, rather than individuals, are the primary units of learning. If teams cannot learn, the entire organization will be unable to learn. In group settings, individuals learn from each other, pose shared questions, and

receive mutual feedback. Significant decisions are often made at the team level. Thus, team learning is grounded in collaboration, shared use of skills, and effective team formation. To foster such a culture, organizations must value and reward collaboration and teamwork (Watkins and Marsick, 1993; Marsick and Watkins, 1996).

5. Systems Thinking: As the cornerstone of learning organizations, systems thinking helps individuals see the bigger picture. This approach reveals the relationships among the various components of an organization, enabling individuals to identify patterns of behavior and focus on systemic processes rather than linear cause-and-effect relationships. With systems thinking, individuals develop a deeper understanding of the organization as a whole and their role within it. This systemic awareness empowers individuals to comprehend the consequences of their actions on other parts of the organization. Systems thinking also facilitates collaboration among organizational members and can extend across organizations (Hodgkinson, 2000). Studies have shown that systems thinking can facilitate learning. For example, Zulauf's (2007) study found that students familiar with systems thinking could better understand the connections between their decisions and their consequences, identify delays in the system, and avoid blaming others. Systems thinking integrates the other four disciplines, forming a complete system. Without systems thinking, the other four disciplines operate in isolation. For instance, by highlighting the relationships between individuals and organizational parts, individuals can understand the consequences of their actions on other parts. This understanding of "connectedness" can contribute to the development of a shared vision and team learning. Nair (2001) argues that managers who view organizations as thinking and creative systems are more likely to encourage experimentation, creativity, questioning assumptions and methods, and reinforce double-loop learning

2.8. Examining the paradigm of learning organizations: An interpretive perspective

The interpretive paradigm, with its emphasis on meaning, interpretation, and social interactions, offers a compelling framework for studying learning organizations. This perspective enables us to comprehensively understand learning processes, the construction of shared meanings, and the complexities inherent in organizations (Kim, 2003) . By employing qualitative research methods, we can delve deeper into the experiences of individuals within learning organizations, gaining valuable insights to enhance their performance.

Ontology of learning organizations: In learning organizations, knowledge is not merely an individual asset but a collective resource, shaped and nurtured through shared interactions and collaborative learning (Antonacopoulou and Chiva, 2005). This perspective, in contrast to traditional views that treat knowledge as a fixed, measurable quantity, positions it as a dynamic, social phenomenon. Within this framework, absolute knowledge does not exist; different individuals and groups hold varying interpretations (akin to mental models). These disparities in perception arise from social, cultural, and historical factors that influence how individuals perceive and interpret reality. Moreover, knowledge within organizations is dynamic, continuously evolving in response to changing organizational conditions and needs

(Antonacopoulou and Chiva, 2005) . Learning organizations are characterized as complex, self-organizing systems in which individual actions and decisions can have ripple effects throughout the system. This systems perspective underscores the importance of understanding the interactions between organizational components and their reciprocal influence. Organizations are viewed as living, dynamic entities that continually learn and adapt to their environments. This distinguishes learning organizations from traditional organizations that emphasize fixed structures and processes. Grasping this systemic nature is essential for designing and implementing effective learning strategies within organizations. (Vines and Hall, 2011)

Epistemology of learning organizations: In Peter Senge's theory of learning organizations, the epistemology governing knowledge creation diverges significantly from traditional research approaches such as positivism. While positivism emphasizes objectivity, researcher neutrality, and the discovery of objective truths, the epistemology underlying learning organizations adopts a constructivist and action-oriented approach. Within this framework, knowledge is not viewed as fixed and objective truth but as a product of social interactions and collective construction among individuals. Knowledge in learning organizations emerges through interactions, dialogues, and the exchange of experiences. The experiences, assumptions, and prior knowledge of each individual influence how phenomena are perceived and interpreted, consequently shaping the knowledge produced within the organization. In learning organizations, the researcher is not considered a detached and external observer but an integral part of the system. The researcher not only observes phenomena but also shapes the produced knowledge by participating in social interactions and learning. This reciprocal, action-oriented relationship implies that the knowledge generated within an organization is contingent on the values, beliefs, and goals of its members.

Methodology of the learning organization theory: While Peter Senge does not provide a specific methodology for creating learning organizations, he offers a framework of five fundamental disciplines to guide research in this field. Adopting a mixed-methods approach, Senge employs a variety of methods to examine and understand the learning process within organizations. In-depth case studies enable him to examine the complex nuances and social contexts that shape organizational learning. Quantitative and qualitative data analysis, including statistical analysis, modeling, and simulation, are used to identify patterns and trends in organizational learning. Additionally, dialogues and interviews with organizational members reveal individual and collective perspectives on the learning process. Direct observation of activities and interactions within organizations contributes to a better understanding of the

social and cultural contexts that shape learning. This mixed-methods approach allows researchers to gain a deeper understanding of the learning process within organizations and develop more comprehensive theoretical models.

3. Research methodology

This study adopts an interpretive approach to conduct an in-depth analysis and interpretation of the research topic. In contrast to traditional positivist methodologies, this approach emphasizes understanding the meanings and concepts embedded within the phenomenon under investigation.

- **Ontologically**, this research is grounded in idealism. Social reality is viewed as a social construct, shaped by human interactions. Rather than seeking universal laws, this study delves into the model's deep structure, its philosophical foundations, and the conditions of its emergence.
- **Epistemologically**, the researcher plays an active role in shaping and constructing knowledge. Knowledge in this study is the product of the interaction between the researcher and the research subject, and the researcher is considered an integral part of the research process.
- **Methodologically**, this research focuses on theory critique. By employing this method, the researcher evaluates and critiques existing models, identifying their strengths and weaknesses.

This study conducts a comprehensive examination of the learning organization theory using a critical and systemic approach. To comprehensively evaluate this theory, the criteria proposed by Bacharach (1989), Thomas and Tymon (1982), Weick (1989), and Klimoski (1991)are used. These criteria, by providing a precise and multifaceted framework, enable the assessment of the strengths and weaknesses of learning organization theory and its generalizability. This approach enables a deeper understanding of the theory's effectiveness and limitations in management and ultimately offers suggestions for its more practical application in contemporary organizations. In other words, this study seeks to contribute to the development of knowledge in this field by employing scientific critique, identifying the strengths of learning organization theory, challenging some of its assumptions, and offering solutions to improve and adapt it to new conditions.

4. Results

4.1. A critique of the learning organization theory

Before evaluating the theory of learning organizations through various criteria, it is essential to introduce Peter Senge, the primary architect of this theory. Born in 1947, Senge graduated from

Stanford with an engineering degree and subsequently earned a master's in social systems modeling from MIT before completing his doctorate in management. He is a senior lecturer at MIT and the founding chair of the Society for Organizational Learning.

An examination of Senge's published works reveals a gradual shift in his focus over the years, from the theoretical underpinnings and principles of learning organizations to more practical concerns, including creating learning environments, developing leadership, and addressing the complex challenges of the modern world. In his earlier works, he emphasized the conceptual framework of learning organizations. However, in his later writings, he delved into more practical issues such as fostering learning cultures, cultivating leadership, and confronting the intricate challenges of the contemporary world.

The numerous awards bestowed upon Peter Senge offer a clear picture of his prominent position in the fields of management and organizational development. Honors such as the Peter F. Drucker Award for Management Consulting in 2000, the International Sustainability Leadership Award in 2008, the Academy of Management's Organizational Behavior Division Lifetime Achievement Award in 2018, and multiple awards from the Society for Organizational Learning are just a few examples of his accolades. These awards attest to the widespread impact of his work on the broader field of management, his continuous intellectual leadership, his commitment to sustainable development, and his global renown.

4.2. A historical exploration of the learning organization theory

The concept of a learning organization, now widely recognized as a necessity for organizational survival and growth, is rooted in historical developments and the convergence of several intellectual currents. To fully grasp this concept, it is essential to examine the three primary streams that have shaped its formation:

1. **Organizational Development (OD)** Organizational Development can be considered one of the historical antecedents of the learning organization theory. With a focus on organizational change and improvement, OD seeks to create environments that foster continuous learning and growth. By emphasizing employee participation in change processes, skill development, and cultural transformation, OD has served as a foundational pillar of the learning organization concept. Researchers such as Donald Schön and Chris Argyris, with their emphasis on experiential learning and an organization's ability to adapt to new circumstances, have played a significant role in shaping this perspective (Fenwick, 1996).
2. **Economic Transformations of the 1980s** The 1980s witnessed profound changes in the global economy. Increased competition, globalization, and the emergence of new technologies presented organizations with unprecedented challenges. Under these conditions, the learning organization emerged as a response. Organizations capable of rapid

learning and adaptation to new circumstances were more likely to survive and thrive in the competitive marketplace.

3. **Total Quality Management (TQM)** Numerous studies have shown a strong connection between TQM and learning organizations. By creating an environment conducive to organizational learning (Sohal and Morrison, 1995), TQM has been recognized as a foundation for developing learning organizations (Terziovski et al., 2000). TQM, through its emphasis on customer focus, employee empowerment, and a shift away from hierarchical structures, fosters a culture of learning within organizations (Luthans et al., 1995). By encouraging small-group work, collaborative learning, and problem-based learning, this approach fosters organizations capable of continuous learning and adaptation to environmental change. In fact, TQM is often viewed as a prerequisite for the creation of learning organizations, as both emphasize continuous improvement, customer focus, and organizational learning. Although the learning organization is seen as an evolution beyond TQM (Luthans et al., 1995), the principles of TQM continue to play a vital role in the creation and maintenance of learning organizations (Chang and Sun, 2007).

In this research, the theory of learning organizations is examined through Bacharach's evaluation framework. The subsequent section will present the overarching criteria of this framework for assessing the theory of learning organizations, including its explicit and implicit assumptions. (See Table 4)

Table 4. Critical evaluation of senge's learning organization theory based on Bacharach's criteria

Criteria	Critique of learning organization theory	Suggestion	References
Measurement issues	A significant weakness of learning organization theory lies in the operationalization and measurement of its core constructs, which hinder its falsifiability. While constructs such as "organizational learning," "shared vision," and "systems thinking" are frequently discussed, their translation into measurable variables lacks sufficient rigor. For example, "organizational learning" may be vaguely defined, making it difficult to specify how it differs from related concepts such as "knowledge management" or "organizational development." Similarly, "shared vision" may be assessed through surveys susceptible to social desirability bias, which may fail to capture the true extent of shared understanding and commitment. 1 Furthermore, the time and space parameters of these variables are often poorly defined.	Leverage AI technologies to address measurement challenges by: (1) Developing machine learning algorithms that analyze multi-modal organizational data (e.g., communication patterns, workflow logs, and decision trails) to create behaviorally anchored indicators of core constructs; (2) Implementing natural language processing to quantify 'shared vision' through semantic analysis of strategic documents and meeting transcripts, reducing social desirability biases.	(Adzic, 2018; Garvin, 2000; Örtenblad, 2019; Snyder and Cummings, 1998)
Construct validity	The core construct of a "learning organization" is often vaguely defined and inconsistently operationalized across studies. For example, attempts to measure "organizational learning" vary widely, ranging from surveys of employee perceptions to assessments of knowledge management systems. This lack of convergent validity raises concerns about	Future research should prioritize developing clear, operational definitions of learning organization constructs and employing multiple measurement methods to establish both convergent and discriminant validity. This would	(Araujo and Easterby-Smith,1996;Loermans, 2002; Snyder and Cummings, 1998)

Criteria	Critique of learning organization theory	Suggestion	References
	whether these measures are actually capturing the same underlying phenomenon. Furthermore, it's often unclear how the "learning organization" differs from related constructs such as "adaptive organization" or "innovative organization," which can lead to problems with discriminant validity. Until learning organization theory can establish more rigorous construct validity for its key concepts, its empirical testability and, ultimately, its scientific value will remain limited.	strengthen the theory's foundation and enable more meaningful empirical investigation	
Logical adequacy , empirical adequacy	Logically, the core propositions linking learning practices to organizational outcomes (e.g., increased adaptability, innovation) can be tautological. For instance, if "organizational learning" is defined by the very outcomes it purports to cause, the theory becomes self-verifying and unfalsifiable. Furthermore, the causal relationships are rarely specified with sufficient clarity. Is shared vision necessary, sufficient, or both for organizational learning? Such ambiguity makes empirical testing difficult. Empirically, measuring organizational learning and its impact is challenging.		(Adzic, 2018; Driver, 2002; Salaman, 2001)
Variable scope	Current learning organization theory exhibits limitations in its variable scope, hindering its explanatory power. The theory's reliance on a collection of somewhat isolated variables prevents the development of a truly integrated and parsimonious theoretical system. For instance, existing measures of organizational learning may overemphasize specific aspects, such as knowledge acquisition, while neglecting equally important dimensions like knowledge sharing or application. This narrow focus on a limited set of variables restricts the theory's ability to fully capture the complex dynamics of organizational learning. A broader scope of variables, encompassing a more comprehensive range of relevant factors, is necessary to enhance the theory's explanatory potential.	This could involve incorporating a wider range of learning processes, considering different levels of analysis (individual, team, organization), and exploring the interplay between formal and informal learning mechanisms. However, this expansion must be carefully balanced with the need for parsimony. The goal should be to develop a more comprehensive yet concise theoretical framework that can effectively explain and predict organizational learning outcomes.	(Adzic, 2018; Akella, 2008; Grieves, 2008)
Construct scope	The scope of the construct within learning organization theory also warrants attention. The theory currently suffers from a lack of integration among its constructs, resulting in a fragmented understanding of organizational learning. This fragmentation manifests logically as a collection of isolated constructs, which prevents the development of a cohesive and parsimonious theoretical framework. For	Expanding the scope of constructs to encompass the multifaceted nature of organizational learning and exploring the interrelationships between these constructs is crucial for advancing the theory.	(Adzic, 2018; Akella, 2008; Grieves, 2008)

Criteria	Critique of learning organization theory	Suggestion	References
	example, the constructs of "knowledge acquisition," "knowledge sharing," and "knowledge application" are often treated as separate entities rather than interconnected components of a broader learning process. Empirically, this translates to a reliance on variable-driven analysis and empirical generalizations, rather than a robust, theory-driven approach.		
Explanatory potential, predictive adequacy	Regarding the "objects of analysis," it frequently fails to clearly define what constitutes a "learning organization." Is it a specific organizational structure, a culture, a set of processes, or some combination? This ambiguity makes it difficult to compare different learning organization models and hinders empirical testing. Furthermore, the "nature of the relationship" between learning mechanisms (e.g., knowledge sharing, systems thinking) and organizational outcomes (e.g., innovation, performance) is often underspecified. While learning organization theory posits that these mechanisms should lead to positive outcomes, it often lacks detail about how these linkages work, under what conditions they are strongest, and what potential mediating or moderating factors might exist. This lack of specificity weakens the theory's explanatory power. Regarding "scope and parsimony," while the theory aims to be broadly applicable, its propositions are sometimes too general, making it difficult to derive testable hypotheses. The sheer number of variables associated with learning organizations can also make it challenging to develop parsimonious models. Finally, concerning "predictive adequacy," learning organization theory often struggles to generate precise, testable predictions. While it might suggest that learning organizations are more likely to be innovative, it rarely specifies when or to what extent this will occur. This makes it difficult to empirically validate the theory and distinguish it from other explanations of organizational performance.	1) Develop a multi-faceted definition of "learning organization" with measurable indicators for structure, culture, processes, and leadership behaviors. 2) Specify how learning mechanisms link to outcomes by detailing the underlying processes and identifying mediating/moderating factors. 3) Formulate focused, testable propositions with clearly defined variables and consider contingency factors. 4) Improve predictive adequacy by generating precise hypotheses, employing longitudinal/comparative studies, and iteratively refining the theory based on empirical evidence.	(Adzic, 2018; Dixon, 1993; Driver, 2002; Fenwick, 1996; Garvin, 2000; Örtenblad, 2019)

4.3. Thomas and Tymon's criteria

Table 5 presents a critical evaluation of Senge's learning organization theory based on Thomas and Tymon's Criteria for evaluating theories. This analysis identifies key strengths and weaknesses of the theory, highlighting areas for improvement.

Table 5. Critical evaluation of senge's learning organization theory based on Thomas and Tymon's criteria

Criteria	Critique of learning organization theory	Suggestions for improvement	Source
Descriptive relevance	The concept of a learning organization oversimplifies the complex process of developing individual and social knowledge in the workplace, including the interplay between knowledge and organizational policies, interpersonal relationships, and complex human dimensions such as emotions, moods, and intuition. It reduces this complex process to an idealized image of honest dialogue and empathetic relationships. This approach overlooks the dynamic and multifaceted nature of learning processes in organizations and instead focuses on idealized and simplified aspects of this process. As a result, this concept is insufficient in describing the complex and dynamic realities of organizational learning.	To strengthen the description, it can be enriched by providing more detailed and in-depth case studies of successful learning organizations. Additionally, one could explore how this theory can be adapted to different types of organizations (such as small, medium, and large organizations, or organizations in different industries). Furthermore, future research should explicitly examine how the core tenets of a learning organization, such as knowledge acquisition and sharing, are being reshaped by the integration of artificial intelligence, and how organizations can leverage AI to overcome the inherent complexities of knowledge development and dissemination.	(Adzic, 2018; Driver, 2002; Fenwick, 1996; Garvin, 2000; Hsu and Lamb, 2020; Pedler and Burgoyne, 2017; Salaman, 2001)
Goal relevance	Although it describes a desirable state, it does not clearly establish a link between the five disciplines and specific organizational goals such as performance improvement or innovation. Despite significant investments in employee training and development at companies such as Rover, the company ultimately failed to achieve sustained financial success. This case highlights the potential gap between the theoretical concepts of learning organizations and practical business objectives.	It should be more clearly demonstrated how each of the five disciplines contributes to achieving specific organizational goals. For example, conceptual models can be developed to illustrate the relationships between these disciplines and organizational outcomes. Moreover, future work should articulate how the strategic adoption and integration of artificial intelligence tools and strategies can act as a catalyst or a barrier to achieving these goals within the framework of a learning organization.	(Adzic, 2018; Fenwick, 1996 ; Örtenblad, 2019)
Operational validity	While it provides a general framework, it offers insufficient practical guidance for implementing the five disciplines. While Senge's principles are valuable, they don't provide clear, observable characteristics or practical guidelines for implementing a learning organization. The theory lacks operational specificity and doesn't offer concrete tools or techniques for organizational change.	Providing step-by-step operational guidelines for implementing each of the five disciplines is essential. These guidelines can include tools, techniques, and practical examples. Crucially, these guidelines must be updated to incorporate actionable strategies for leveraging AI technologies in the implementation of each discipline. It includes specifying AI-powered tools for knowledge management, collaborative platforms enhanced by AI, and methods for fostering AI literacy and ethical AI application within the learning processes.	(Araujo and Easterby-Smith,1996؛ Loermans, 2002; Snyder and Cummings, 1998)
Non obviousness	The theory of learning organizations introduces several innovative concepts, such as systems thinking, personal mastery, team learning, shared vision, continuous adaptation, and critical reflection, which collectively provide a more comprehensive framework for understanding and fostering	Further emphasize the nonobviousness by providing empirical evidence or case studies that demonstrate unique outcomes or insights generated by applying the learning organization theory. In the current context, highlight the non-obvious ways in which the challenges and opportunities presented by artificial intelligence necessitate a re-evaluation and potential augmentation of traditional learning organization principles. This could involve	(Adzic, 2018; Fenwick, 1996; Pedler and Burgoyne, 2017)

Criteria	Critique of learning organization theory	Suggestions for improvement	Source
	organizational learning.	exploring novel learning dynamics emerging from human-AI interaction and the ethical considerations unique to AI-driven organizational learning.	
Time liness	Although it emphasizes adaptability in dynamic environments, it may not adequately address new challenges, including digital transformation, workforce diversity, and climate change.	Given recent advances in management and learning, it should be updated to incorporate new ideas such as data-driven learning, artificial intelligence, and machine learning. Specifically, future research must directly address the challenges posed by the AI era to organizational learning. It includes investigating how organizations can learn to adapt to rapidly evolving AI technologies, address the skills gap created by AI-driven automation, foster a culture of continuous learning in the face of AI disruption, and ethically integrate AI into organizational learning processes. The theory needs to evolve to provide relevant guidance for organizations navigating the complexities of the artificial intelligence landscape.	(Adzic, 2018; Hsu and Lamb, 2020; Salaman, 2001; Yang et al., 2004)

4.4. Weick's criteria

Table 6 presents a critical evaluation of Senge's learning organization theory based on Weick's Criteria for evaluating theories. This analysis identifies key strengths and weaknesses of the theory, highlights areas for improvement.

Table 6. Critical evaluation of senge's learning organization theory based on Weick's criteria

Criteria	Critique of learning organization theory	Suggestions for improvement	References
Recognition of the subject matter	The theory effectively identifies the problem of organizations' inability to adapt to rapid change and provides a framework for addressing it.	To further strengthen this, a deeper exploration of different types of organizational changes and how learning organizations respond to each could be conducted.	(Adzic, 2018; Fenwick, 1996; Garvin, 2000; Hsu and Lamb, 2020; Pedler and Burgoyne, 2017)
Nonlinear and iterative progress	The theory acknowledges the complex, interconnected nature of organizations and necessitates a holistic, systems-thinking approach aligned with nonlinear, iterative processes.	(1) Utilize network analysis algorithms to visualize knowledge flows and feedback loops in real-time, (2) Implement adaptive computational models that simulate learning trajectories under varying environmental conditions. These AI applications can reveal hidden patterns in organizational learning processes that traditional linear models cannot detect.	(Fenwick, 1996; Snyder and Cummings, 1998)
Creativity and systematicity	The theory introduces innovative concepts such as mental models, systems thinking, and learning teams, but it may sometimes lack the specificity required for rigorous empirical testing and simplification of complex organizational phenomena.	(1) Developing hybrid AI systems that combine generative models for creative ideation with constrained optimization algorithms for systematic implementation, (2) Applying natural language processing to quantify and track the evolution of mental models through organizational discourse, and (3) Creating AI-assisted diagnostic tools that maintain the richness of systems thinking while providing measurable indicators of team learning effectiveness. This approach preserves the theory's innovative concepts while enabling rigorous empirical validation through computational social science methods.	(Adzic, 2018; Salaman, 2001)

4.5. Klimoski 's criteria

Table 7 presents a critical evaluation of Senge's learning organization theory based on Klimoski's criteria for evaluating theories. This analysis identifies key strengths and weaknesses of the theory, highlights areas for improvement

Table 7. Critical evaluation of senge's learning organization theory based on Klimoski's criteria

Criteria	Critique of learning organization theory	Suggestions for improvement	Source
Transparency of the phenomenon under study	The theory is ambiguous in providing a precise and operational definition of organizational learning. Moreover, it has not adequately addressed the critical role of technology in facilitating organizational learning and its transformations. Additionally, an excessive focus on soft aspects and the neglect of the complex interaction between the organization and its external environment are other weaknesses of this theory.	Provide a comprehensive and measurable definition of organizational learning that encompasses individual, group, and organizational dimensions. It is also essential to specify the role of technology in this process.	(Dixon, 1993; Garvin, 2000; Salaman, 2001)
Definition of units of analysis	This criticism is based on the fact that the theory does not clearly specify whether the main focus is on individuals, small groups, departments, or the entire organization.	Reconceptualize units of analysis through an AI-augmented lens by: (1) employing network analytics to map dynamic learning interactions across hierarchical levels, (2) utilizing machine learning to identify emergent learning units that transcend traditional boundaries (e.g., algorithmically determined project teams or AI-mediated communities of practice), and (3) developing multi-level analytics frameworks that simultaneously capture individual, group, and organizational learning patterns through digital trace data. This approach should account for how AI systems themselves become active participants in organizational learning processes, creating hybrid human-AI learning units that require new theoretical consideration.	(Dixon, 1993; Driver, 2002; Garvin, 2000)
Determination of boundary conditions	Being limited to internal factors may lead to the overlooking of certain learning factors.	Expand the theory's boundary conditions to explicitly incorporate AI-driven environmental scanning capabilities. This should include: (1) real-time analysis of market dynamics through AI-powered predictive analytics, (2) automated monitoring of technological disruptions using machine learning algorithms, and (3) adaptive organizational learning mechanisms that leverage AI to process external big data streams.	(Adzic, 2018; Akella, 2008; Grieves, 2008)
Are the assumptions clearly stated?	Some of the theory's assumptions, particularly in individual and social psychology, are implicit and not sufficiently clear.	Clarify assumptions, particularly in individual and social psychology, and provide logical justifications for them.	(Driver, 2002; Salaman, 2001)

Criteria	Critique of learning organization theory	Suggestions for improvement	Source
Are the theoretical constructs identified?	The concepts presented often have abstract definitions and lack the precision necessary for robust empirical testing. The theory relies heavily on anecdotal evidence and case studies, making it difficult to establish strong causal links between the proposed constructs and desired organizational outcomes. Many constructs are difficult to falsify due to their broad and subjective nature. Defining clear criteria for when a learning organization has truly failed to achieve its goals is challenging.	Operationalize abstract concepts such as "systems thinking" and "team learning" and provide measurement indices for them.	(Snyder and Cummings, 1998)
Are theoretical variables identified?	Faces challenges in precisely identifying and quantifying theoretical variables.	Precisely identify independent and dependent variables and employ suitable statistical methods for data analysis.	(Snyder and Cummings, 1998)
Are propositions fully stated?	Senge's theory does not adequately explain how a change in one construct (e.g., mental models have. affects the state of other constructs, nor the mechanisms that facilitate such changes.	Develop dynamic models to illustrate how different constructs interact and change over time.	
Are propositions illustrated?	Despite its emphasis on systems thinking, the theory has been insufficiently successful in using diagrams and visual models to depict complex interactions among organizational components. This complicates understanding causal relationships and the dynamics of organizational systems.	Employ simulation models and system flow diagrams to visualize complex interactions in learning organizations.	
Logical adequacy of propositions	Its propositions linking learning mechanisms (e.g., systems thinking) to outcomes (e.g., performance) often lack clear causal explanations. Additionally, some propositions are tautological and offer little explanatory power.	Future research should prioritize establishing clear causal pathways between learning mechanisms and organizational outcomes. This involves specifying the processes and mediating factors involved. Furthermore, propositions should be carefully examined for tautologies and, where necessary, reformulated to provide substantive explanations.	(Adzic, 2018; Salaman, 2001)
Are the underlying processes explained?	There is sometimes ambiguity regarding the operational details and the practical implementation of these concepts. For instance, although Senge emphasizes the importance of systems thinking and team learning, the exact mechanisms for creating and reinforcing these concepts in organizations are not sufficiently clear.	Provide practical guidelines for implementing the theory's concepts in organizations, including training methods, team development, and the creation of a learning culture.	
Are hypotheses fully stated?	Senge's theory focuses more on describing the characteristics of learning organizations and providing a general model than on formulating precise, testable hypotheses. While this facilitates a general understanding of the concept, it limits the possibility of a precise and quantitative evaluation of the theory.	Develop precise, testable hypotheses to examine relationships among variables in the learning organization model.	

Criteria	Critique of learning organization theory	Suggestions for improvement	Source
Added value of the theory	The theory lacks a clear and explicit comparison with existing theories of organizational learning. This omission makes it difficult to accurately assess its unique contributions and potential improvements over existing frameworks.	Conduct a detailed comparison of Senge's theory with other theories of organizational learning and identify its strengths and weaknesses.	(Adzic, 2018; Fenwick, 1996; Pedler and Burgoyne, 2017; Salaman, 2001)
Connection of the theory to practical issues	Although it emphasizes the importance of learning, the theory does not sufficiently rely on providing empirical and quantitative evidence to prove the effectiveness of this model in organizations.	Conduct empirical studies to examine the effectiveness of the learning organization model in various organizations.	(Adzic, 2018; Fenwick, 1996; Örtenblad, 2019)
Testability of the theory	Full implementation of this theory in organizations requires time, resources, and fundamental changes in organizational culture, which may be difficult for some organizations.	Develop AI-powered assessment tools to operationalize and test the theory's components by: (1) creating machine learning algorithms that quantify learning culture metrics from digital trace data, (2) implementing natural language processing to analyze organizational discourse for learning indicators, and (3) designing predictive analytics models that correlate learning processes with performance outcomes. These technological solutions can reduce implementation barriers by providing real-time diagnostics and scalable measurement of learning-organization characteristics across contexts.	(Adzic, 2018; Fenwick, 1996; Örtenblad, 2019)

As previously discussed, a comprehensive evaluation of a complex theory such as the learning organization necessitates a multifaceted approach that relies on multiple criteria. Each of the four sets of criteria presented here examines distinct facets of the theory. By employing these criteria, we can conduct a more comprehensive assessment of learning organization theory. For instance, Thomas and Tymon's criteria assist in examining the theory's practical applications, while those of Wick and Klimosky enable us to evaluate its philosophical and methodological underpinnings. This multifaceted approach mitigates the risk of biased evaluation and enhances the credibility of our findings by demonstrating that our assessment is grounded in the established scientific standards of the research community. Ultimately, by synthesizing results across multiple criteria, we can gain a deeper understanding of the theory and make more informed decisions about its application and development.

5. Discussion and conclusion

This research has critically examined Peter Senge’s learning organization theory, exploring its

enduring relevance in the context of a rapidly evolving, AI-driven world. By applying multiple established evaluation criteria (Bacharach (1989), Thomas and Tymon (1982), Weick (1989), and Klimoski (1991)), we have identified both strengths and weaknesses of the theory and offered concrete suggestions for its enhancement and modernization. Our analysis reveals that while Senge's framework offers valuable insights into systemic learning, shared vision, and mental models, its original conceptualization requires significant refinement to address the transformative challenges and opportunities presented by artificial intelligence.

Several key themes emerged from our evaluation:

Measurement Challenges and AI Solutions

The theory suffers from persistent operationalization issues, particularly with constructs like "organizational learning" and "shared vision." Emerging AI technologies can mitigate these limitations through (1) machine learning analysis of digital trace data (e.g., communication patterns, workflow logs) to quantify learning culture indicators; (2) NLP-based semantic analysis of strategic documents to assess shared vision objectively; and (3) predictive analytics linking learning processes to performance outcomes. These advancements address Hsu and Lamb's (2020) critique of the theory's empirical vagueness, thereby enabling more rigorous validation.

Expanding Theoretical Scope for AI Integration

The original framework inadequately addresses AI-driven learning modalities, including AI-curated knowledge acquisition, machine-learning-enabled adaptation, and algorithmic mediation of collaborative learning. Our findings suggest expanding the theory's constructs to include the evolving dynamics of human-AI team learning, the redefinition of mental models in algorithmic decision-making contexts, and ethical dimensions of AI-augmented learning (e.g., algorithmic bias, data privacy, and human judgment displacement). This aligns with Caldwell's (2012) call for the decentralization of learning structures but adds critical technological dimensions.

Strengthening Logical and Empirical Foundations

The causal mechanisms between learning practices and outcomes remain underspecified. AI can enhance theoretical precision through computational simulations of learning dynamics and data-driven identification of mediating variables (e.g., how AI tools mediate team learning-innovation relationships). This addresses Driver's (2002) critique about tautological reasoning by introducing empirically testable pathways.

AI's Dual Role: Enhancement vs. Ethical Risks

While AI enables personalized learning at scale, boundaryless knowledge sharing, and adaptive decision-making, overreliance risks eroding human-centric learning elements such as critical reflection and creative problem-solving. The revised theory must explicitly balance the analytical power of AI with the preservation of humanistic values, particularly in systems thinking and ethical governance. In conclusion, Senge's learning organization theory, while offering valuable foundational principles, requires significant evolution to remain relevant in the AI-driven world. By addressing measurement issues, expanding the scope of the construct and variables, strengthening logical and empirical adequacy, and explicitly integrating AI and its ethical implications, the theory can be transformed into a more robust and applicable framework. This research provides a roadmap for such evolution, advocating for hybrid models that leverage the analytical power of AI while preserving human creativity, ethical governance, and the core values of organizational learning.

5.1. Future research

Future research should empirically test the proposed hybrid model by examining the interplay between AI and human learning across diverse organizational contexts. Studies should explore how AI-powered tools can enhance specific learning processes, while simultaneously investigating and mitigating associated ethical risks such as algorithmic bias and data privacy concerns. Longitudinal research designs are needed to assess the long-term impact of AI integration on organizational learning and ethical governance. Further investigation into the evolving definitions of "systems thinking" and "shared vision" in the AI era is crucial. Comparative studies across industries and organizational structures can identify best practices and contextual factors that influence the success of AI-augmented learning organizations. Finally, research should refine the theoretical framework to ensure its continued relevance and applicability amidst ongoing technological advancements.

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A Traceable Integration of Soft Systems Methodology and Theory of Constraints–Thinking Processes for Stakeholder Conflict Resolution and Organisational Alignment

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ABSTRACT

Through a systemic intervention grounded in critical realism, this study integrates Soft Systems Methodology and the Theory of Constraints-Thinking Processes in a participatory inquiry to achieve stakeholder consensus and to design a conceptual model aligned with strategic objectives. This critical-realist systemic design addresses organisational complexity by acknowledging both socially constructed perceptions and underlying generative mechanisms, fostering actionable understanding in a real-world context. Conducted in a family-run firm within Iran's lubricant supply chain, the study focuses on resolving stakeholder tensions related to performance evaluation and strategic misalignment. Participatory workshops elicited multiple viewpoints and synthesised them using Customers-Actors-Transformation-Weltanschauung-Owners-Environment analysis and Evaporating Clouds, supported by a Current Reality Tree to make causal logic explicit. These dialogues led to a shared root definition and a collaboratively constructed Future Reality Tree—a conceptual artefact designed to clarify performance criteria, realign incentive mechanisms, and strengthen strategic coherence. Rather than pursuing immediate implementation, the study concludes at the conceptual modelling stage, emphasising shared understanding and logical transparency as precursors to sustainable organisational change. Methodologically, it bridges interpretive and analytical paradigms and offers a replicable approach for scholars and practitioners navigating complex socio-technical dilemmas where consensus-building and causal clarity are jointly required.

Keywords

Critical realism; Systemic design; Stakeholder consensus; Strategic alignment; Soft Systems Methodology (SSM); Theory of Constraints-Thinking Processes (TOC-TP).

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1. Introduction

Contemporary organisations increasingly face complex challenges, marked by diverse stakeholder interests, dynamic market conditions, and intertwined socio-technical systems. Addressing these multifaceted issues often exceeds the capacity of linear, reductionist methodologies, underscoring the need for systemic and participatory approaches that integrate conflicting viewpoints and generate stakeholder consensus (Checkland and Poulter, 2020; Mingers and White, 2010). Soft Systems Methodology (SSM), developed by Checkland (1981), is widely recognized for its interpretive strength in managing ill-defined problems through comprehensive stakeholder engagement. However, despite its capacity to surface diverse perspectives, SSM has limitations in clearly identifying root causes of conflicts or translating qualitative insights into actionable solutions, especially in contexts marked by profound stakeholder disagreements (Mingers and Rosenhead, 2004). Such scenarios demand structured analytical tools capable of explicitly addressing deep systemic conflicts and constraints.

The Theory of Constraints-Thinking Processes (TOC-TP), introduced by Goldratt (1994), provides robust logical tools for systematically identifying and resolving organisational constraints. Core instruments of TOC-TP, notably the Current Reality Tree (CRT), Evaporating Cloud (EC), and Future Reality Tree (FRT), offer clear cause-effect structures and precise conflict resolution mechanisms (Dettmer, 2007). Nonetheless, the purely logical, top-down approach of TOC-TP can be criticized for potentially marginalizing stakeholder perspectives, highlighting the necessity of embedding these logical tools within a participatory framework (Mabin and Davies, 2010; Rahman, 1998).

Acknowledging the complementary strengths and limitations of both methodologies, this paper proposes an integrated systemic approach combining the interpretive richness of SSM with the rigorous logic of TOC-TP. Specifically, we substitute the traditional Rich Pictures of SSM with the CRT to explicitly map complex cause-and-effect relationships, and employ ECs in conjunction with CATWOE (Customers-Actors-Transformation-Worldview-Owners-Environmental constraints) analysis to transparently resolve stakeholder conflicts.

Beyond prior partial integrations, this study renders the SSM–TOC-TP pipeline traceable and auditable by specifying entry and exit criteria at each stage, defining cross-step validity checks (for example, member checks, CRT sufficiency and *and-ellipses*, and FRT negative-branch reservations), and maintaining version-controlled artefacts (UDE register → CRT →

EC/CATWOE → FRT). Together, these features establish an integration audit trail that links raw evidence to each design decision (see Figure 1 and Table 1).

The methodological integration presented here aligns philosophically with critical realism, recognizing organisational phenomena as outcomes shaped by both stakeholder perceptions and deeper systemic mechanisms (Bhaskar, 1979; Mingers, 2014). Furthermore, following Habermas's classification of cognitive interests (Habermas, 1971), our integrated approach effectively balances practical interests (consensus-building and mutual understanding through SSM) with technical interests (structured diagnosis and analytical rigour through TOC-TP). Such methodological pluralism is particularly suited to complex organisational contexts, enabling the creation of conceptual models that enjoy stakeholder legitimacy and logical transparency.

Empirically, this paper demonstrates the utility of our integrated SSM–TOC-TP approach through a detailed case study conducted in a family-owned lubricant supply firm in Iran's competitive B2B market. This company faced escalating internal conflicts regarding performance evaluation, declining market share, and strategic misalignment, intensified by the COVID-19 pandemic. Through iterative participatory workshops involving stakeholders at managerial and operational levels, this study systematically identified core conflicts, articulated root causes, and developed a collaboratively endorsed conceptual model grounded in CRT, EC, and FRT.

We deliberately stop at the conceptual modelling stage to lock in auditable causal logic and stakeholder buy-in before any field execution. The agreed FRT serves as a testable design artefact for the subsequent implementation and empirical validation study.

In sum, this paper contributes a philosophically coherent SSM–TOC-TP integration that combines interpretive participation with auditable causal logic to address complex organisational dilemmas.

2. Literature review

2.1. Soft systems methodology (SSM): Strengths and limitations

SSM, developed through Checkland's action-research programme (Checkland, 1981; Checkland and Scholes, 1990) and later consolidated for practitioners (Checkland and Poulter, 2006), provides a structured interpretive framework for addressing complex, ill-structured organisational problems involving diverse stakeholder viewpoints. Its primary strengths lie in surfacing implicit stakeholder assumptions and building mutual understanding through

iterative, participatory inquiry (Checkland and Poulter, 2006; Mingers and Rosenhead, 2004).

However, critics argue that SSM's iterative, predominantly qualitative, and exploratory nature can delay decisive action or practical implementation, particularly when stakeholder perspectives diverge significantly (Mingers and White, 2010). Furthermore, its reliance on consensus without explicitly structured conflict-resolution mechanisms may exacerbate tensions in scenarios characterized by deep-rooted stakeholder conflicts or entrenched systemic constraints (Checkland and Poulter, 2020). Hence, despite its interpretive strengths, SSM alone may be insufficient in systematically diagnosing root causes or proposing actionable interventions for highly complex situations, indicating a need for complementary analytical tools (Mingers, 2014).

2.2. Theory of constraints-thinking processes (TOC-TP): Capabilities and limitations

Introduced by Goldratt (1994), the TOC-TP offers robust analytical tools designed to systematically identify and resolve core organisational constraints through logical cause-effect analysis. Specifically, tools such as CRT, EC, and FRT help clearly articulate organisational conflicts and solutions (Dettmer, 2007; Kim et al., 2008).

We also grounded our facilitation in applied work from the Iranian industrial context that traces how TOC-TP is put into practice and how production is organized (Sepasi, 2014a), and in an auto-parts case that verifies feasibility under inflationary pressures and tight capacity (Sepasi, 2014b). Without a participatory anchor, though, such tools risk privileging expert logic over stakeholder legitimacy (Mabin and Davies, 2010; Rahman, 1998).

Nevertheless, TOC-TP has been criticized for potentially oversimplifying complex, multi-constraint organisational scenarios by assuming a single dominant constraint (Rahman, 1998). Additionally, the linear logic of TOC-TP diagrams may inadequately capture nonlinear interactions and dynamic feedback loops prevalent in real organisational contexts (Trietsch, 2005). Another notable critique involves TOC-TP's traditionally expert-driven, top-down methodology, which can marginalize stakeholder input and reduce organisational acceptance of proposed solutions (Mabin and Davies, 2010; Nave, 2002).

2.3. Integrating SSM and TOC-TP: Addressing methodological gaps

Our design follows multimethodology principles (e.g., Mingers and Brocklesby, 1997; Jackson, 2019), pairing SSM's participatory sense-making with TOC-TP's causal-logic structuring. We address a persistent traceability gap in reported interventions by making auditable design

choices explicit; the operational detail—entry/exit criteria, cross-step validity checks, and version-controlled artefacts—is specified in the Methods (Section 3.5) and consolidated in the integration map (see Table 1).

Prior studies have explored partial integrations. For example, Mabin and Davies (2010) embedded ECs within SSM to strengthen conflict resolution. However, a systematic coupling of multiple TOC-TP tools across SSM's phases remains underdeveloped.

This paper addresses that gap through a comprehensive integration of SSM's interpretive, participatory approach with TOC-TP's analytical rigour. The main design moves are:

- Structured identification of Undesirable Effects (UDEs): making UDEs an explicit artefact during SSM's exploratory stage.
- Substituting Rich Pictures with a CRT: mapping cause-and-effect structures to enhance stakeholder comprehension and causal clarity.
- Integrating CATWOE with ECs: combining interpretive boundary work with explicit assumption surfacing for conflict resolution.
- Using a FRT as the conceptual model: producing an actionable, logically coherent transition design endorsed by stakeholders.

Taken together, these moves retain robust participation while adding systematic conflict resolution and auditable logic, thereby addressing well-noted limitations when each methodology is used in isolation (Mingers and White, 2010; Rahman, 1998).

3. Method

3.1. Philosophical orientation

This research adopts a critical realist stance, viewing organisational phenomena as shaped by both stakeholder-constructed meanings and deeper structural mechanisms (Bhaskar, 1979; Mingers, 2014). Critical realism legitimizes methodological pluralism, combining interpretive techniques to surface stakeholder perspectives (SSM) with analytical tools to explore underlying causal structures (TOC-TP).

3.2. Research strategy

We conducted a participatory systemic intervention in a family-owned lubricant supplier facing strategic misalignment and conflicts in performance evaluation. The study explicitly maps Goldratt's four guiding questions ("Why change?", "What to change?", "What to change to?", "How to cause the change?") onto corresponding SSM stages. Our research specifically aimed to achieve stakeholder consensus on the core problem definition and develop a logically coherent conceptual model.

3.3. Researcher stance, reflexivity, and bias mitigation

The lead author acted as an insider-facilitator; to control access-related bias we instituted a documented reflexive and audit trail: (a) reflexive memos after each session (n = 11); (b) member checking of interim CRT/EC/FRT in 4 plenaries with recorded accept/reject notes; (c) paired coding of interview excerpts informing UDEs with a shared codebook (Cohen's $\kappa = 0.78$ after reconciliation across 3 coding rounds); (d) an external logic audit by an independent OR scholar (non-participant, no organisational ties) reviewing sufficiency links and negative-branch reservations; (e) version control for all diagrams (CRT v_1–v_4, FRT v_1–v_3); (f) negative-case analysis to actively surface disconfirming evidence in workshop transcripts; and (g) role separation (facilitation ≠ managerial appraisal) with written informed consent under the organisation's internal research policy. These safeguards separate facilitation from endorsement, preserve critical distance, and leave an auditable trail linking data to each logic link.

3.4. Data generation and stakeholder participation

Empirical materials were generated over four months through three day-long participatory workshops (14 stakeholders across senior management, department heads/line managers, and HR) plus one validation plenary for member-checking the interim CRT/EC/FRT artefacts; nine semi-structured interviews probing fairness, motivation, and strategic alignment; and targeted document analysis of appraisal policies, incentive schemes, and operational lifecycle diagnostics. Real-time group-modelling captured explicit causal assumptions and emergent consensus. Participants were purposively sampled across managerial tiers and functions to maximise diversity and triangulation across workshops, interviews, and documents.

3.5. Method integration

We integrated participatory sense-making with causal-logic analysis in a four-stage flow from SSM problem appreciation to a TOC-TP conceptual design (Figure 1). Interviews and document review first produced a register of Undesirable Effects (UDEs). We then built a CRT and tested it for sufficiency and and-ellipses to identify the core constraint. Next, CATWOE and ECs clarified viewpoints and surfaced assumptions, yielding a shared root definition and a set of validated injections. Finally, we developed a FRT and stress-tested it using negative-branch reservations (NBRs), culminating in a stakeholder-endorsed conceptual model.

The analysis proceeded retroductively—in the critical-realist sense of moving from recurring UDE patterns to hypothesised generative mechanisms (Bhaskar, 1979; Danermark et al., 2019). We then challenged each candidate against disconfirming evidence, counterexamples raised in plenary sessions, and the formal checks already noted—CRT sufficiency and and-ellipses, and FRT negative-branch reservations. Mechanisms were retained only if they improved explanatory coherence across interviews, workshops and documents, and withstood these tests.

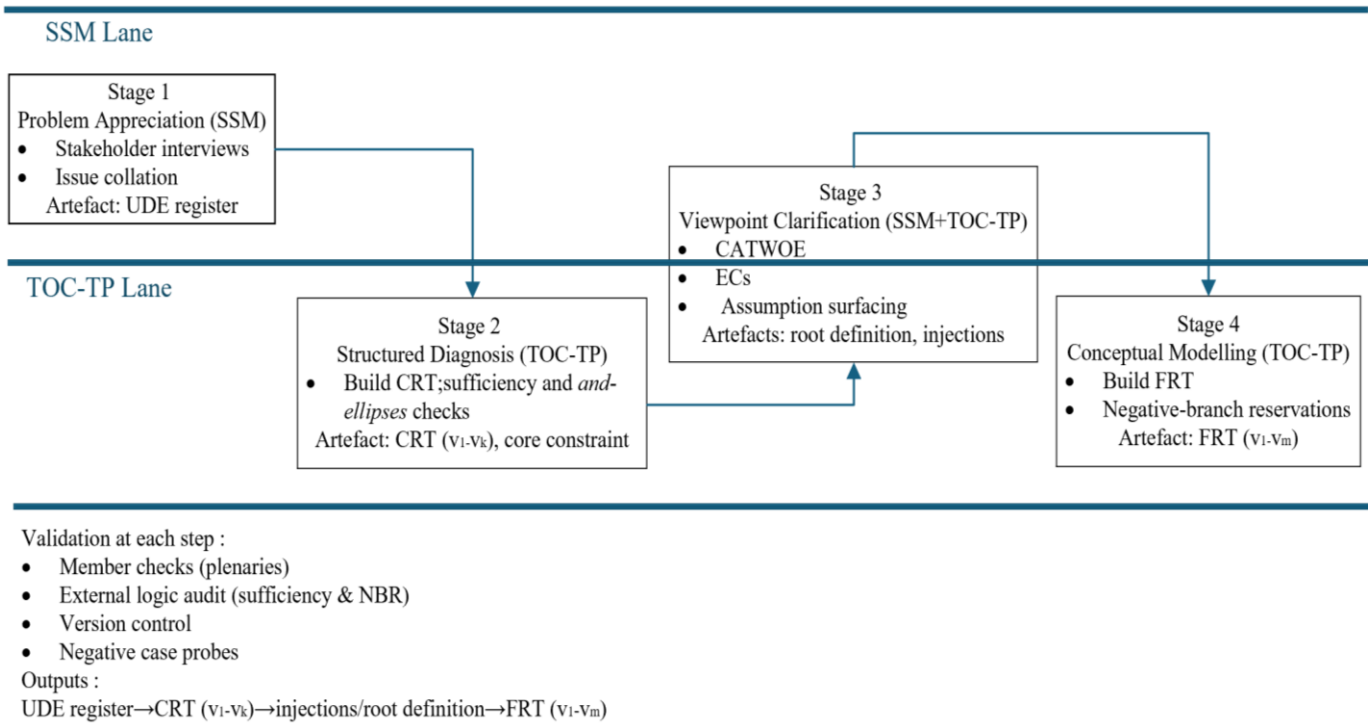

Figure 1. SSM↔TOC-TP integration (swimlane view)

To ensure auditability and control insider bias, each transition in the flow left a traceable record (Table 1): inputs (interview extracts, policies), facilitation activities (CRT/EC/FRT work), validation checks (member checks in plenaries; an external logic audit of sufficiency and NBRs; version control for all diagrams; and negative-case probes), and named artefacts (UDE register → CRT v_1–v_k → injections/root definition → FRT v_1–v_m). This audit trail links raw evidence to each *if–then* claim in the logic trees while preserving critical distance and the contextual advantages of the insider-facilitator stance.

Table 1. Integration map

Step	Purpose	Inputs	Activities/Tools	Validation	Output / Artefacts	Versioning
S_1	Elicit issues (SSM)	Interview notes; policies	Open coding; issue clustering	Member checks (plenaries)	UDE register	—
S_2	Diagnose constraint (TOC-TP)	UDE register	Build CRT; sufficiency and and-ellipses checks	Plenary challenge; negative-case probes*	CRT; core constraint	CRT v_1–v_k
S_3	Surface assumptions and align views (boundary)	CRT root causes	CATWOE + ECs (assumption surfacing)	Assumption testing; negative-case probes*	Root definition; injection set	EC set v_1–v_j
S_4	Design conceptual solution (TOC-TP)	Injections	FRT; negative-branch reservations	Plenary sign-off; external logic audit	Stakeholder-endorsed FRT	FRT v_1–v_m

**Note.* Negative-case probes were applied primarily in S_2–S_3 to seek disconfirming evidence in workshop transcripts.

Together, Figure 1 and Table 1 establish one-to-one traceability from stakeholder data to the endorsed conceptual model; Section 3.6 now addresses trustworthiness and analytical rigour.

3.6. Trustworthiness and analytical rigour

Credibility was ensured by validating interim models during participatory workshops and iteratively incorporating stakeholder feedback until consensus was achieved. An explicit audit trail comprising workshop notes, flipcharts, and version-controlled diagrams enhanced dependability. Transferability considerations included clearly specifying the organisational context conditions that influence generalisability.

3.7. Scope and Limitations

The intervention deliberately concluded at the conceptual modelling stage, emphasizing conceptual clarity and stakeholder agreement over immediate practical implementation. While establishing robust foundations for future implementation studies, this delimitation precludes immediate evaluation of behavioural or performance impacts, warranting further research to explore these dimensions.

4. Results

The intervention unfolded through four distinct yet interrelated stages, each aligning a phase of SSM with the corresponding guiding question from the Theory of Constraints-Thinking Processes (TOC-TP). The combination of interpretive exploration and structured analytical

tools facilitated a systematic progression from initial problem identification to the creation of a robust, stakeholder-endorsed conceptual model. Within a family-owned company operating in Iran's lubricant supply chain, specific TOC-TP tools (CRT, EC, and FRT) were integrated into the stages of SSM to explicitly address stakeholder conflicts, achieve consensus, and enhance strategic alignment.

4.1. Stage 1: Unstructured problem situation ("Why change?")

This initial stage focused explicitly on exploring and understanding the complex, ambiguous, and unstructured problem situation faced by stakeholders in the case organisation. Adopting an interpretive stance, open-ended stakeholder dialogues and interviews were conducted to surface diverse perspectives, tensions, and early indications of organisational misalignment (Figure 2).

The key issues identified included substantial delays in quarterly bonus disbursements, resulting in diminished employee morale and motivation. Concurrently, senior managers expressed dissatisfaction with employee performance evaluations, reflecting underlying mistrust and communication gaps. Additionally, external pressures from the competitive B2B lubricant market, intensified by macroeconomic instability and the COVID-19 pandemic, amplified the urgency for organisational change

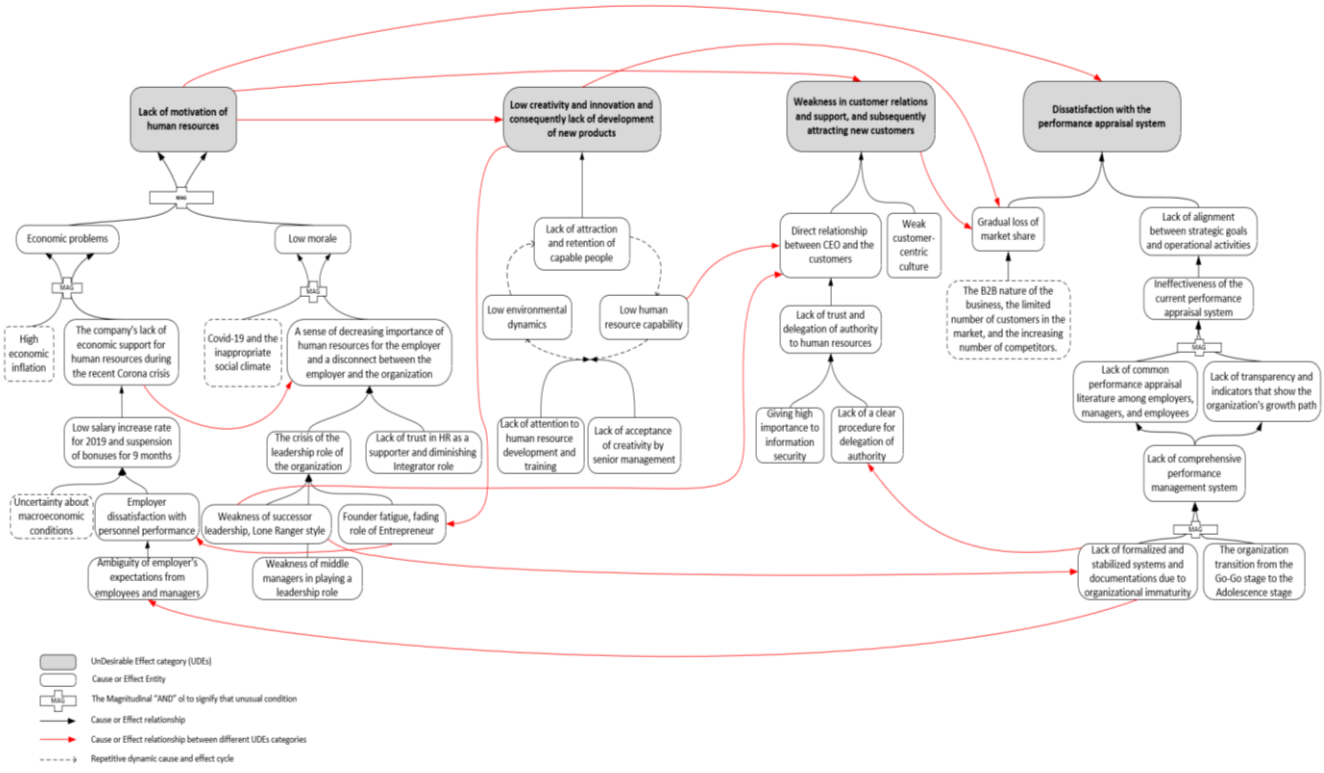

Figure 2. Initial list of undesirable effects (UDEs)

4.2. Stage 2: Structured problem situation—CRT ("What to change?")

To move from unstructured exploration toward structured diagnosis, the traditional Rich Picture used in SSM was replaced by a Current Reality Tree (CRT) from TOC-TP. The CRT explicitly captured logical cause-and-effect relationships among the identified undesirable effects, clarifying how issues such as inconsistent performance appraisal criteria, motivational decline, and misalignment of incentives were interconnected and driven by deeper organisational constraints.

The CRT enabled stakeholders to identify and agree upon performance appraisal systems as the primary organisational constraint, forming the basis for subsequent problem-solving steps. Each causal link within the CRT followed sufficiency-based logic, clearly articulating how multiple conditions jointly produced observed undesirable outcomes.

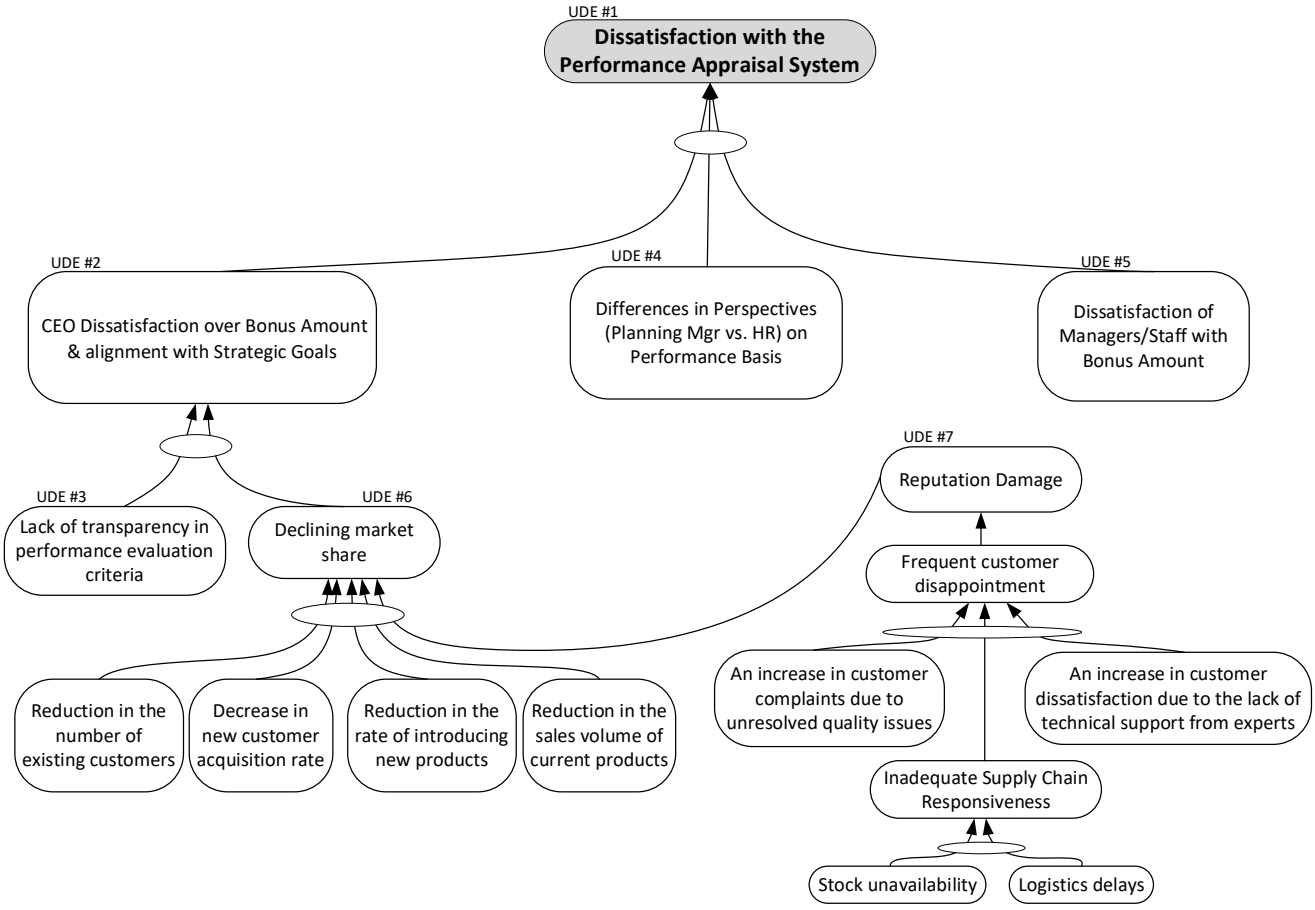

Figure 3. CRT for performance appraisal issues

Figure 3 illustrates the CRT developed to map performance appraisal issues, visually mapping the core UDEs and underscoring how dissatisfaction with appraisal outcomes connects

to broader organisational challenges such as motivational decline, misaligned incentives, and weakened strategic goal attainment.

In constructing the CRT, each cause-effect relationship is expressed using an if–then statement, underscoring sufficiency-based logic (Dettmer, 2007; Goldratt, 1994). When multiple causes must coexist to produce a single undesirable effect, they are visually joined by an ellipse—often referred to as an "and-ellipse"—indicating that all contributing factors must be present for the outcome to occur (Cox and Schleier, 2010). This approach not only highlights individual root causes but also shows how distinct conditions collectively produce the same undesirable outcomes.

The resulting CRT illustrates how these dissatisfaction-related UDEs cluster around core systemic shortcomings in the definition, measurement, and reward of performance. For instance, the diagram highlights misalignments between managerial expectations and actual appraisals, gaps in the communication of performance standards, and the absence of transparent, consistent bonus mechanisms. By disclosing these interdependencies, the CRT offers a robust foundation for subsequent problem-solving stages: it ensures that any proposed interventions will target the critical leverage points rather than merely treating symptoms (Dettmer, 2007; Goldratt, 1994).

Through this structured CRT analysis, Stage 2 pinpointed the performance appraisal system as the central predicament of the case organisation, with cascading effects on employee motivation, managerial trust, and alignment with strategic goals. In Stage 3, the analysis will shift to integrating ECs with Checkland's CATWOE framework. By systematically exploring stakeholder assumptions and potential resolutions, the next phase aims to build on the CRT's findings and forge consensus on root definitions and actionable improvements.

4.3. *Stage 3: Root definition—integration of CATWOE and ECs ("What to change?")*

Stage 3 aims to clearly define the core problem by systematically exploring and clarifying the differing stakeholder viewpoints and the underlying conflicts previously identified. To accomplish this, two complementary analytical tools are integrated:

- CATWOE (from SSM)
- ECs (from Theory of Constraints-Thinking Process (TOC))

CATWOE is an analytical tool designed to structure and understand complex problems by capturing stakeholder views in a structured, comprehensive way. It involves examining the following elements explicitly from stakeholders' perspectives:

- Customers (C): Who directly benefits or suffers from the current situation?
- Actors (A): Who is responsible for implementing potential changes?
- Transformation (T): What change is required—from the current problematic state to a desirable future state?
- Worldview (W): What underlying beliefs or assumptions influence stakeholders' perceptions and actions?
- Owners (O): Who holds the authority to approve changes?
- Environment (E): What external constraints or conditions influence potential solutions?

During structured discussions, stakeholders systematically considered each CATWOE element to ensure a balanced and comprehensive view of key organisational challenges, particularly regarding performance evaluation and human resource management issues.

The EC is a structured, logical tool from TOC specifically designed to identify and articulate organisational conflicts clearly. It visually represents opposing positions, highlights hidden assumptions behind each position, and ultimately helps stakeholders clearly see why conflicts arise.

- A typical EC structure includes:
- Objective: The overall goal or purpose that stakeholders seek to achieve.
- Requirements: Two necessary conditions to achieve the objective.
- Prerequisites: Conflicting actions or positions believed necessary to fulfil each requirement.
- Underlying Assumptions: The deep-seated beliefs explaining why stakeholders maintain their conflicting positions.

At this stage, the primary goal is not to propose specific solutions (termed "injections" in TOC-

TP), but rather to clearly expose and document conflicts and underlying assumptions, thereby laying the groundwork for consensus-building and solution development in subsequent stages.

A representative EC analysed in this study (Figure 4) captures a conflict around managing human resources, specifically between the company founder and the second-generation leadership:

- Objective: Exploring new creative human resources while effectively utilizing existing employees.
- Requirement #1: Retain current human resources.
- Prerequisite #1: Commitment to organisational values (entrepreneurship, livelihood, human resource retention).
- Founder's Assumption: Even employees performing poorly should be retained due to our values and the high costs associated with finding replacements.
- Requirement #2: Recruit capable and creative human resources.
- Prerequisite #2: To remain competitive, the organisation needs highly skilled and innovative employees.

- Second-generation Assumption: Organisational stagnation is largely due to poor employee performance, culture, and lack of innovation. Retaining low-performing employees undermines competitive success.

This explicit conflict arises from fundamentally different assumptions:

- The founder values loyalty, stability, and retention even at the expense of performance.
- The second-generation leadership prioritizes performance, innovation, and competitiveness, even if it means replacing current employees.

At this stage, this EC analysis does not attempt to resolve the conflict but clearly identifies and documents opposing assumptions, thereby enabling stakeholders to discuss the roots of their disagreements openly and explicitly.

While the EC diagrams help surface and clarify the underlying assumptions behind stakeholder conflicts, they do so by focusing on one key dilemma at a time. In contrast, the CATWOE framework offers a broader, more holistic view by systematically capturing the roles, worldviews, and contextual constraints of all major stakeholders involved. Together, these tools complement one another: EC exposes the hidden tensions that hinder agreement, while CATWOE structures those tensions into a coherent understanding of what change is needed, who is involved, and what environmental realities shape possible interventions. To consolidate insights from both tools and link them directly to the Undesirable Effects (UDEs) identified in Stage 2, the following table presents an integrated analysis that maps each major issue to its corresponding CATWOE components.

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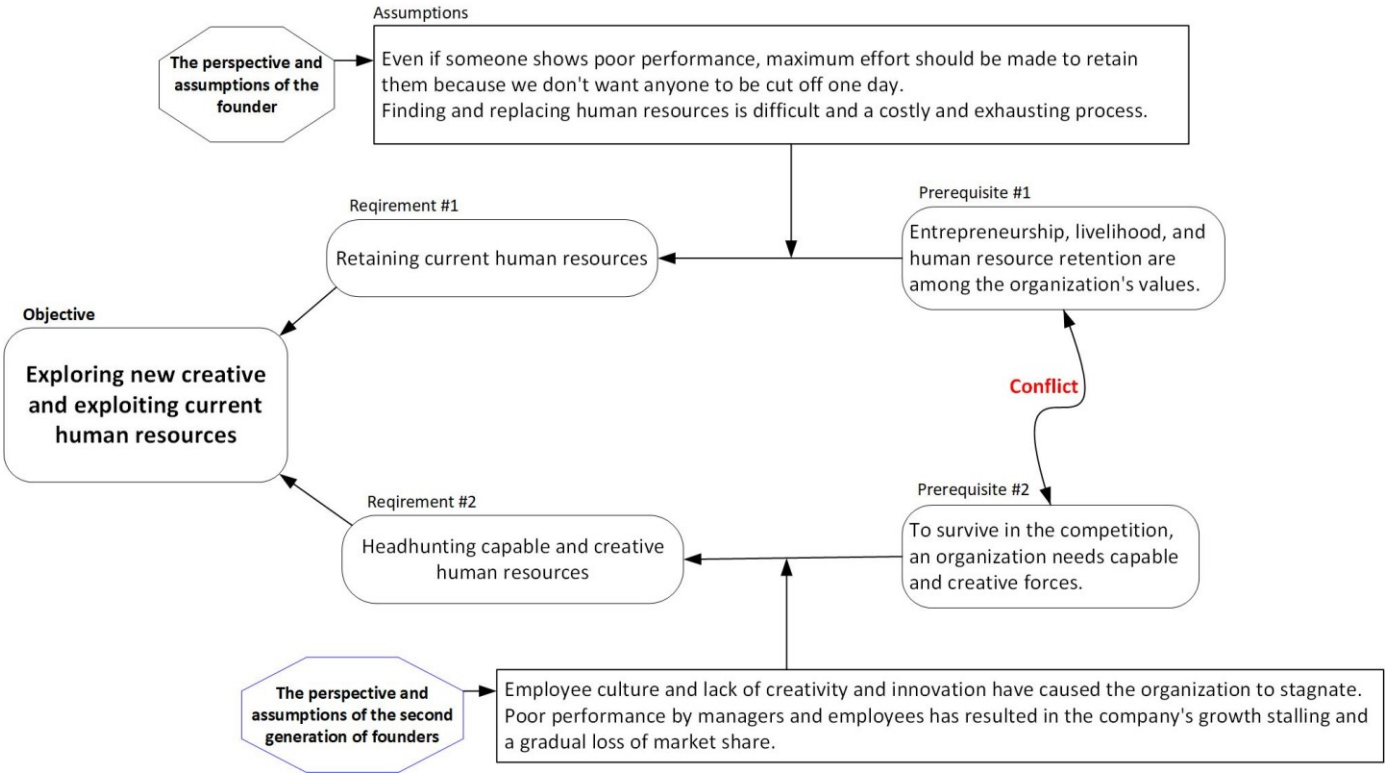

Figure 4. EC Example—Conflict in human resource management

To systematically consolidate insights from CATWOE analysis and ECs, a comprehensive analytical framework that combines the UDEs identified in Stage 2 with the CATWOE dimensions is presented in Table 2.

Table 2. Integration of CATWOE elements with undesirable effects (UDEs)

#	Undesirable effect (UDE)	Customer (C) primary beneficiaries or victims	Actor (A) who must act	Required transformation (T) from ➔ to	World-view (W) core belief driving action	Owner (O) ultimate authority	Environment (E)
1	Widespread dissatisfaction with the performance appraisal system	Employees, line managers, CEO who depend on fair evaluations	HR department; line supervisors	From ad-hoc, inconsistent ratings to a transparent, internally consistent appraisal framework	A credible appraisal process is pivotal for motivation and organisational trust	Chief Executive Officer (sets HR policy)	Intensifying B2B competition demands efficiency and accountability
2	CEO dissatisfaction over bonus alignment with strategic goals	Whole organisation (mis-aligned incentives weaken competitiveness)	Strategic-planning office; HR	From purely behavioural targets to appraisal and reward metrics tightly linked to long-term strategy	Performance management should be a primary lever for executing strategy	Planning Manager (monitors alignment)	Niche B2B market with rapid tech shifts, needing integrated HR–strategy tools
3	Lack of transparency in performance criteria	Employees seeking clarity on what constitutes “good performance”	HR Department, performance appraisal designers	From vague or contradictory performance metrics to explicit,	Visibility into performance standards increases trust and helps employees align	Founder and second-generation successors	Cultural norms favour hierarchical control; multiple stakeholders push

#	Undesirable effect (UDE)	Customer (C) primary beneficiaries or victims	Actor (A) who must act	Required transformation (T) from ➔ to	World-view (W) core belief driving action	Owner (O) ultimate authority	Environment (E)
				measurable indicators linked to strategic objectives	behaviour with organisational goals		for clarity yet fear losing flexibility
4	Divergent views between the Planning Manager and HR Manager on the evaluation basis	Employees suffering from mixed signals	Planning Manager and HR Manager	From dual, conflicting measurement logics to a single, integrated set of strategic + behavioural indicators	Strategic goals must converge with human resource practices; conflicting assumptions hamper synergy	Deputy CEO (2nd-generation leadership)	Organisational immaturity (limited documentation) vs. drive for standardization
5	Dissatisfaction of managers/ staff with bonus amounts	Staff whose income depends on predictable incentives	HR and Finance units	From sporadic, opaque pay-outs to a metrics-driven, predictable reward mechanism	Monetary rewards must reflect real effort and strategic contribution—uncertainty erodes morale	CEO + senior leadership team	Macroeconomic volatility (inflation, post-COVID cost pressures)
6	Declining market share in a competitive B2B arena	The organisation as a whole (leadership, shareholders, employees)	Sales, Marketing, R&D, Strategic Planning	From sporadic or misaligned marketing/product strategies to a dynamic, customer-centred approach that reverses market-share losses	Survival requires fast adaptation to customer needs and a clear competitive advantage	CEO and executive team	The dynamic B2B market is facing macroeconomic uncertainties and intensifying competition, requiring agile innovation and responsiveness
7	Damage to the employer / corporate reputation	Clients, existing partners, potential recruits, the brand's public image	HR, Corporate Communications, Senior Executives	From a tarnished or ambiguous brand to a transparent, reliable reputation that attracts customers and talent	Reputation is a critical intangible asset; quality and integrity must be visible and verifiable	CEO and the brand/communications team	High social-media scrutiny, talent war, stakeholders' rising expectations for transparency

This structured representation clarifies which stakeholders are affected, who has authority to initiate change, and precisely what transformations are necessary—explicitly linking stakeholder worldviews to underlying conflicts outlined by ECs.

Four primary ECs emerged, capturing conflicts over centralized versus delegated managerial control, standardized versus flexible bonus structures, qualitative versus quantitative evaluation criteria, and performance-focused versus development-oriented appraisals. Each EC explicitly revealed underlying assumptions, facilitating structured stakeholder dialogues that ultimately produced a single agreed-upon root definition:

"To institutionalize a transparent, auditable performance-and-rewards system by using a dual-criteria (approximately 80/20) rubric, version-controlled indicators, and participatory

review, so that improvements in measured performance credibly reflect organisational value rather than score maximization."

This agreed-upon definition sets the stage for developing comprehensive, logical, and acceptable solutions in the subsequent stage (Stage 4: Conceptual Modelling), where explicit solutions ("injections") will be developed to directly address these documented conflicts.

Stage 3 systematically integrates CATWOE analysis with ECs to elicit and organize stakeholder perspectives in a structured manner. This combined approach facilitates the formulation of well-founded root definitions that serve as a foundation for coherent and collectively endorsed transformations in the subsequent stage.

4.4. Stage 4: Conceptual modelling—FRT ("What to change to?")

Stage 4 corresponds explicitly to the conceptual-modelling phase of SSM, in which the collaboratively agreed-upon root definition from Stage 3 is Operationalized into a systemic conceptual model (Checkland and Poulter, 2020). Traditionally, SSM utilizes abstract activity models; however, our integrated approach employs the FRT from the TOC-TP. This selection was deliberate, as the FRT combines the participatory engagement of SSM with TOC-TP's rigorous cause-effect logic, ensuring conceptual clarity, logical coherence, and stakeholder acceptance.

The FRT (Figure 7) is a structured cause-and-effect diagram that explicitly maps a set of clearly defined interventions, known as "injections," through intermediate effects (IEs) toward desirable effects (DEs). Each intervention was directly derived from stakeholder-agreed solutions formulated during the EC analyses in Stage 3. The FRT systematically addresses each undesirable effect (UDE) identified previously in the CRT, clearly illustrating how these interventions resolve the core organisational tensions (Dettmer, 2007).

Among several ECs developed in Stage 3, two critical ECs were unanimously identified by stakeholders as capturing fundamental conflicts within the organisation's performance management system:

- EC-Bonus Fairness (Figure 5): This cloud clarified tensions between employees, who considered quarterly bonuses as an integral part of their compensation, and the CEO, who emphasized performance-contingent and financially viable bonuses. Four specific injections were collaboratively proposed:
    - Realignment of salary bands to industry benchmarks.
    - Explicit formula-driven bonus distributions linked directly to measurable KPIs.
    - Transparent quarterly communication of strategic targets.

  - Institutionalization of performance evaluation linked to organisational objectives.
- EC-Performance Appraisal Transparency (Figure 6): This cloud addressed conflicts between qualitative and quantitative appraisal methodologies advocated by HR and the Planning Manager, respectively. Stakeholders agreed on two injections:
  - Implementation of a dual-criteria appraisal system (80% quantitative, 20% qualitative).
  - Co-creation and explicit publication of the KPI rubric through participatory workshops.

These EC analyses played a dual role: they surfaced underlying assumptions fuelling stakeholder disagreements and concurrently provided candidate injections validated collectively for further analysis in Stage 4

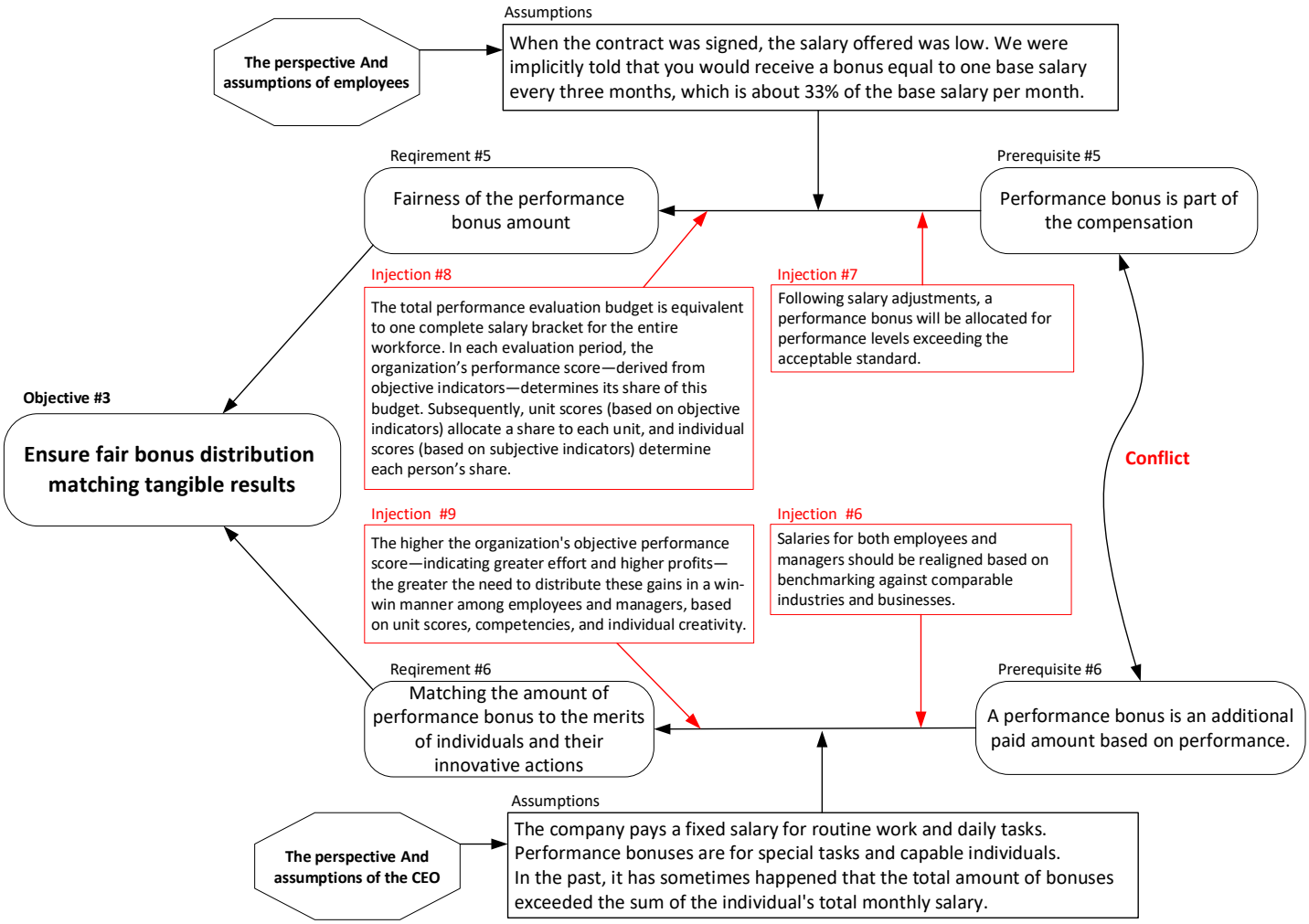

Figure 5. Bonus fairness EC

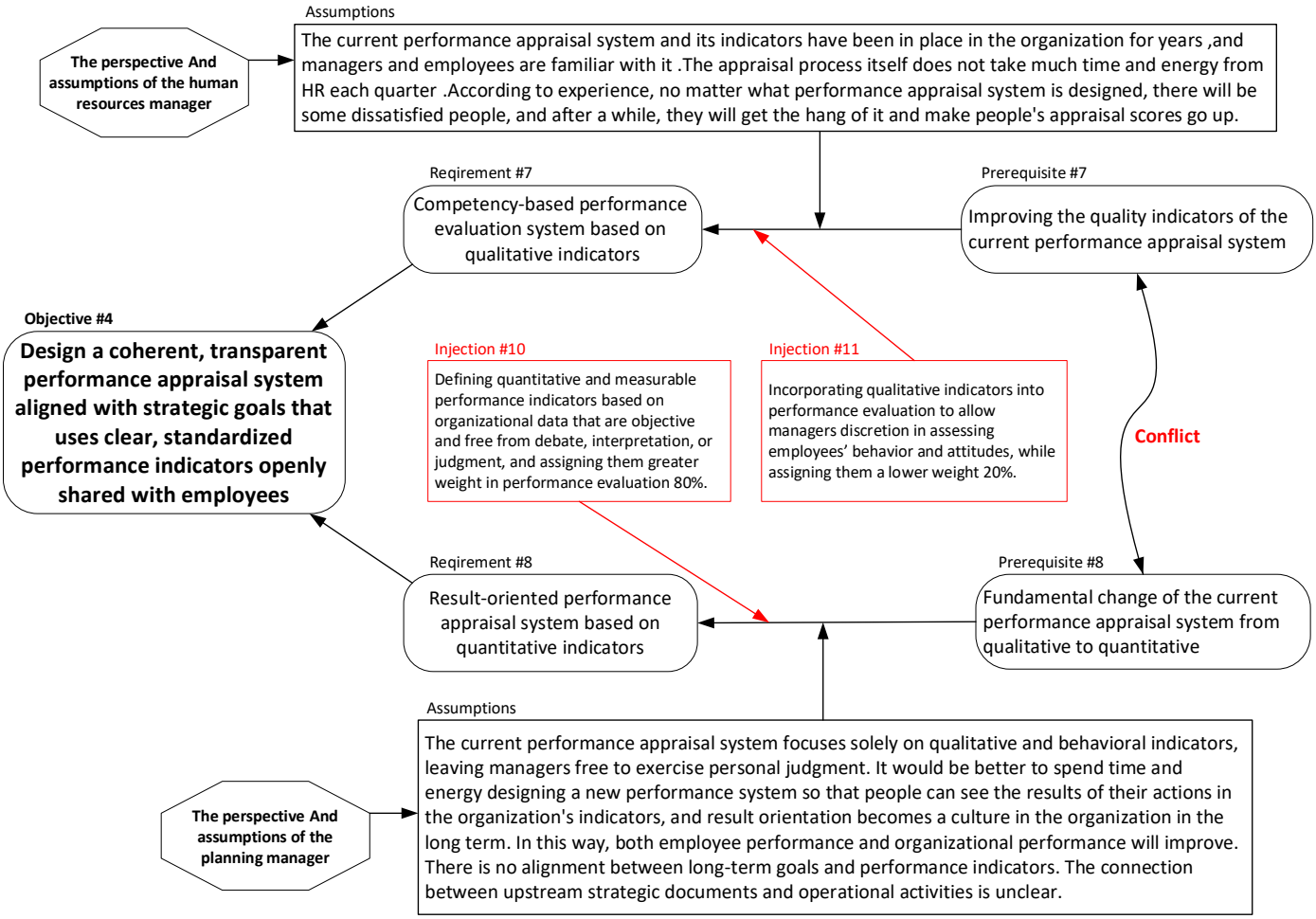

Figure 6. Performance appraisal transparency cloud (EC)

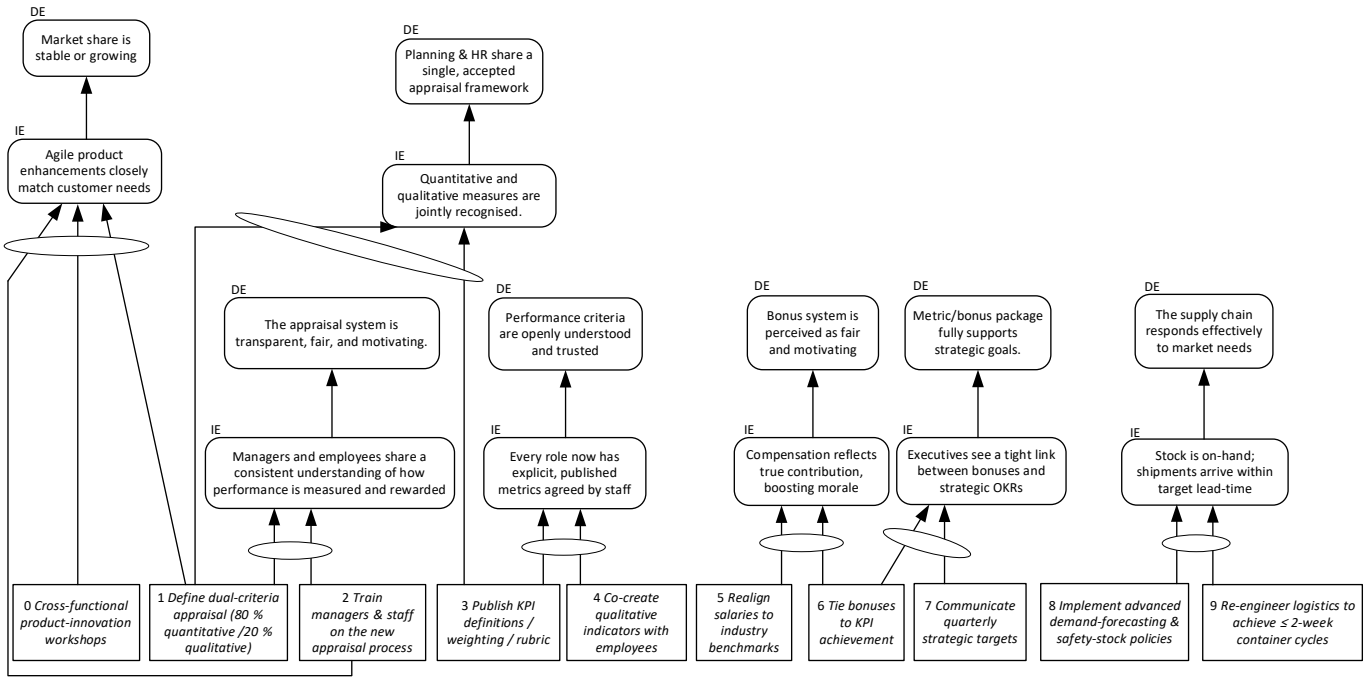

Figure 7. FRT

The injections agreed upon during the EC workshops constitute the foundational layer of the Future Reality Tree (Figure 7). Successive layers connect these injections, via rigorously validated intermediate effects, to the desirable effects that express the organisation's strategic intent. Each causal link was scrutinized and accepted in plenary sessions, giving the organisation a single, stakeholder-owned conceptual model that is both internally coherent and empirically testable in the next phase of work.

5. Discussion

5.1. Philosophical implications of SSM–TOC integration

The integration of SSM and TOC-TP rests on complementary epistemological positions and yields a robust multi-paradigm approach. SSM is fundamentally interpretivist, emphasising stakeholder perceptions, negotiated meanings and iterative dialogue in order to explore complexity (Checkland and Poulter, 2020; Mingers and White, 2010). By contrast, TOC-TP brings analytical rigour through explicit cause-effect reasoning to diagnose constraints and articulate structured responses (Dettmer, 2007; Goldratt, 1994).

This combination aligns with Habermas's account of cognitive interests (Habermas, 1971). SSM primarily serves the practical interest by promoting shared understanding and stakeholder agreement, whereas TOC-TP addresses the technical interest through disciplined causal analysis and problem structuring. Taken together, the approach couples interpretive flexibility with analytical rigour, which is essential for problems that are at once socio-political and systemic.

Ontologically, the integration is anchored in critical realism, which posits a stratified reality comprising the empirical, the actual, and the real (Bhaskar, 1979; Mingers, 2014). In our reading, SSM foregrounds experienced phenomena and negotiated meaning that sit within the empirical and actual, while TOC-TP emphasises causal explanation oriented to underlying mechanisms associated with the real (Goldratt, 1994; Dettmer, 2007). We use this mapping heuristically to guide artefact selection rather than as a categorical partition of critical-realist domains.

This positioning reconciles subjective stakeholder experience with disciplined causal-logic analysis and recognises the multidimensional character of organisational phenomena (Jackson, 2019; Mingers and Brocklesby, 1997). Methodologically, the integration enacts pluralism. SSM secures participatory engagement, rich problem appreciation, and iterative consensus building, while TOC-TP provides the logic-tree toolset—CRT, EC, and FRT—to identify constraints,

resolve conflicts, and design targeted injections. Making the boundary shifts between interpretive dialogue and analytic reasoning explicit reduces paradigm friction and strengthens both theoretical coherence and practical applicability.

Boundary critique in the sense of Ulrich is embedded across the work by documenting who is affected, who decides, and which indicators enter evaluation rubrics, with contested inclusions surfaced and negotiated transparently (Ulrich, 2001). Situated within complex-adaptive and design-science sensibilities, the integration remains flexible in dynamic conditions while preserving traceability of rationale (Jackson, 2019).

From a design-science perspective, the study exemplifies action-oriented inquiry. SSM contributes context-sensitive, stakeholder-informed problem definitions, and TOC-TP translates these into logically coherent proposed interventions that are appraised for sufficiency and for negative-branch robustness prior to any field execution. In this way, the integration advances organisational design science by offering a theoretically coherent and practice-ready framework for systemic intervention (Van Aken, 2004; Baskerville et al., 2009).

5.2. Practical implications and critical reflections

The present study addressed critical organisational issues of fragmented stakeholder understanding, declining strategic coherence, and systemic constraints through an integrated methodological approach combining SSM with the TOC-TP. By explicitly aligning interpretive and analytical paradigms, our approach successfully facilitated structured stakeholder dialogues, conflict resolution, and conceptual clarity within a family-owned lubricant supply firm facing pronounced organisational complexity.

A central contribution of this research lies in its explicit demonstration of methodological pluralism (Jackson, 2019; Mingers, 2000), bridging traditionally separate interpretive and functionalist paradigms. This integration not only responds to calls within systems thinking literature to overcome paradigm exclusivity but also clearly illustrates practical complementarities between SSM and TOC-TP methodologies. Specifically, while SSM effectively surfaced multiple stakeholder perspectives and fostered consensus-building dialogues, TOC-TP provided precise analytical tools (CRT, EC, FRT) that explicitly addressed deeper systemic constraints and facilitated logical clarity.

Significantly, Stage 3 emerged as a critical juncture in our intervention process, combining CATWOE and EC to clarify and resolve underlying stakeholder conflicts. By explicitly articulating conflicting assumptions, stakeholders were able to transparently negotiate and

agree upon a clear, shared root definition, significantly enhancing organisational legitimacy and acceptance. This consensus provided the necessary foundation for effective conceptual modelling in Stage 4, which translated negotiated agreements into structured FRTs, offering stakeholders a logically coherent pathway toward strategic alignment and operational improvement.

Another noteworthy aspect of our intervention strategy was the explicit decision to conclude the intervention at the conceptual modelling stage, emphasizing the critical importance of achieving comprehensive stakeholder buy-in and conceptual clarity before attempting practical implementation. This strategic delimitation clearly positions the present study within the boundaries of design-oriented systemic inquiry (Van Aken, 2004; Baskerville et al., 2009), explicitly emphasizing the rigorous formulation of robust conceptual frameworks as a necessary precursor to sustainable organisational change.

Our methodological approach also holds significant practical implications. Organisations facing complex, socio-technical challenges involving multiple stakeholder conflicts can greatly benefit from systematically integrating interpretive participatory dialogues with structured analytical tools. This integration not only promotes a richer understanding and greater stakeholder legitimacy but also yields clearer, more actionable strategies for organisational improvement. Therefore, the proposed integrated approach offers valuable guidance for practitioners and researchers navigating similar complex organisational environments.

5.2.1. On non-linearity and context

TOC-TP logic trees privilege sufficiency chains, whereas real organisations feature feedback, delays, and path dependence. Our CRT/FRT captured conjunctions via *and-ellipses* and screened for negative branches, yet we did not quantify feedback strengths. Context also matters: cultural and governance patterns can shift causal salience; in our family-owned Iranian case, founder–successor dynamics may amplify assumptions around loyalty and control. A follow-on study will pair the validated FRT with complementary systemic formalisms (e.g., system-dynamics stock–flow models or Viable System Model (VSM) diagnostics) to stress-test robustness under feedback, delays, and varying cultural priors (see also Section 6, Limitations).

5.2.2. Practitioner translation and implementation roadmap

To translate the stakeholder-endorsed Future Reality Tree into practice without overstating implementation, we set out a concise, audit-ready roadmap (Table 3) for the Performance and

Rewards branch (Injections 1–4, 6–7, plus salary benchmarking [5]), with explicit ownership, validation checks, and metrics. The Operations, Supply Chain, and Product branch (Track B; Injections 0, 8–9) is defined as a separate stream and mapped in Table 4 to preserve one-to-one traceability from the FRT to execution artefacts.

Table 3. Implementation roadmap — track A (Performance and Rewards)

Milestone	Time frame	Owner(s)	Key activities	Deliverables	Validation / Controls	Metrics
M0 – Governance setup	4–6 wks	Owner: CEO (or delegate); Sponsor: COO/HR; Independent Facilitator; Cross-functional Design Cell	Charter scope; risk register; ethics/data plan; comms cadence	Project charter; risk log; ethics/data note	Role separation (facilitation ≠ appraisal); stakeholder sign-off	—
M1 – KPI rubric and baseline	3–4 wks	HR + Line heads	Co-create approximately 80/20 quantitative/qualitative rubric; train raters; baseline	Published rubric; training records; baseline sheet	Inter-rater reliability (κ/ICC); version control	Lead: rubric coverage %, comprehension quiz score
M2 – Incentive alignment (pilot)	4–6 wks	HR + Finance + 2 pilot depts	Bonus formula and thresholds; communicate quarterly strategic targets; run one pilot cycle	Payout worksheet; FAQ; comms brief	NBR review; gaming detection (variance spikes)	Lead: on-time evaluation % · Lag: bonus satisfaction index
M2b – Compensation benchmarking (parallel)	3–5 wks (parallel)	HR + Finance	Salary realignment to market benchmarks	Benchmark report; adjustment plan	Equity/fairness audit	Lag: voluntary turnover %
M3 – Review and rollout decision	2–3 wks	Steering group	Review NBR observations; update injections; formal sign-off for rollout	Revised injections; rollout decision note	External logic audit (sufficiency/NBR)	Complaint rate; sales margin %

As a domain exemplar, our prior work on the Strategic Alignment Framework (SAF)—integrating Objectives and Key Results (OKRs), Critical Success Factors (CSFs), and financial metrics—demonstrates how Track A (Performance and Rewards) can be operationalized in practice. We cite the data-driven articulation of SAF to support practitioner translation of the roadmap (Sepasi, 2024) and a companion, process-focused study that details execution design—workflows, roles and handoffs, escalation rules, and in-process controls (Sepasi, Tabatabaei Rafiei, and Madandar, 2024). These citations are provided solely to guide

implementation and should not be read as methodological validation of the SSM–TOC-TP integration.

Table 4 maps each FRT injection to the corresponding milestone(s) in Table 3, marking Track A as Operationalized and Track B as specified for subsequent implementation.

Table 4. FRT → Roadmap traceability

FRT branch	Injection ID	Injection (label)	Track	Milestone(s) in Table 3	Status
Performance and Rewards	1	Dual-criteria appraisal (approximately 80/20)	Track A	M1	Operationalized
Performance and Rewards	2	Train managers and staff on the new process	Track A	M1	Operationalized
Performance and Rewards	3	Publish KPI metrics/weights/rubric	Track A	M1	Operationalized
Performance and Rewards	4	Co-create qualitative indicators with employees	Track A	M1	Operationalized
Performance and Rewards	5	Salary realignment to market benchmarks	Track A	M2b	Operationalized (parallel)
Performance and Rewards	6	Tie bonuses to KPI achievement	Track A	M2	Operationalized
Performance and Rewards	7	Communicate quarterly strategic targets	Track A	M2	Operationalized
Ops/SCM and Product	0	Cross-functional product-innovation workshops	Track B	PRD-1	Specified for subsequent track
Ops/SCM and Product	8	Demand-forecasting and safety-stock policy	Track B	SC-1	Specified for subsequent track
Ops/SCM and Product	9	Logistics re-engineering to ≤2-week cycles	Track B	SC-2	Specified for subsequent track

Together, Table 3 and Table 4 provide a traceable, auditable bridge from the FRT (Section 4.4) to execution, consistent with our bounded scope; empirical testing of Track A and staged implementation of Track B follow in subsequent work.

Although field outcomes are outside our bounded scope, pre-implementation evidence comprises stakeholder sign-off on the FRT, documented member-checks across four plenaries, and an independent external logic audit (see Sections 3.3 and 3.5).

6. Conclusion

This study explicitly concludes at the conceptual modelling stage, emphasizing the critical role of stakeholder consensus and logical coherence prior to practical implementation. Although the question of "How to cause the change?" lies beyond the current research scope, the work establishes a robust foundation for future studies and real-world applications. A complementary question worth future exploration is "How to measure and sustain the change?"—specifically,

how to embed continuous improvement and progress-monitoring processes within the SSM–TOC framework.

Through a detailed empirical case study conducted in a mid-sized enterprise within Iran's lubricant industry, this research has demonstrated both the practical value and theoretical strength inherent in combining SSM with the TOC-TP, explicitly grounded in a critical realist philosophical stance. Specifically, we illustrated how rigorous analytical reasoning, combined with structured stakeholder engagement and dialogue, can systematically untangle complex organisational issues, leading to meaningful consensus and conceptual clarity.

A key outcome of this integrated intervention was the collaborative development and validation of a FRT—a clearly articulated, logically rigorous conceptual model endorsed by stakeholders. This model explicitly addressed challenges surrounding performance appraisal, strategic misalignment, and motivational conflicts within the organisation. The deliberate decision to pause the intervention at this conceptual stage underscores our argument that sustainable organisational change fundamentally requires robust consensus-building processes and transparent logical foundations prior to practical implementation.

The research significantly enriches the literature on systemic interventions by showcasing a viable methodological pathway for integrating interpretive and analytical paradigms in organisational contexts characterized by complexity and competing stakeholder interests. From a theoretical perspective, the study clearly illustrates the feasibility, advantages, and philosophical coherence of methodological pluralism, particularly highlighting how interpretive (SSM) and analytical (TOC-TP) methodologies can complement one another when addressing intricate organisational dilemmas.

Nevertheless, recognizing the inherent limitations imposed by the conceptual focus, this study explicitly excludes empirical implementation and practical evaluation. Therefore, there remain important opportunities for extending this research in several specific directions:

- Practical Implementation and Validation: Empirical testing and validation of the interventions identified in the FRT will be essential for evaluating their operational effectiveness, stakeholder acceptance, and real-world strategic impact over time.
- Longitudinal Studies: Examining the long-term sustainability and adaptability of the conceptual model will provide critical insights into how organisations can continuously realign their activities and strategies to respond effectively to evolving stakeholder expectations and market conditions.
- Integration with Additional Methodologies: Future research could beneficially explore the incorporation of other complementary systemic or analytical approaches—such as System Dynamics for quantifying feedback loops, or Complexity Theory for

addressing emergent properties—to enhance the model's robustness in confronting increasingly complex organisational challenges.

In conclusion, by thoughtfully integrating interpretive dialogue with rigorous analytical reasoning within a coherent philosophical framework, this research provides a robust theoretical contribution and a valuable practical approach for addressing complex organisational problems. Extending these initial conceptual findings through empirical implementation and broader contextual studies promises substantial advancements in both the theory and practice of systemic organisational interventions.

This study concludes at the conceptual modelling stage and does not proceed to practical implementation. While the systemic intervention generated a logically coherent and stakeholder-endorsed FRT, the model's operational effectiveness and long-term impact remain untested. Additionally, the case context—a mid-sized, family-run company in Iran's lubricant sector—may limit the generalizability of the findings across industries or cultural settings.

The dual role of the lead researcher as an insider-facilitator, although beneficial for contextual access and stakeholder engagement, may have introduced interpretive bias despite efforts at reflexivity and triangulation. Furthermore, the focus on a single case study limits the statistical generalizability of the results, although the aim of this qualitative research was analytical generalization and conceptual insight.

Future research is encouraged to empirically implement and evaluate the proposed interventions across different organisational settings, possibly using comparative case designs. Moreover, integrating additional systemic approaches, such as System Dynamics or the Viable System Model, could further enhance analytical depth and broaden the scope of participatory modelling in resolving complex organisational dilemmas.

Disclosure statement

The lead author was previously employed as Planning Manager in the case organisation but has no current affiliation or financial relationship with the company. The authors declare no competing interests—financial or non-financial—related to the content of this manuscript.

Abbreviations

CSF— Critical Success Factors
CRT — Current Reality Tree
EC — Evaporating Cloud
FRT — Future Reality Tree
KPI — Key Performance Indicator
NBR — Negative-Branch Reservation

OKR— Objectives and Key Results
SAF— Strategic Alignment Framework
SSM — Soft Systems Methodology
TOC-TP — Theory of Constraints–Thinking Processes
UDE — Undesirable Effect
VSM—Viable System Model

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Systems Thinking in Investigating the Youth Unemployment Problem in Iran

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ABSTRACT

Youth unemployment in Iran is a long-standing and complex issue. It results from the interaction among structural barriers, behavioral patterns, and economic shocks, which reinforce one another over time. This study employs a qualitative system dynamics (SD) model to examine how these mechanisms sustain high unemployment among young people. The model is presented through a Causal Loop Diagram (CLD). It draws on evidence from research, policy reports, and theory to map key feedback loops in the labor market. The analysis identifies several reinforcing loops. These include educational inflation, skill mismatch, informal employment traps, and economic contraction due to sanctions. Each loop intensifies unemployment. In contrast, balancing loops, such as public-sector hiring and vocational training, offer only short-term relief. These feedbacks explain why isolated policies often fail to produce lasting change. The findings highlight key leverage points. These include better alignment between education and employment, stronger labor-demand policies, and improved labor-market information systems. While qualitative, the model offers a solid foundation for future simulations and for designing feedback-aware strategies to reduce youth unemployment in Iran and similar contexts.

Keywords

Youth unemployment, System dynamics, Causal loop diagram, Labor market policy, Skill mismatch

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1. Introduction

Youth unemployment is one of the most persistent socioeconomic challenges worldwide. In most countries, unemployment rates among young people are more than double those of adults (Fergusson, 2021). This pattern indicates that young entrants encounter structural barriers, including limited work experience, skill mismatches, and institutional inflexibility. Unemployment also has lasting social and psychological effects. It lowers happiness, life satisfaction, and mental health, even when controlling for income or education. These negative outcomes often persist after re-employment, producing what is known as the scarring effect, a long-term loss of motivation, skills, and earnings potential (Clark et al., 2001; Arulampalam, 2001; Gregg and Tominey, 2005).

The causes of youth unemployment extend beyond short-term economic shocks. They emerge from the interaction of economic, institutional, and behavioral mechanisms that evolve over time. Traditional labor-market models typically view unemployment as a static imbalance between labor supply and demand. However, empirical research increasingly highlights the role of feedback loops, i.e., self-reinforcing processes linking educational choices, labor-market expectations, and employment outcomes (Yokoyama et al., 2024). For instance, when graduates face limited job opportunities, many remain in education or pursue additional degrees, further increasing labor-market pressure. Similarly, discouraged workers may withdraw from the labor force, thereby masking the true level of unemployment. Such feedbacks create nonlinear and path-dependent dynamics that standard models fail to capture.

In Iran, youth unemployment reflects these global mechanisms but is intensified by domestic conditions. A large youth cohort, rapid expansion of higher education, and weak alignment between academic programs and industrial needs have produced an oversupply of graduates. Economic sanctions and structural inefficiencies have constrained job creation, reduced investment, and encouraged informal employment (Salehi-Isfahani, 2011; Kelishomi and Nisticò, 2024). Many young people now work in low-productivity or insecure positions with limited upward mobility. These patterns reinforce each other, creating a self-sustaining cycle of educational inflation, underemployment, and human-capital erosion.

Most existing Iranian studies on youth unemployment rely on statistical or econometric analyses that treat causal relationships as linear and unidirectional. These methods cannot fully capture the delayed and feedback-driven nature of unemployment dynamics. This study addresses this gap by employing system dynamics (SD) to model youth unemployment as a feedback system linking education, labor demand, and macroeconomic constraints. The SD

approach enables exploration of how structural and behavioral factors interact, how delays influence outcomes, and where the most effective intervention points lie.

The study's innovation lies in developing a qualitative SD model that integrates endogenous behavioral responses with exogenous labor-market shocks specific to Iran. Unlike traditional econometric or structural models, SD explicitly represents feedback loops, accumulation processes, and time delays. This allows analysis of policy resistance and unintended consequences, especially under conditions such as international sanctions. The resulting Causal Loop Diagram (CLD) identifies both reinforcing and balancing structures and provides theoretical insight into why youth unemployment persists despite repeated policy efforts.

The remainder of the paper proceeds as follows. Section 2 reviews prior research on youth unemployment and summarizes key findings relevant to the Iranian context. Section 3 presents the methodological framework and outlines the process of constructing the SD model. Section 4 describes the feedback structure and explains the main reinforcing and balancing loops. Section 5 discusses the policy implications and leverage points, and Section 6 concludes with the main findings, limitations, and directions for future simulation research.

2. Literature review

Youth unemployment is a long-standing and multifaceted problem that affects both individuals and societies. It reduces productivity, slows economic growth, and increases social and political pressures. Researchers have examined its causes and consequences from many perspectives, including economic, demographic, institutional, and behavioral. This section summarizes key insights from these studies and highlights the gaps that motivate the present system dynamics approach.

Many studies link youth unemployment to the changes in macroeconomic conditions, labor demand, and institutional arrangements. In the Euro Area, shifts in aggregate demand and in wage-setting mechanisms account for much of the variation in unemployment rates, particularly during economic crises (Charalampidis, 2020). Labor-market rigidities, such as high minimum wages or strong employment protection for older workers, can impede the entry of young people into the workforce (Speckesser et al., 2019).

Personal characteristics also influence employment outcomes. Research shows that lower self-esteem, weak motivation, or an external locus of control during adolescence increase the risk of early school leaving and unemployment (Mendolia, 2015). Similarly, employers' hiring preferences are shaped by applicants' work histories. Long unemployment spells reduce

interview callbacks, and younger or much older candidates often face implicit age bias (Farber, 2019). The same study showed that both younger and older applicants were less likely to be called back than those in middle age. Interestingly, even applicants who were already employed received fewer callbacks, possibly because employers assumed they would be harder or more expensive to hire.

Technological change adds another layer of complexity. Automation and artificial intelligence are replacing routine tasks and reshaping job structures. Workers in highly automatable occupations experience longer unemployment spells and wage penalties when re-employed (Schmidpeter and Winter-Ebmer, 2021; Nazareno, 2021). These long-term trends increase the need for flexible training and re-skilling programs.

The connection between education systems and labor-market outcomes is central to understanding youth unemployment. Skill mismatch and overqualification are recurring themes in both developed and developing economies. When education systems expand without aligning programs with market needs, graduates often struggle to find suitable employment. This educational inflation creates a cycle in which young people pursue more degrees to improve their chances, even when labor demand is stagnant (Vedder et al., 2013; Yokoyama et al., 2024).

Cross-country evidence shows that countries with stronger vocational and work-based training systems tend to have lower youth unemployment rates. For example, apprenticeship programs in Germany and Austria improve school-to-work transitions by combining academic and practical training (Cahuc and Hervelin, 2024; Cefalo, 2024). In contrast, systems with weak vocational pathways, such as in the United Kingdom, experience persistent youth unemployment and underemployment (Maguire, 2020).

In Iran, the mismatch between education and employment is a major driver of youth joblessness. Rapid expansion of universities since the 1990s has produced many graduates, but the labor market has not generated enough high-skill jobs to absorb them (Salehi-Isfahani, 2011). Studies also show that fields of study are often poorly aligned with industry demand, leading to both unemployment and underemployment among educated youth (Rafiei and Van Dijk, 2025). These patterns demonstrate that education policy and labor-market structure must be analyzed as interconnected systems.

Governments and international organizations have tested many policy tools to reduce youth unemployment. Active Labor Market Policies (ALMPs), such as job training, wage subsidies, and job creation programs, aim to increase employability and stimulate hiring. Evidence from European countries suggests that wage subsidies are often the most effective for young workers,

while training programs produce mixed results (Speckesser et al., 2019). Similarly, unemployment insurance and income-support schemes can stabilize consumption during downturns, indirectly supporting job creation (Kekre, 2023).

In developing economies, policies must also address structural constraints, including informality and limited fiscal space. In Iran, international sanctions have reduced foreign investment, weakened private-sector growth, and increased reliance on informal employment (Kelishomi and Nisticò, 2022; Kelishomi and Nisticò, 2024). Government programs to promote youth employment, such as subsidized public hiring or entrepreneurship initiatives, have provided temporary benefits but have not altered the underlying structure of the labor market. As a result, informal employment continues to serve as an absorbing buffer, providing income without long-term security or productivity gains.

Much of the youth unemployment literature focuses on Europe and North America, leaving fewer studies on the Middle East and North Africa (MENA). Yet the problem is particularly severe in this region, where demographic pressures and limited private-sector diversification restrict job creation. Regional studies by the International Labor Organization (ILO, 2022) highlight persistent skill mismatches, informal employment, and gender disparities in labor participation. For example, Egypt, Jordan, and Tunisia face similar patterns of educational expansion without corresponding labor-market absorption. Comparing these contexts with Iran helps to understand how structural and behavioral feedback can lead to persistent unemployment across the Global South.

Researchers have applied several analytical methods to study the dynamics of unemployment. Econometric and time-series models are commonly used to quantify relationships among macroeconomic indicators such as GDP, inflation, and unemployment (Charalampidis, 2020). Micro-level studies rely on surveys and audits to analyze individual job-search behavior and employer decisions (Farber, 2019). While these methods provide valuable evidence, they often assume linear and one-directional causality, overlooking delayed or feedback-driven interactions.

SD offers an alternative approach. It emphasizes circular causality and captures the effects of feedback loops and time delays. SD has been widely used in economics, education, and health to understand complex social problems (Jo et al., 2023; Sterman, 2002). However, few studies apply SD to labor-market analysis in developing countries. The existing literature, therefore, provides rich empirical insights but lacks an integrated framework that connects structural and behavioral mechanisms within a dynamic system.

Despite the breadth of research, most studies analyze youth unemployment using partial or static models that cannot capture its cumulative and feedback-driven nature. These approaches underestimate how education policies, labor-market structures, and macroeconomic conditions interact over time. They also pay limited attention to informal employment and sanctions, which are critical in Iran's case. This study fills these gaps by developing a qualitative system dynamics model that integrates endogenous feedbacks and exogenous shocks into a single conceptual framework. The model explains why conventional interventions often produce short-term improvements but fail to alter long-term trends in unemployment, and identifies leverage points at which policy changes can achieve more sustainable results.

3. Methodological framework

SD provides a powerful approach for analyzing how complex social and economic systems evolve over time. It has been widely applied to problems that involve feedback, delay, and policy resistance. Unlike econometric models that estimate static cause-and-effect relationships, SD represents circular causality, the idea that cause and effect reinforce or balance each other through feedback loops and time delays. This feature allows researchers to investigate how structures within a system generate observed patterns of behavior rather than simply correlating variables. It can also explain why well-intentioned policies sometimes produce counterintuitive or temporary outcomes.

3.1. The system dynamics perspective and its relevance

Youth unemployment exhibits the type of complexity that SD is designed to address. It is shaped by multiple interacting subsystems that evolve together over time. These subsystems include reinforcing mechanisms, such as educational expansion and job-seeking behavior, as well as balancing mechanisms, such as policy interventions or demographic shifts. Simple regression or equilibrium models cannot adequately capture these processes, because they ignore how changes in one part of the system propagate through feedback channels and produce delayed or counterintuitive outcomes. The SD approach provides a structured way to represent these interconnections, trace their implications, and identify points where targeted interventions can produce systemic change.

3.2. Formulation of the dynamic hypothesis

Formulating a dynamic hypothesis is a central step in developing a system dynamics model. It

serves as a working theory that explains how the system structure generates its observed behavior over time. In this study, the dynamic hypotheses describe the feedback mechanisms that sustain high youth unemployment in Iran despite recurrent policy interventions. Each hypothesis is grounded in empirical evidence, theoretical reasoning, and expert insight, and together they guide the construction of the CLD presented in Section 4.

In this study, the CLD was developed around three interrelated dynamic hypotheses that together explain the persistence of youth unemployment in Iran.

Hypothesis 1 – Skill mismatch and educational inflation

A reinforcing feedback mechanism connects the rapid expansion of university education with the labor market's limited ability to absorb graduates. As the number of graduates grows faster than job creation in the formal sector, the mismatch between qualifications and available employment opportunities widens. Over time, the declining labor-market value of academic credentials encourages even more young people to remain in higher education or to pursue additional degrees, further delaying their entry into the workforce. This behavior intensifies educational inflation, increases the pool of job seekers, and strengthens the feedback loop between unemployment and higher education enrollment. The result is a self-reinforcing dynamic that perpetuates youth unemployment despite rising educational attainment.

Hypothesis 2 – Labor-force exit and hidden unemployment

Persistent job search failure and repeated rejection discourage many young job seekers, leading them to withdraw from active participation in the labor market. Some stop looking for work altogether, while others seek opportunities abroad. These behaviors reduce the official unemployment rate statistically but conceal a growing pool of underutilized human capital. The apparent short-term improvement in unemployment figures thus masks deeper structural weaknesses in labor-force participation. Over time, this process creates a hidden unemployment problem, weakens domestic productivity, and erodes economic resilience. The loop reflects a balancing mechanism that appears stabilizing on the surface but actually contributes to long-term economic stagnation.

Hypothesis 3 – Sanctions and labor-market segmentation

External shocks, particularly international sanctions, exert a strong exogenous influence on Iran's economic system. Sanctions restrict access to foreign investment, limit export revenues,

and suppress aggregate demand. Reduced business activity lowers the need for labor, constraining formal job creation and widening the gap between labor supply and demand. Consequently, many young people are pushed into informal and insecure employment, thereby weakening overall productivity and perpetuating labor-market segmentation. This process interacts with the other two feedback structures: it reinforces the skill-mismatch loop by reducing demand for skilled labor and amplifies the labor-force exit mechanism by discouraging job seekers. The combined effect deepens the structural persistence of youth unemployment.

These three dynamic hypotheses form the conceptual backbone of the model. Together, they portray youth unemployment in Iran as a path-dependent system shaped by reinforcing and balancing feedback loops, delayed effects, and strong interactions between endogenous behavior and exogenous shocks. The hypotheses collectively illustrate why simple or isolated policy actions are insufficient to resolve the issue. Section 4 presents the CLD, which visually represents these interconnections and clarifies how the identified feedback mechanisms interact over time.

3.3. Definition of variables and relationships

The development of the qualitative system dynamics model began with the identification and definition of the key variables, system boundaries, and causal relationships. The variables were classified either as endogenous, those shaped by internal system behavior, or exogenous, representing external forces that influence the system. Each variable was selected through an iterative process that triangulated evidence from three sources: empirical studies and policy reports, theoretical reasoning from labor economics and human capital theory, and expert consultations to ensure contextual relevance and logical coherence.

To enhance clarity and support future simulation work, Table 1 presents each variable alongside its classification, conceptual definition, associated feedback loops within the CLD, and suggested operational indicators. The inclusion of loop references helps readers trace how each variable functions dynamically within the model. Operationalization notes offer guidance on how these variables might be measured or approximated in future quantitative models, thereby bridging the qualitative framework with empirical analysis.

Table 1. Principal variables of the qualitative system dynamics model and their classifications

Variable	Type	Description	Loop Ref.	Operationalization
Youth Unemployment Rate	E	Share of youth (15–24) in the labor force who are unemployed.	All loops	Labor force survey data; ILO definitions
Youth Labor Supply	E	Number of youth actively seeking employment.	R1, R3	Labor force participation rate; census data
Job Creation Rate (Youth)	E	Rate of new job openings for youth.	R3, B3	Employment statistics; firm-level hiring data
Number of Unemployed Youth	E	Total unemployed youth aged 15–24.	R1, R4	National unemployment registry; survey data
Formal Employment Capacity	E	Ability of the formal sector to absorb youth labor.	R3, B3	Public/private sector employment data
Informal Employment Capacity	E	Extent of informal sector absorption of youth labor.	R2, B4	Informal employment share: household surveys
Higher Education Enrollment	E	Rate of youth entering post-secondary education.	R1, R5	Enrollment statistics; Ministry of Education reports
Deferred Labor Market Entry	E	Delay in job search due to continued education.	R1	Age at first job; average graduation-to-employment gap
Overqualification	E	Holding credentials exceeding job requirements.	R5	Qualification-job match surveys; employer feedback
Emigration of Skilled Youth	E	Migration of educated youth seeking better jobs abroad.	R6	Emigration records; visa application data
Household Consumption	E	Aggregate household spending affecting labor demand.	R3, R7	Household expenditure surveys; GDP components
Human Capital	E	Accumulated skills and experience of youth.	R2, R4	Education level; work experience; skill assessments
Skill Mismatch	E	Misalignment between youth skills and job requirements.	R1, R5	Employer surveys; job vacancy analysis
Job Search Frustration	E	Discouragement from repeated job search failures.	B1	Survey data on job search duration and dropout rates
Informal Job Acceptance	E	Youth willingness to accept informal work.	R2, B4	Informal employment entry rates; survey responses
Education Attainment Level	X	Highest formal education level completed.	R1, R5	Census data; education ministry records
Vocational/Technical Training	X	Access to skill-based non-academic training.	B5	Enrollment in vocational programs; training completion
Youth Labor Size	X	Total number of youth entering the labor force.	R1, R3	Demographic data; labor force projections
Economic Growth (GDP per capita)	X	Overall economic performance affects job creation.	R3	National accounts; GDP growth rate
Government Spending on Youth Employment	X	Fiscal allocation to youth employment programs.	B3, B5	Budget reports; program evaluations
Labor Market Regulations	X	Rules governing hiring, firing, and wages.	B6	Labor law indices; World Bank Doing Business reports
Wage Subsidies / Employment Incentives	X	Financial incentives to promote youth hiring.	B5	Subsidy program data; employer uptake rates
Public Sector Hiring Capacity	X	The public sector's ability to absorb unemployed youth.	B3	Government employment statistics
International Sanctions	X	External constraints are reducing investment and job creation.	R3, R6	Sanctions database; trade and investment indicators
Political and Social Pressure	X	Public demand for job creation or education reform.	B2, B6	Media analysis; protest frequency; policy response data

4. Causal loop diagram and feedback structure

To facilitate a deeper understanding of youth unemployment, a high-level conceptual model was developed to define the system's scope and structure.This model helps define the system's scope and structure. It makes the problem easier to grasp, particularly for readers unfamiliar with feedback systems. By focusing on key areas instead of detailed loops, the model simplifies complex ideas and improves clarity.

The model divides the system into three connected parts: structural drivers, behavioral mechanisms, and system outcomes. Structural drivers include broader conditions such as education policies, population trends, and labor market changes. These factors shape the contextual framework for school-to-work transitions among youth. Behavioral mechanisms are how individuals respond to these conditions. They include options such as continuing education, actively seeking employment, or informal work. These behaviors influence the overall system. The primary outcome is the youth unemployment rate, which indicates how well the system is functioning.

Overall, the conceptual model offers a strategic foundation for the CLD. Figure 1 illustrates this model .

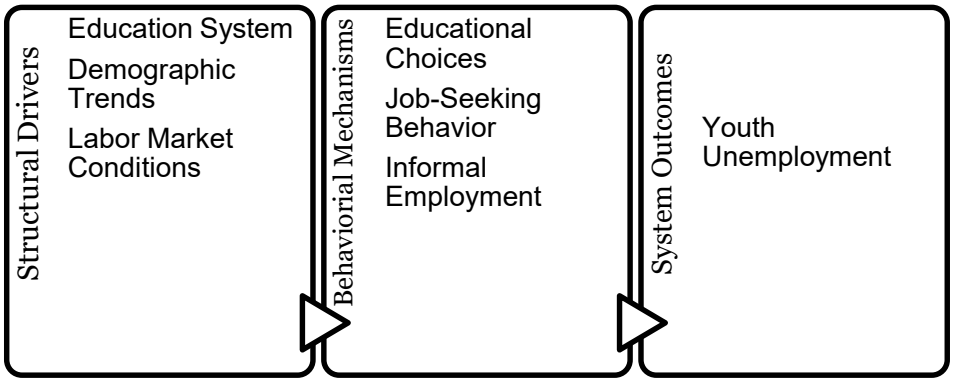

Figure 1. The conceptual model of youth unemployment dynamics

4.1. Diagram overview

Figure 2 depicts the CLD, which captures how different components of Iran's youth unemployment system are connected and influence one another over time. The diagram begins with external and structural factors, such as population pressure, education policies, and international sanctions, and traces how these forces affect job creation, informal work, and other labor-market behaviors.

For clarity, the CLD is divided into two visual components: reinforcing feedback loops (Figure 3) and balancing feedback loops (Figure 4). This separation improves readability while

preserving the model's integrity and enables readers to follow the dynamic relationships described in the text.

At the center of the diagram is the youth unemployment rate, which both affects and is affected by multiple feedback loops. These loops illustrate how challenges such as an oversupply of university graduates, limited job opportunities, or skill mismatch can persist and even intensify unless systemic change occurs.

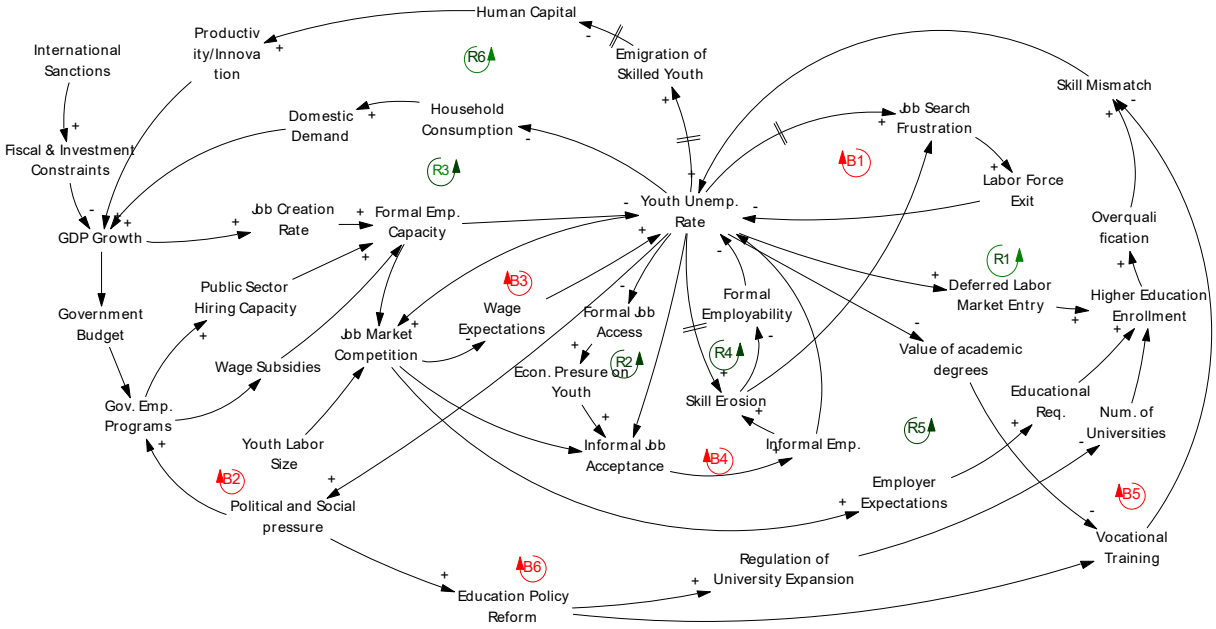

Figure 2. Overall causal loop diagram representing the feedback structure of youth unemployment in Iran

4.2. Reinforcing loops

The CLD includes several reinforcing feedback loops (labeled R1 to R6) that explain how youth unemployment can grow and persist over time. These loops demonstrate how certain problems, such as educational mismatch, informal employment, or economic stagnation, tend to feed back on themselves, exacerbating the situation unless disrupted by strong interventions.

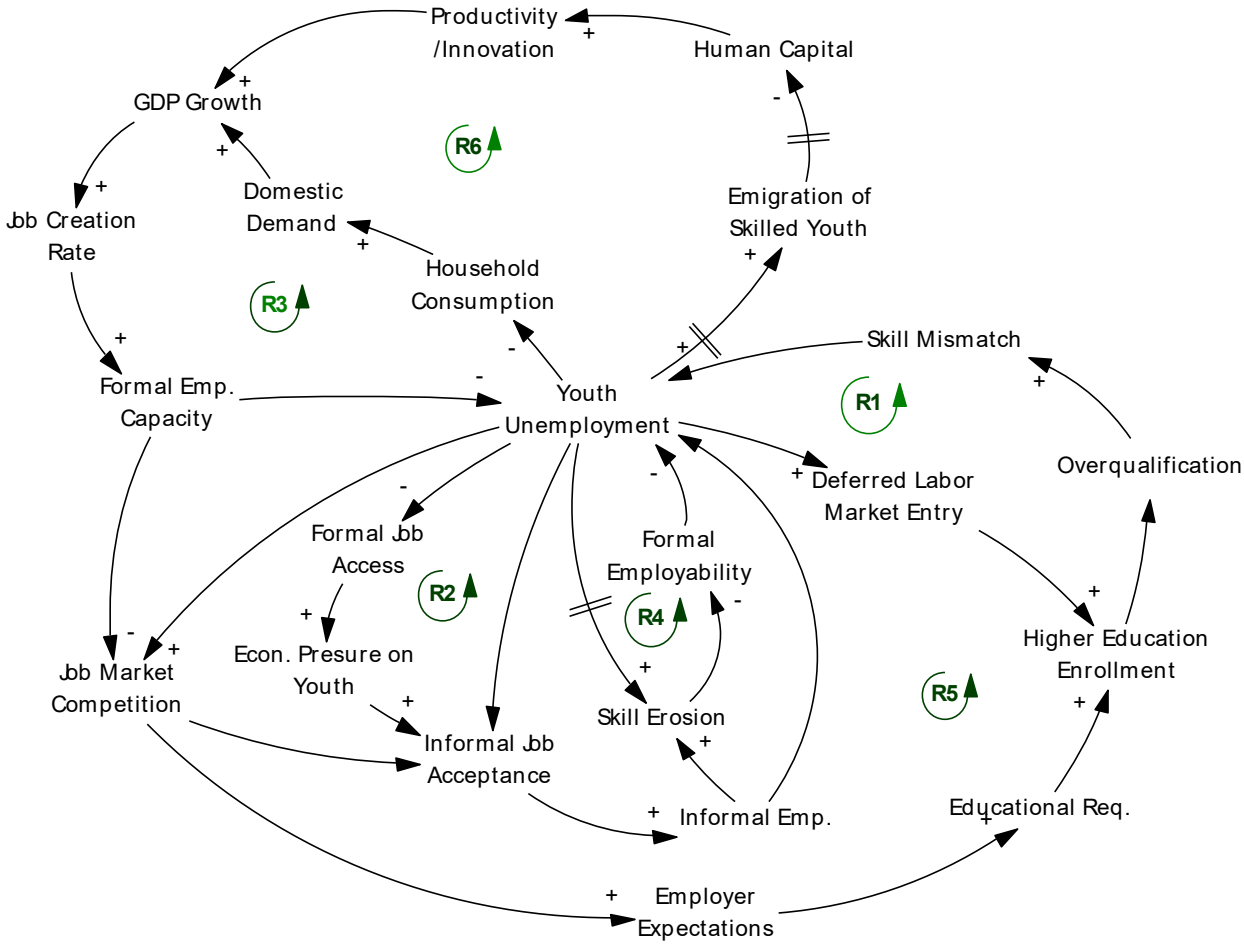

Figure 3. Reinforcing feedback loops corresponding to the mechanisms described in hypotheses 1–3.

R1 – Educational inflation loop: Many young people are encouraged to go to university, but the job market cannot absorb all the graduates. Because there aren't enough suitable jobs, their degrees often don't help them get employed. As a result, more youth decide to stay in school longer or get more degrees, hoping this will improve their chances, yet this only increases the number of unemployed graduates over time.

R2 – Informal employment trap loop: When formal jobs are scarce, many young people take informal or low-quality work. These jobs often lack security and do not build useful skills. This hurts their chances of finding better jobs later, making it harder to move into stable employment. As a result, they remain excluded from the formal economy.

R3 – Sanction-Driven economic contraction loop: International sanctions reduce foreign investment and government revenues, slowing economic growth. This weakens job creation, especially in the formal sector. As unemployment rises, household spending drops, which further reduces demand and job opportunities, creating a downward spiral.

R4 – Human capital erosion loop: Long periods of unemployment can cause young people to lose motivation and relevant skills. The longer they remain out of work, the harder it becomes to get hired. Over time, they become more disconnected from the job market.

R5 – Credentialism loop: When many people apply for the same job, employers raise degree requirements—even for basic roles. This pushes more young people to get extra qualifications, even when they are not needed. As a result, overqualification increases. The gap between skills and job needs grows wider.

R6 – Migration disincentive loop: Because jobs are limited, many skilled young people move abroad to find better opportunities. This reduces the country's human capital. With fewer skilled workers, it becomes harder to create new jobs at home. As a result, unemployment gets worse for those who stay.

4.3. Balancing feedback loops

Besides the reinforcing loops that worsen unemployment, the system also includes several balancing loops (B1 to B6). These loops can reduce unemployment or slow it down, but many of them only offer temporary solutions or hide deeper problems.

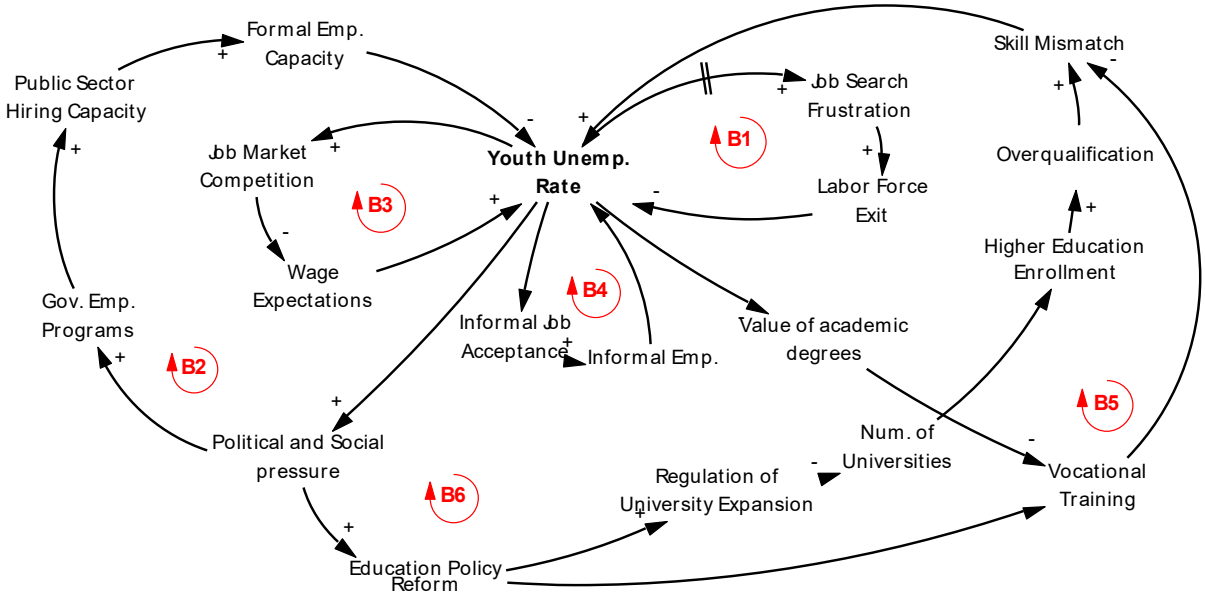

Figure 4. Balancing feedback loops, illustrating stabilizing mechanisms, and short-term adjustments.

B1 – Discouraged worker loop: When young people cannot find jobs for a long time, some stop looking. This means they are no longer counted as unemployed. But the problem still exists—it is just less visible. Over time, repeated rejections lead to discouragement. This delay makes it even harder to rejoin the job market.

B2 – Public sector employment buffer loop: As youth unemployment rises, people expect the government to create more public jobs. This may reduce unemployment in the short term, but due to budget limits and slow processes, it often cannot continue for long and solve the core problems.

B3 – Wage adjustment loop: In theory, when there are many unemployed people, they may lower their wage expectations to find work. This could help employers hire more youth. But in Iran, this loop is weak due to wage laws, labor market rules, and cultural customs that protect older workers.

B4 – Informal employment adjustment loop: Some unemployed youth turn to informal jobs, which helps reduce the number of officially unemployed. However, these jobs often have low pay and no security. While it looks like a short-term solution, it keeps people in unstable situations.

B5 – Vocational realignment loop: As more graduates remain unemployed, some young people may choose technical or vocational training rather than university degrees. This can help match their skills with real job needs and improve employability. However, this shift is often slow due to cultural preferences for academic education. In Iran, cultural bias toward academic credentials delays this shift.

B6 - Political feedback into education reform: When youth unemployment stays high for a long time, it creates public and political pressure for education reform. This may lead to changes in university policies, better training programs, or limits on unnecessary degree expansion. These changes take time but can help reduce the mismatch between education and jobs in the long run. Although the effects of this loop are often delayed, due to bureaucratic inertia and the cyclical nature of political processes, it plays a crucial role in driving long-term structural adjustments within the education system. Furthermore, this balancing mechanism helps mitigate the reinforcing dynamics of educational inflation (R1) and credentialism (R5), which might otherwise persist unchecked in the absence of robust regulatory intervention.

5. Discussion and policy implications

The CLD offers more than just an explanation. It helps identify where and how to intervene in the system. By understanding the feedback loops, we can see why youth unemployment in Iran remains high and why many policies fail to make lasting change.

This section analyzes the dynamic behavior captured in the CLD by interpreting systemic feedback mechanisms and identifying high-leverage intervention points. The goal is to bridge

the gap between conceptual insights and practical policy design by examining how reinforcing and balancing loops interact under various structural and behavioral conditions. The implications are intended to guide policymakers toward comprehensive strategies that are robust under constraints such as economic sanctions.

5.1. Interpretation of system behavior

The CLD illustrates a structurally persistent system in which youth unemployment in Iran is driven by reinforcing feedback loops that dominate over balancing mechanisms. These dynamics involve nonlinear relationships, time delays, and self-reinforcing cycles that sustain high unemployment levels despite policy efforts.

The main reinforcing loops—R1 (Educational Inflation), R2 (Informal Employment Trap), R3 (Sanction-Driven Contraction), and R5 (Credentialism)—create a system with strong path dependency. In loop R1, the expansion of higher education, combined with the labor market's limited capacity to absorb graduates, leads to overqualification and delays in entering the workforce. This effect is reinforced by R5, where employers increase academic requirements, raising the demand for formal credentials without improving job matching. At the same time, R2 pushes young job seekers into informal employment, which offers little stability or opportunity for advancement. The longer youth remain in this sector, the more their skills deteriorate, reducing their future employability, as captured in R4.

External constraints, particularly economic sanctions (R3), further reduce labor demand by discouraging investment, limiting government spending, and restricting private sector growth. These factors reduce formal job opportunities, forcing many young people into unstable employment and reinforcing the unemployment cycle.

Although balancing loops, such as B2 (Public Sector Employment) and B5 (Vocational Realignment), provide some counteracting forces, their effects are often limited by institutional inertia, budgetary constraints, and a strong social preference for academic rather than vocational education. Other balancing mechanisms, like B1 (Discouraged Worker Effect) and B4 (Informal Employment Adjustment), reduce the visible rate of unemployment but conceal deeper structural issues by encouraging labor market withdrawal or informal absorption.

As a result, the system shows strong resistance to simple or isolated policy interventions. Policy measures that do not address the structural links, particularly those between education and employment, and on the demand side of the labor market, tend to be absorbed by the system without lasting impact. Therefore, long-term behavioral changes and comprehensive structural

reforms are necessary to weaken the reinforcing loops and move the system toward a more balanced state.

5.2. Policy implications

Addressing youth unemployment in Iran, therefore, requires system-oriented policies that consider the feedback effects and time delays embedded in the system. Based on the model's insights, several policy implications emerge.

First, education policy should prioritize skill alignment rather than expansion alone. Developing stronger connections between universities, vocational institutions, and industry can reduce the skill mismatch. Encouraging technical and applied education, internships, and cooperative programs would also help balance the reinforcing loop that links educational expansion with unemployment.

Second, labor-market policies should aim to enhance employability and encourage active participation. Programs that improve job-search support, career counseling, and training for high-demand skills can prevent discouragement and labor-force withdrawal. Policies that target hidden unemployment should recognize that inactivity or informal work often results from structural barriers rather than a lack of motivation.

Third, macroeconomic and industrial policies must strengthen formal job creation. Stimulating private-sector investment, supporting small and medium-sized enterprises, and improving business conditions are essential for expanding productive employment. Under conditions of external constraint, such as sanctions, domestic diversification and import substitution can partially offset the loss of external demand. Policies designed to stabilize aggregate demand, such as targeted fiscal spending and local procurement, can reduce the reinforcing effects of macroeconomic contraction.

Fourth, public-sector employment policies should be redesigned to avoid short-term balancing effects that ultimately reinforce structural problems. Instead of relying on temporary hiring as a buffer against unemployment, the public sector should focus on facilitating entrepreneurship, labor-market transparency, and skill matching through better information systems.

Finally, proactive strategies for migration management and diaspora engagement can mitigate the long-term negative impacts of skilled emigration. By facilitating knowledge transfer, remote collaboration, and investment channels, states can partially compensate for domestic human capital losses and foster continued innovation.

5.3. Identifying leverage points

The CLD also helps identify potential leverage points, areas where interventions can produce the largest systemic impact. Strengthening the connection between education and labor demand can weaken the reinforcing loop of educational inflation. Policies that improve the efficiency of labor-market information systems can shorten the delay between job creation and job matching, reducing policy resistance. At the macro level, stabilizing aggregate demand through consistent fiscal and monetary coordination can dampen the reinforcing impact of sanctions-related contractions.

These leverage points correspond to structural rather than symptomatic interventions, meaning that they target the feedbacks generating the problem rather than its outcomes. Effective policies, therefore, require simultaneous coordination across education, labor-market, and macroeconomic domains, supported by continuous monitoring and adaptive learning.

5.4. Directions for future research

To enhance the policy relevance and analytical rigor of the model, future research should pursue several important extensions. First, translating the current CLD into a quantitative stock-and-flow simulation model would enable scenario analysis, parameter sensitivity testing, and forecasting of policy impacts. Such a model should pay particular attention to incorporating time delays in transitions from education to employment, as well as the lagged effects of macroeconomic adjustments, especially under conditions of international sanctions.

Second, introducing disaggregation and behavioral microfoundations would significantly improve the model's realism. Incorporating demographic and sectoral heterogeneity, such as distinctions by gender, region, and industry, would allow for a more nuanced understanding of how different groups are affected by policy interventions. Additionally, embedding behavioral sub-models that account for individual expectations, risk tolerance, and cultural norms, particularly in relation to vocational training and informal employment, would enhance the explanatory capacity of the model.

Third, empirical calibration and validation are essential for improving credibility and practical application. Despite constraints on data availability, existing sources, such as historical labor market statistics, panel surveys, and administrative datasets, can support parameter estimation. Engaging in participatory modeling with key stakeholders, including government

agencies, employers, and youth, would further enhance the model's accuracy and relevance by ensuring that it reflects on-the-ground realities and institutional perspectives.

By extending the current framework in these directions, researchers can move beyond conceptual analysis toward the development of simulation-based decision support tools. Such tools would offer greater precision and credibility in guiding the design and evaluation of youth labor market policies in Iran.

6. Conclusion

This study explored the problem of youth unemployment in Iran using a qualitative SD approach. It identified how education, labor market behavior, and economic conditions interact through feedback mechanisms. These interactions explain why youth unemployment remains high despite many policy attempts.

The CLD identified six reinforcing feedback loops that fall into three main groups: skill mismatch and educational inflation; labor-force exit and hidden unemployment; and Sanctions and labor-market segmentation. Together, these loops create a cycle that perpetuates youth unemployment. They also explain why simple, one-dimensional policies have not produced lasting results.

From a policy perspective, the findings identify that real progress requires addressing the system's feedback structures. Short-term solutions, such as temporary government hiring or wage subsidies, may provide quick relief but do not change the system's long-term behavior. Sustainable improvement needs coordinated actions that target the root causes of these feedbacks.

Policies should better connect education with labor market needs, encourage private-sector job creation, and reduce the impact of external shocks. Over time, such coordinated strategies can reshape the system and lower resistance to policy changes.

The qualitative model developed in this study also serves as a foundation for future quantitative work. Using real data to calibrate the model would allow simulations of different policy options and help predict their long-term effects. Future studies could also integrate factors such as gender differences, technological change, and regional inequality to improve the model's relevance.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Modeling Platform Business Growth Using Open Innovation and Agent-Based Approach

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ABSTRACT

Open innovation is increasingly recognized as a critical factor in the growth of platform businesses, while agent-based modeling offers a practical approach to exploring development scenarios due to the complexity and dynamic nature of these businesses. In this study, agents are classified as service receivers or service providers. Service receivers are further classified as interactive/analytical or normal/indifferent, whereas service providers are identified as active/interactive or normal/indifferent. These classifications account for all dimensions of participation and the platform's operational environment.

Platform–agent interactions are modeled using attraction, facilitation, and adaptation mechanisms, whereas agent–agent interactions are defined by positive or negative impacts. The model was designed using the Taguchi experimental design method (Qualitek software) to generate four-level scenarios for key indicators, including Absorptive capacity, networking and network management, knowledge and technical capacity, and collaborative capability. The scenarios were then simulated using AnyLogic.

Results indicate that the optimal levels for attraction, networking, and technical capacity correspond to the fourth level, while the third level is optimal for collaborative capability. The simulation further demonstrates that implementing the optimal scenario enhances overall platform performance, yielding a value of 0.957. These findings provide practical insights for managing platform-based businesses and contribute to a better understanding of how to integrate open innovation with agent-based modeling to optimize platform growth.

Keywords

Scenario, Platform Development, Open innovation, Agent-Based simulation, Businesses development.

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1. Introduction

Over the past few years, the structure of businesses has changed from traditional structures to a platform. Alstyne and Parker (2017) define platform business as a new business model that applies technology for making an interactive connection between people, organizations, and resources that results in Value creation.

Platforms play a fundamental role in connecting service providers and receivers (Rochet and Tirole, 2003), and platform businesses can create many opportunities that provide a new ground for exchanging information and services and act as a critical driver for socio-economic change (Meijerink and Keegan, 2019). It is critically important to develop an appropriate approach to building platform businesses in a highly competitive and dynamic world.

Platform development has not been properly investigated though such important issues have been explored as the nature of platform, the strategy and Dynamicsof platforms (Wan et al., 2017), the consequences of using platform (Gawer and Cusumano, 2014), platform leadership (Eisenmann et al., 2011), challenges and structural problems of platform (Hagiu and Wright, 2015). Moreover, Skold and Karlsson (2012) and Jagstedt and Persson (2019) argue that platform development has not been properly understood, and that further investigation is required to clarify the issue. Idea development refers to activities that lead to business development (Golembiewski, 2017). Among the things that may help platform businesses to achieve their development is open innovation.

Open innovation enables platform businesses to enhance their competences. It is evident that, given the context and activities of platform businesses, open innovation may be an effective solution to various challenges. Open innovation aims to leverage others' findings in innovation processes through formal or informal channels (Schwab et al., 2011). Huizingh (2011) believes that open innovation initiatives are processes taken by managers for making decisions about the time, way, aim, and method of cooperating with other partners.

Open innovation is now evidently playing a significant role in developing platform businesses, but A precise model is needed to be designed. Simulation method is a highly effective toolfor designing the model and identifying optimal scenarios to improve the business process (Keller, 2004). Given the system's complexity, this study employs an agent-based simulation as a practical solution. This method is a useful approach to modeling complex systems and phenomena, as it enables designers to model the system by identifying the rules governing agent behavior and to analyze and assess the behavior of the whole system as the model output. In agent-based modeling, researchers can simulate their optimal model, Conduct

experiments on the designed model, present experts' opinions in the form of different scenarios (Billari, 2015; Tylor, 2014; Silverman et al., 2013), and at the end, choose the best solution from among the proposed scenarios and implement it.

Given the rapid growth and strategic significance of platform businesses, understanding how to achieve sustainable, value-creating development remains a major challenge, owing to the complexity and dynamism of these markets. This study addresses this challenge by integrating open innovation with agent-based modeling, providing both theoretical insights and practical guidance for platform managers. The primary objective of the research is to identify and evaluate platform development scenarios and select the optimal strategy that maximizes value creation. To achieve this, the research procedure comprises three main steps: first, platform development scenarios are defined through open innovation; second, these scenarios are formulated and analyzed in AnyLogic; and third, the modeling method is applied to select the scenario with the highest overall desirability. The findings of this study contribute to a better understanding of platform development processes and offer actionable insights for managers seeking to optimize performance and growth in platform-based businesses.

2. Literature review and hypothesis development

2.1. Platform development

Platform businesses are among the business models that have attracted the attention of many entrepreneurs. Platform is a broad, flexible concept; that is, different things for specific applications can be considered as a platform. A platform is defined as a set of hardware, software, and operating systems that the platform itself is a member of the software (Jovanovic et al., 2022). Platforms provide the rules and infrastructures that facilitate interactions and reduce transaction costs and inefficiencies. Moreover, platforms enable us to communicate with people who are not close to us and to overcome the obstacles of previous years (Aloisi, 2016). They enable a two-way or multi-way communication with a specific goal (Huotari and Ritala, 2017).

Since the number of platform businesses has increased over the last few decades (Yablonsky, 2018), going towards developing platform businesses is imperative. Business development mechanism consists of a set of solutions that facilitate business development and make the ground for entrepreneurs to improve their competitive position in the market.

To determine the platform development framework, first identify and conceptualize the requirements, then design a model to guide the platform's development. As such, businesses

like platform businesses operate in dynamic markets, they face serious challenges for achieving success, and innovation can be the main solution. Simple innovation and established research patterns, with closed boundaries on innovation and foreign knowledge in the current context, would not be sufficient. A proposed model in this regard is open innovation (Bigliardi and Dormio, 2012). It can also be said that research such as Mady et al. (2025), Nagy et al. (2025), Li et al. (2025), Topalova et al. (2024), Raco et al. (2024) is mentioned in regard to Platform development.

2.2. Open innovation

The increasing changes in business and competitiveness have led people to pay greater attention to the role of innovation in business development. In this regard, open innovation was proposed in the early 2000s that is now considered a new innovation paradigm (Virlee et al., 2015).

Today, applying open innovation is a must. It is the main driver of development and creation of competitiveness, and a phenomenon that gains importance for platform businesses increasingly. Open innovation is now increasingly used in many modern industries, such as software (Henkel, 2006; Pykalainen, 2007; West and Gallagher, 2006) and electronics (Chesbrough, 200ך). It originates from a way of thinking and refers to businesses' simultaneous use of outward and inward knowledge flows to strengthen internal innovation and external use (Chesbrough, 2017). The main logic of open innovation is managing the inbound mainstream (inbound open innovation) and outbound (outbound open innovation), information, knowledge, and technology, skills, and infrastructures for improving the internal innovation and maximizing the use of external innovation in all types of businesses (Cheng and Shiu, 2015). Chesbrough (2006) believes that open innovation is the purposeful use of incoming (internal) and outgoing (external) flows of knowledge for accelerating innovation in the market and as well as increasing the use of internal knowledge in external markets. These attitudes towards innovation remove the clear boundary between a company and its environment, so its clear and hard boundary fades (Chesbrough, 2006). It is noteworthy that open innovation is an overarching subject and covers a wide range of concepts, but all structures can not necessarily be adapted to the open innovation. So, applying open innovation to businesses is far more than applying a simple management tool, but it requires adapting the business model with the adopted strategy. Considering the aim of this research that focuses on the developing platform businesses and also considering the nature of open innovation, the framework used in this study is agent-based modeling. The aim is to present a comprehensive and accurate perspective for

improving decision-making and planning for the development of platforms and boosting their performance. It can also be said that research such as Sá et al. (2025), do Prado et al. (2025), Obradović et al. (2021), and Barlatier et al. (2023) is mentioned in regard to open innovation.

2.3. Agent-based modeling

Simulation means Replicating systems in various scenarios (Brailsford et al., 2018) and simulation techniques are very useful for identifying the alternative scenarios of improving businesses' process (Keller, 2004). Simulation models provide the opportunity of having various decisions and analyzing their results with the aim of helping managers in making their decisions. In this regard, agent-based modeling offers features suitable for simulating complex social phenomena. It models clearly producing macro-level patterns by behaviors and also the interaction of people at the micro-level. It is a bottom-up modeling approach, as it focuses on the behavior of individual objects to derive the overall model. In agent-based modeling, by using simple decision-making rules, one can describe complicated business phenomena (Epstein and Axtell, 1996). According to Crooks and Heppenstall (2012), agent-based modeling allows simulating the individual actions of various agents and assess the behavior and results of the system over time. The purpose of agent modeling is to trace interactions among agents in their virtual environment and to identify approaches that emerge from general behavioral patterns (Sawhney et al., 2003).

According to Crooks et al. (2017), the most significant components of an agent-based model are: Agents (the autonomous and independent component that have specific features, actions, and goals); the modeling space (embraces all components of a modeling system except for agents), interactions and communications between agents, environment, and agents (interactions are non-linear as the overall behavior does not equal to the sum of the behavior of all agents and the interactions are done by information exchange); the decision-making procedure of agents (based on their limited rationality); the rules about the decisions of every agent (learning or adaptation). It is worth noting that for simulating agent-based models, software such as REPAST, SWARM, MASON, NETLOG, ANYLOGIC, and JADE can be used. Each software has advantages and disadvantages and is used based on users' goals. AnyLogic was used for this study. This software has a suitable graphic environment and can be used for both agent-based models and dynamic systems, and as many users have applied the software, it has been promoted; moreover, the user can easily get output from this software. It

can also be said that research such as Rodríguez-Arias et al. (2025), Manhães et al. (2025), (Stummer, 2024), Čeh et al. (2022) is mentioned in the regard Agent-based modeling.

3. Methods

The study procedure, following the problem statement and identification of research objectives, is summarized in Figure 1. The expert population consisted of specialists in platform businesses, open innovation, and managers with practical experience in platform operations. Participants were selected through purposive sampling and snowball sampling.

Step 1: Defining agents and interactions: Agents were classified as service receivers or service providers. Service receivers were further classified as interactive/analytical or normal/indifferent, while service providers were classified as active/interactive or normal/indifferent. Interactions were modeled at two levels: Platform–agent interactions, represented through attraction, facilitation, and adaptation mechanisms. Agent–agent interactions are determined based on positive and negative impacts. The operational environment and all dimensions of participation were also defined.

Step 2: Formulating scenarios of platform development. Key development indicators for platform businesses that rely on open innovation were identified through an extensive literature review. Scenarios were designed using the Taguchi experimental design method and implemented in Qualitek software. Factors and their four levels were defined to represent various combinations of Absorptive capacity, networking and network management, knowledge and technical capacity, and collaborative capability.

Step 3: Designing the simulation model and implementing scenarios. An agent-based simulation model was developed using AnyLogic software, based on the conceptual framework of the study. Each scenario was implemented in the simulation environment, run, and its effectiveness evaluated.

Step 4: Selecting the optimal scenario: Simulation results for each scenario were analyzed using the Taguchi method in Qualitek to determine the optimal level for each development indicator. The scenario that maximized the created value metric in the platform environment was identified as the optimal scenario.

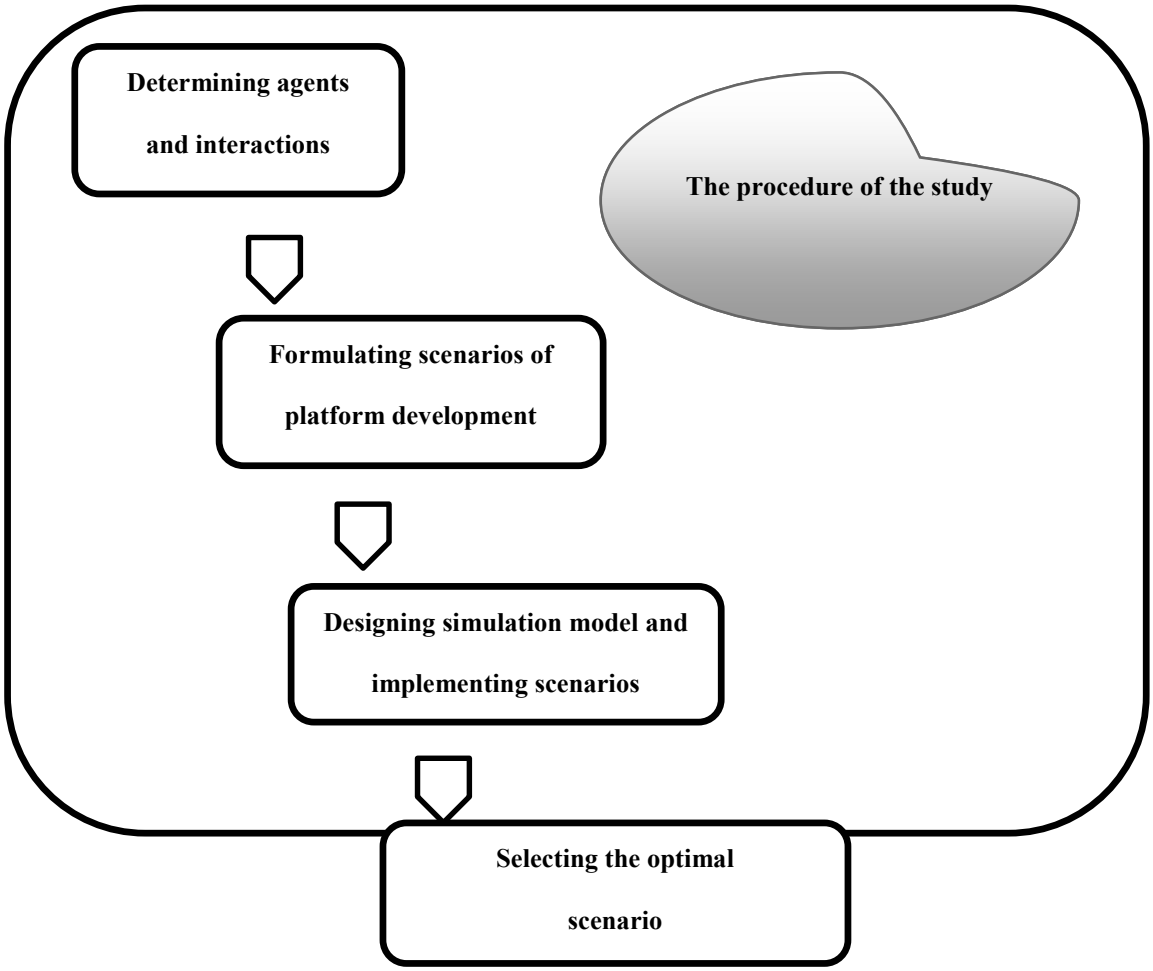

Figure 1. The procedure of the study

4. Results

4.1. Determining agents

Agents may have different roles in the model. In this study, agents served as both service receivers and service providers. Service receivers showed, based on collaborative behavior, specific behaviors in terms of information searching, responsible behavior, personal interaction, and service providers regarding collaborative behavior have specific characteristics in terms of aspects of responsible behavior, personal interaction, informational behavior, and altruistic behavior (taken from such studies as Chen and Raab, 2017; Yi and Gong, 2013). The agents are defined as follows:

- Service receivers are divided into two types of agents: “interactive and analytical service receivers” and “normal and indifferent service receivers regarding all dimensions of participation.
- Service providers are divided into “active and interactive service providers” and “normal and indifferent service providers regarding all dimensions of collaboration”.

4.2. Interaction between platform and agents

Platforms are used to enable mutual communication and facilitate interactions between service providers and recipients. So, one can say that for making interaction with agents, platforms should consider the following things (Parker et al. 2016):

- Attraction: Creating a mechanism for attracting service providers and receivers;
- Facilitation: The interactions and communication between service providers and service receivers should be facilitated.
- Adaptation: Using the information about service providers and receivers, make a useful adapting relationship between them.

4.3. Interaction between agents

Here, considering the four types of service providers and receivers defined by collaborative behavior, the relationships among the four agents are described.

- For the interaction between service providers and each other, as well as between service providers and receivers (positive/negative), favorable effects are taken into consideration.
- For the interaction between the service providers and service receivers, positive and negative effects of Opposing nature are taken into consideration.

4.4. Formulating scenarios

The Taguchi experiment design method and Qualitek software (used for Taguchi experimental design) were used for formulating scenarios. So, the final four indicators of platform business development via using open innovation were determined through deep and extensive study on theoretical foundations and research background to be Absorptive capacity, Networking and network management capacity, knowledge and technical capacity, and collaborative capability (Van Lancker et al., 2019; Lyu et al., 2019; Ibrahimov, 2018; De Oliveira et al., 2017; Cheng et al., 2016; Michelini et al., 2015; Brunswicker and Ehrenmann, 2013; Mu and Di Benedetto, 2012; Chesbrough, 2006). Considering the opinion of experts, four levels (Level 1 between 0 and 0.25, Level 2 between 0.25 and 0.50, Level 3 between 0.50 and 0.75, and Level 4 between 0.75 and 1) were determined for every indicator. The study, therefore, has four indicators with four levels for the design of Taguchi experiments. They were then entered into Qualitek software. Table 1 presents the final output of this step: the scenarios developed by the Taguchi experimental design method, comprising sixteen scenarios.

Table 1. The results of the design of Taguchi L16

Collaborative capability	Knowledge and technical capacity	Networking and network management capacity	Absorptive capacity	Scenario
0-0.25	0-0.25	0-0.25	0-0.25	1
0.25-0.50	0.25-0.50	0.25-0.50	0-0.25	2
0.50-0.75	0.50-0.75	0.50-0.75	0-0.25	3
0.75-1	0.75-1	0.75-1	0-0.25	4
0.50-0.75	0.25-0.50	0-0.25	0.25-0.50	5
0.75-1	0-0.25	0.25-0.50	0.25-0.50	6
0-0.25	0.75-1	0.50-0.75	0.25-0.50	7
0.25-0.50	0.50-0.75	0.75-1	0.25-0.50	8
0.75-1	0.50-0.75	0-0.25	0.25-0.50	9
0.50-0.75	0.75-1	0.25-0.50	0.25-0.50	10
0.25-0.50	0-0.25	0.50-0.75	0.25-0.50	11
0-0.25	0.25-0.50	0.75-1	0.25-0.50	12
0.25-0.50	0.75-1	0-0.25	0.75-1	13
0-0.25	0.50-0.75	0.25-0.50	0.75-1	14
0.75-1	0.25-0.50	0.50-0.75	0.75-1	15
0.50-0.75	0-0.25	0.75-1	0.75-1	16

As the significance of each of the platform development indicators using open innovation is different from the other one, a researcher-made questionnaire was made considering the scenarios. The questionnaires were distributed among twelve members of the expert community. The collected data were summed, defuzzified using the center-of-gravity method, and entered into Qualitek software. Variance analysis was performed, and the percentage of participation for each development indicator on the platform was determined. Finally, using the normalization method (introduced by Saaty), the importance level of each indicator was determined. Table 2 presents the weights of each indicator.

Table 2. The normalized weight of the indicators of platform development

Significance	Platform development indicators using open innovation
25.65	Absorptive capacity
22.2	Networking and network management capacity
44.95	Knowledge and technical capacity
7.2	Collaborative capability

Table 2 shows that “knowledge and technical capacity” is 44.95% important, “Absorptive capacity” is 25.65% important, “Networking and network management capacity” is 22.2% important, and “participatory capability” is 7.2% important.

4.5. Designing the conceptual model of research

Based on the explicit assumptions and the reviewed literature, a conceptual model was developed to explain the model's structure and implementation stages. Figure 2 shows the conceptual model.

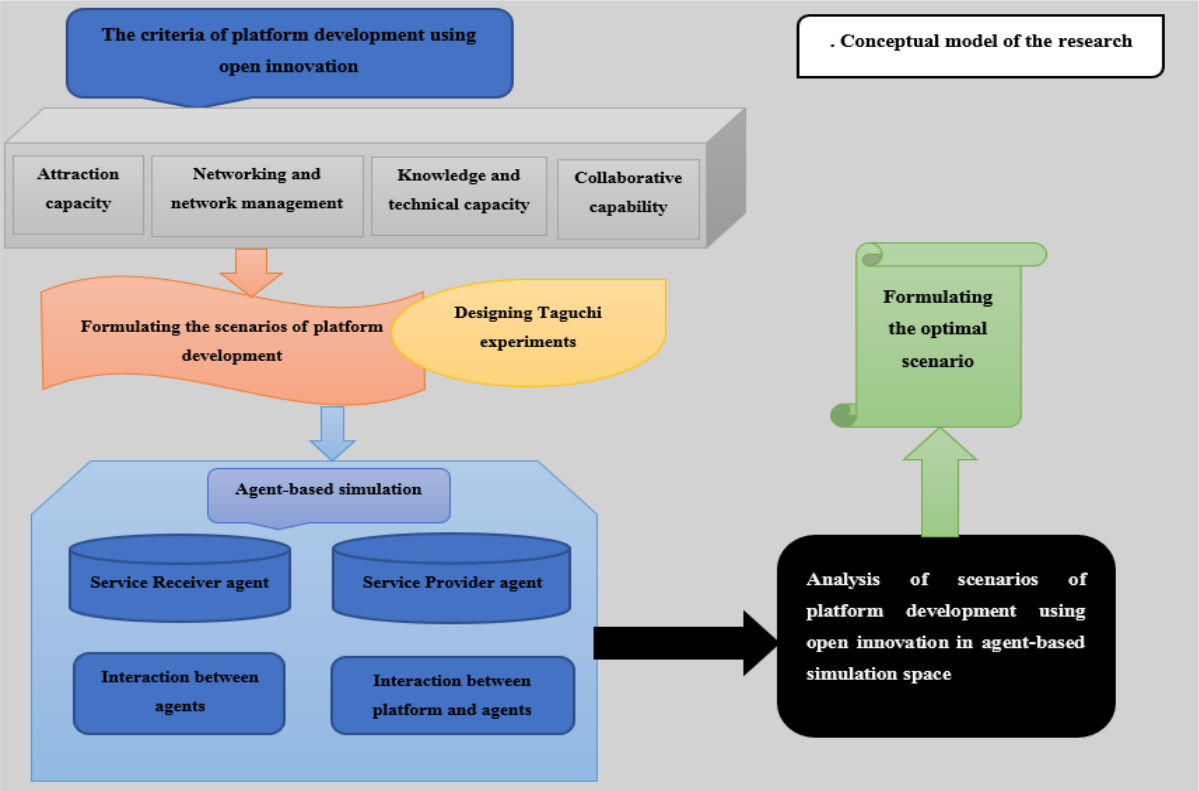

Figure 2. Conceptual model of the research

4.6. Implementing the conceptual model in the AnyLogic software

The conceptual model of this research was implemented in AnyLogic software. The unique feature of this model is its high flexibility. The modeling environment of this research is a platform, and the agents are two service providers (active and interactive; normal and indifferent across all dimensions of participation) and two service receivers (interactive and analytical; normal and indifferent across all dimensions of participation). Several factors were considered for each agent. In the next step, since the agents in the agent-based model interact and communicate with other agents and the surrounding environment, the behavior of each agent was defined in the form of a state chart. Figure 3 shows the state charts for agents that provide and receive services.

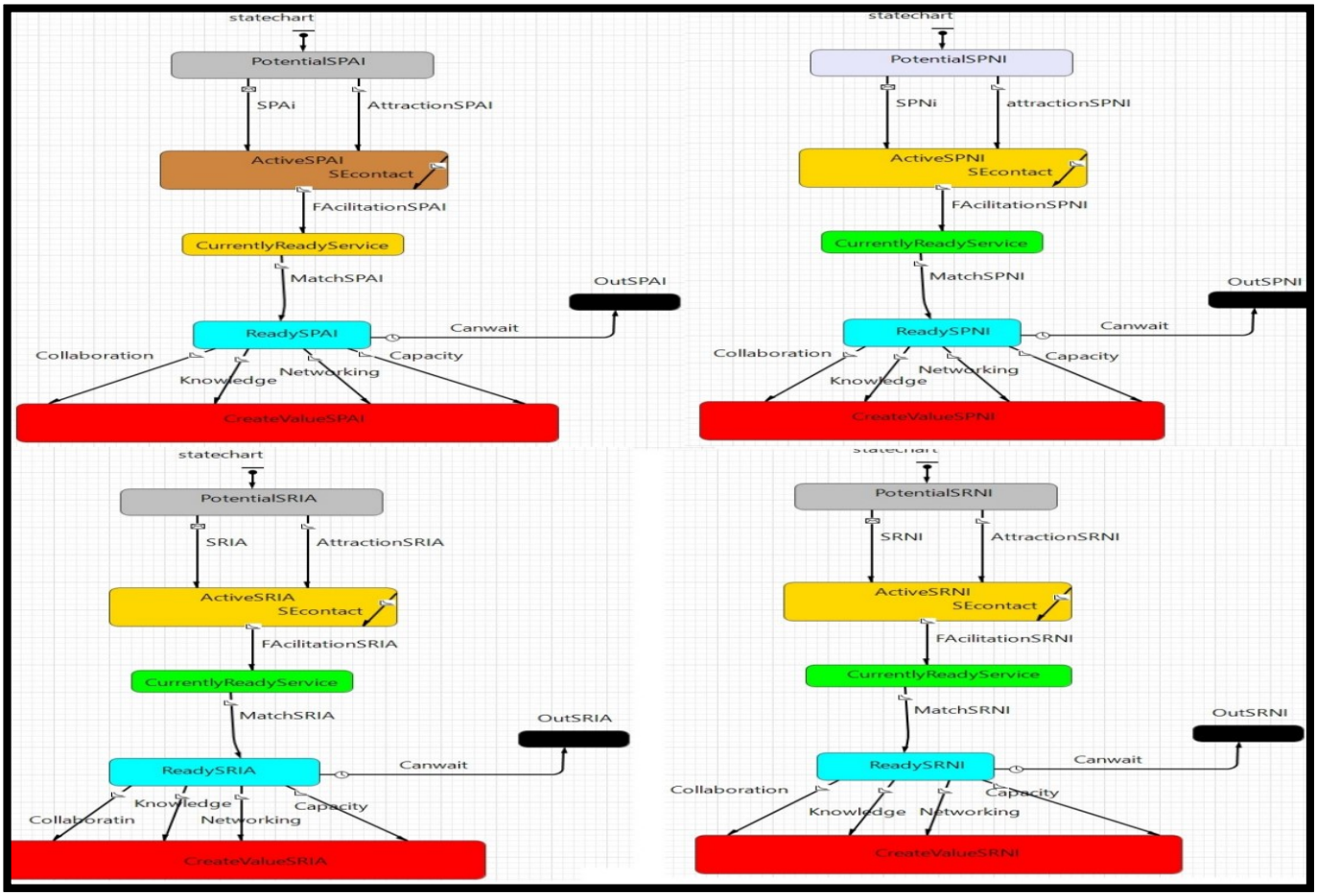

Figure 3. State chart of service provider and service receiver agents

Just before running the model and examining scenarios, the necessary settings were configured using the software's analytical tools, so the agent-based model was prepared for implementation. During the execution stage, the conditions are considered, and each scenario is investigated. After executing each of the sixteen scenarios formulated in AnyLogic and analyzing the results, the output is presented in a table. Table 3 shows the effectiveness of the scenarios.

Table 3. The effectiveness of scenarios

Percentage of created value				Scenarios of platform development
Normal and indifferent service providers regarding all dimensions of participation (SPNI)	Active and interactive service providers (SPAI)	Normal and indifferent service receivers regarding all dimensions of participation (SRNI)	Interactional and Analytic Service Receivers (SRIA)	
0.30	0.52	0.31	0.47	1
0.61	0.84	0.59	0.79	2
0.79	0.95	0.77	0.91	3
0.89	0.98	0.87	0.97	4
0.64	0.87	0.61	0.81	5
0.60	0.84	0.56	0.78	6
0.86	0.97	0.85	0.96	7

Percentage of created value				Scenarios of platform development
Normal and indifferent service providers regarding all dimensions of participation (SPNI)	Active and interactive service providers (SPAI)	Normal and indifferent service receivers regarding all dimensions of participation (SRNI)	Interactional and Analytic Service Receivers (SRIA)	
0.85	0.97	0.83	0.94	8
0.80	0.95	0.79	0.93	9
0.87	0.98	0.87	0.97	10
0.70	0.91	0.68	0.85	11
0.81	0.96	0.80	0.93	12
0.87	0.97	0.86	0.97	13
0.83	0.97	0.83	0.95	14
0.84	0.97	0.82	0.95	15
0.80	0.95	0.78	0.93	16

Since Absorptive capacity of the first scenario is 0-0.25, Networking and network management capacity is 0-0.25, knowledge and technical capacity is 0-0.25 and collaborative capability is 0-0.2 is (Table 1, the results of Taguchi experiments design method), at first the average of each interval (the average of the upper limit and the lower limit of each interval) was measured. In the first scenario, the value-Absorptive capacity is 0.125, Networking and network-management capacity is 0.125, knowledge and technical capacity is 0.125, and collaborative capability is 0.125. Because the importance of each item varies and taking into account the results of previous steps (Table 2: normalized weights of platform development indicators), the measured values were multiplied by their respective importance levels. For the first scenario, the values of Absorptive capacity, Networking and network management capacity, knowledge and technical capacity, and collaborative capability are 0.0321, 0.0278, 0.0562, and 0.009, respectively. Here, the values were entered into AnyLogic as model parameters for the first scenario. The output includes the percentage of the created value. The output of the first scenario is 0.52 for active and interactive service providers, 0.30 for normal and indifferent service providers regarding all dimensions of participation, 0.47 for interactive and analytical service receivers, and 0.31 for normal and indifferent service receivers regarding all dimensions of participation. Figure 4 shows the output of the first scenario in AnyLogic. Moreover, the procedure of all other scenarios (16 scenarios) is the same.

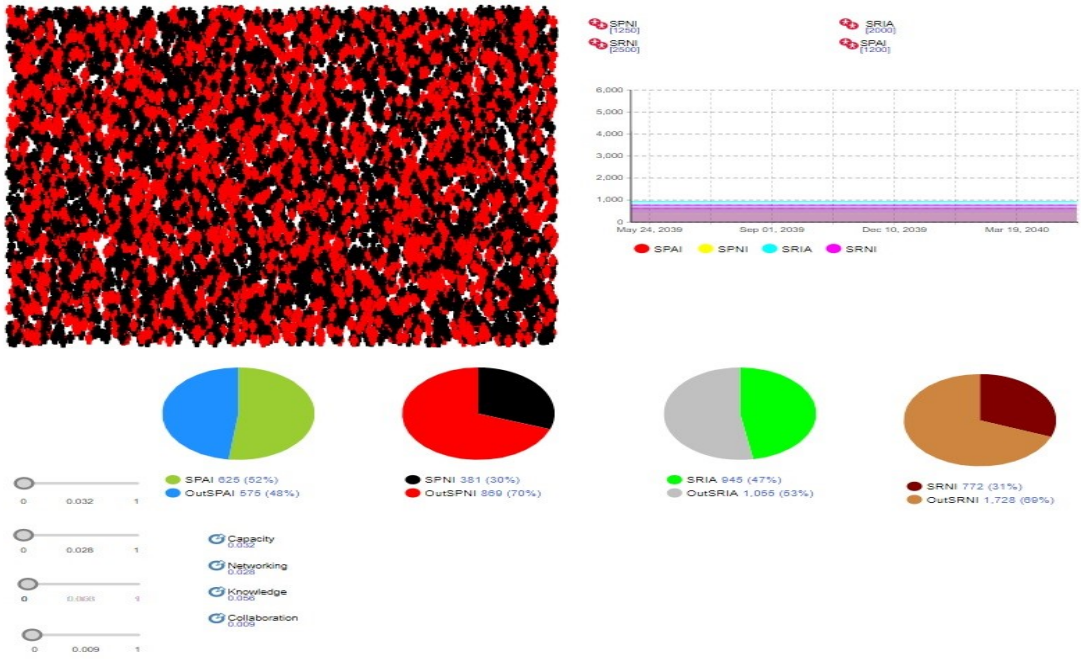

Figure 4. The result of the first scenario

4.7. Formulating the optimal scenarios

The results of formulating the scenarios using the Taguchi method (Table 3, the effectiveness of the scenarios) were analyzed by Qualitek software. Table 4 shows the main impacts of platform development indicators: Absorptive capacity, Networking and network management capacity, knowledge and technical capacity, and collaborative capability for all measured levels.

Table 4. The main impacts of platform development indicators in all levels

LMax – LMin	Level 4	Level 3	Level 2	Level 1	Indicators of platform development using open innovation
2.491	-1.055	-1.405	-2.099	-3.546	Absorptive capacity
2.384	-1.073	-1.417	-2.157	-3.457	Networking and network management capacity
3.205	-0.773	-1.205	-2.148	-3.978	Knowledge and technical capacity
1.324	-1.647	-1.641	-1.851	-2.965	Collaborative capability

Table 4 shows that the optimal level for every indicator of platform development using open innovation is the one in which the main effects are greater. So, the optimal level for the agents of platform development was identified. Table 5 shows the optimal scenario.

Table 5. The optimal scenario

Collaborative capability	Knowledge and technical capacity	Networking and network management capacity	Absorptive capacity	Factors of platform development
Level 3	Level 4	Level 4	Level 4	**The optimal level**
0.5-0.75	0.75-1	0.75-1	0.75-1	

Table 5 shows that in the optimal scenario, the Absorptive capacity is at the fourth level (0.75-1), Networking and network management capacity is at the fourth level (0.75-1), knowledge and technical capacity is at the fourth level (0.75-1), and collaborative capability is at the third level (0.5-0.75). It is worth noting that the optimal scenario obtained at this stage is not among the sixteen scenarios formulated. Here, the optimal scenario is entered into the model in AnyLogic to ensure model validity. In the designed model, the value of each tool of platform development that is 0.2244 for Absorptive capacity, 0.1943 for Networking and network management capacity, 0.3933 for knowledge and technical capacity, and 0.045 for collaborative capability was entered into AnyLogic software. Figure 5 and Table 6 present the model outputs.

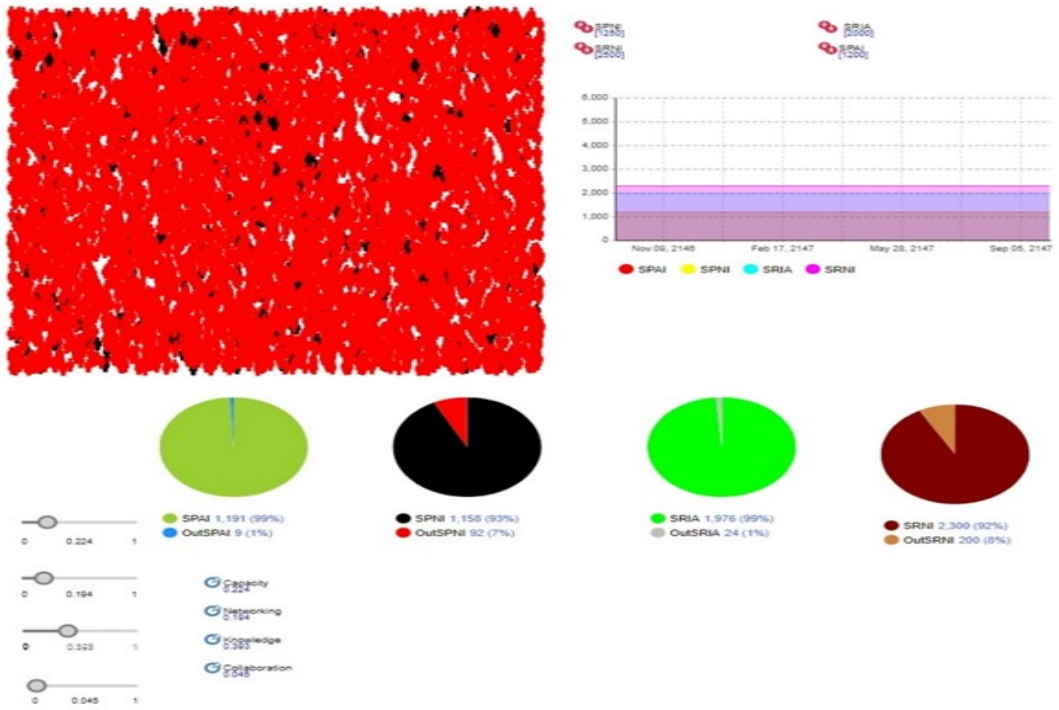

Figure 5. The results of the optimal scenario

Table 6. The effectiveness value of the optimal scenario

Percentage of created value				Scenarios of platform development
Normal and indifferent service receivers regarding all dimensions of participation	**Interactive and analytical service receivers**	**Normal and indifferent service providers regarding all dimensions of participation**	**Active and interactive service provider**	
0.92	0.99	0.93	0.99	**Optimal scenario**

Table 6 shows that in the optimal scenario, the created value for active and interactive service providers is 0.99, the value for normal and indifferent service providers regarding all dimensions of participation is 0.93, the value is 0.99 for interactive and analytical service receivers, and it is 0.99 for normal and indifferent receivers regarding all dimensions of

participation. Moreover, the comparison results of the implementation of the optimal scenario show that the percentage of created value is 0.957 for the implementation of the optimal scenario.

5. Discussion and conclusion

Using an agent-based simulation approach, platform development scenarios using open innovation were analyzed. First, the agents, the environment, the interaction between the platform and the agents, and the interaction among the agents were defined; programming in AnyLogic was then implemented, and the model was designed. The simulation and analysis of scenarios based on open innovation indicators were done using Taguchi experiments design method and Qualitek software (in line with Tian and Qiao, 2014). The output of each scenario is the percentage of created value for interactive and analytical receivers, normal and indifferent service receivers across all dimensions of participation, and active and interactive service providers, as well as normal and indifferent service providers, across all dimensions of participation. Finally, to formulate the optimal scenario, the results of scenario implementation in the simulation environment were analyzed using Qualitek software. It appeared that the optimal level of platform development indicators using open innovation for Absorptive capacity is the fourth level that will enhance the ability of platform businesses in understanding the value of external information, attracting, and apply the. It will also make opportunities for innovation. That is, it decreases the limitations of the internal combination of knowledge resources in the innovation model. Absorptive capacity is a dynamic capability (Zahra and George, 2002) and a key structure in innovation management (Cohen and Levinthal, 1989), and a significant factor for competition. Hafkesbrink and Schroll (2010) believe that Absorptive capacity consists of such steps as identifying opportunities, extracting and mixing, understanding and sharing, publishing and applying.

Networking and network management capacity is the fourth level. It Refers to the ability of businesses to create, manage, and optimally apply network connections to leverage the benefits of business networks. It is a fundamental approach to solving problems, to developing platforms (Aarikka-Stenroos et al., 2014), and to tackling resource limitations and creating new opportunities (McGrath et al., 2019). Moreover, some studies (e.g., Fang et al., 2014) have approved the impact of networking on the success of innovation.

Knowledge and technical capacity are the fourth level. It Refers to the systematic process of understanding, accepting, and implementation ability of a business for the better use of

knowledge in achieving development and creating a sustainable competitive advantage. The findings of studies such as Chen et al. (2014) and Ning et al. (2006) confirm the issue. One can say that this capacity is dynamic and so significant for developing innovative performance. Moreover, to improve the capacity, the necessary hardware and software mechanisms should be designed, and other issues like management information systems should be established, the creation of a knowledge management system should be created, and domestic databases should be developed.

Collaborative capability is at the third level. It Refers to the ability to collaborate from inside to outside and from outside to inside, as well as to the participation of service providers and recipients in the fundamental paradigms of development. Some studies, such as Hafkesbrink and Schroll (2010) and Jacobfeuerbron (2014), mention the indicator. Moreover, collaborative capability is viewed to be the ability of integrating and leveraging the organizational factors to create capability and capacity, and the aim is to enhance interdisciplinary knowledge exchanges within structural boundaries and then develop side interactions between knowledge-functional components for boosting knowledge flows within the boundaries of an organization.

It should be noted that the optimal scenario in this study is not among the sixteen designed scenarios. The selected scenario was entered into the AnyLogic simulation model, and the output (including the percentage of values generated by each agent) was computed. The created value obtained by implementing the optimal scenario is 0.957.

This study explored key indicators of platform development through open innovation using scenario-based simulation. The simulation results revealed that the optimal levels for Absorptive capacity, networking and network management, and knowledge and technical capacity correspond to the fourth level, whereas collaborative capability achieves optimal performance at the third level. Implementing the optimal scenario increased the overall platform value to 0.957, indicating the effectiveness of the proposed agent-based model in enhancing platform growth. These findings can be explained by the interactions among agents and between agents and the platform. High Absorptive capacity enhances user engagement, while effective networking and network management improve knowledge sharing and collaboration. The moderate level of collaborative capability suggests that excessive coordination may not always yield additional benefits, highlighting the importance of balanced agent interactions. The results have both theoretical and practical implications. Theoretically, they demonstrate that open innovation mechanisms, when integrated into an agent-based model, can dynamically influence platform development. In practice, the findings provide managers with actionable insights for

designing and implementing strategies to optimize platform performance. Furthermore, the indicators and scenarios identified in this study can serve as a reference framework for future research in platform business development using alternative methods.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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A Systems Thinking Approach to Energy Sector Stakeholder Engagement: Combining TSI, CSH, and DANP in a Society 5.0 Framework

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ABSTRACT

This study addresses the escalating energy challenges in Razavi Khorasan Province, exacerbated by reliance on fossil fuels and inefficient energy management. By employing a hybrid methodological framework combining Total Systems Intervention (TSI), Critical Systems Heuristics (CSH), and the DANP (DEMATEL-ANP) method, the research identifies and prioritizes key strategies to optimize energy systems. TSI enabled the systematic identification of stakeholders and systemic weaknesses, while CSH provided a critical lens to evaluate stakeholder roles and long-term sustainability goals. The DANP analysis identified clean energy infrastructure development, fostering public-private collaboration, and strengthening scientific institutions as pivotal strategies. The findings emphasize the need to transition to renewable energy, to enhance technological investments, and to foster cultural shifts in energy consumption. The study also highlights the significance of participatory governance and transparent decision-making in effectively addressing complex energy issues. By integrating environmental, technological, and public participation strategies, the proposed E-FLEX 5.0 framework offers a dynamic, scalable model for sustainable energy management. The outcomes underscore the potential for reduced dependence on fossil fuels, improved energy security, and sustainable development. This research contributes to addressing regional and global energy challenges and aligns with the goals of Society 5.0.

Keywords

Energy management, Renewable energy, Participatory Decision-Making, Society 5.0, DEMATEL-ANP.

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1. Introduction

The Global Energy Crisis of 2021-2023 began in 2021, following the COVID-19 pandemic, as much of the world faced shortages and price hikes in oil, gas, and electricity markets (Gholian-Jouybari et al., 2024). This crisis was driven by various economic factors, including a rapid economic recovery after the pandemic that outpaced energy supply (Ebrahimi et al., 2025), and it escalated into a global energy crisis following Russia's invasion of Ukraine in 2022 (Hussain et al., 2023). Natural gas prices reached record highs, leading to increased electricity prices in some markets. Oil prices also soared to their highest levels since 2008 (Khan, 2017). Higher energy costs pushed households into poverty, forced some factories to reduce production or shut down, and slowed economic growth (Yu et al., 2021). Europe, uniquely vulnerable due to its historical dependence on Russian gas, faced gas rationing during the winter of 2022-2023, while many emerging economies experienced surging energy import bills and fuel shortages (Van de Graaf, 2023). Global demand trends and the growth of gas consumption highlight that the Middle East alone has seen significant growth over the past 15 years, consuming as much gas as all of Europe (Lambert et al., 2022) (Figure 1).

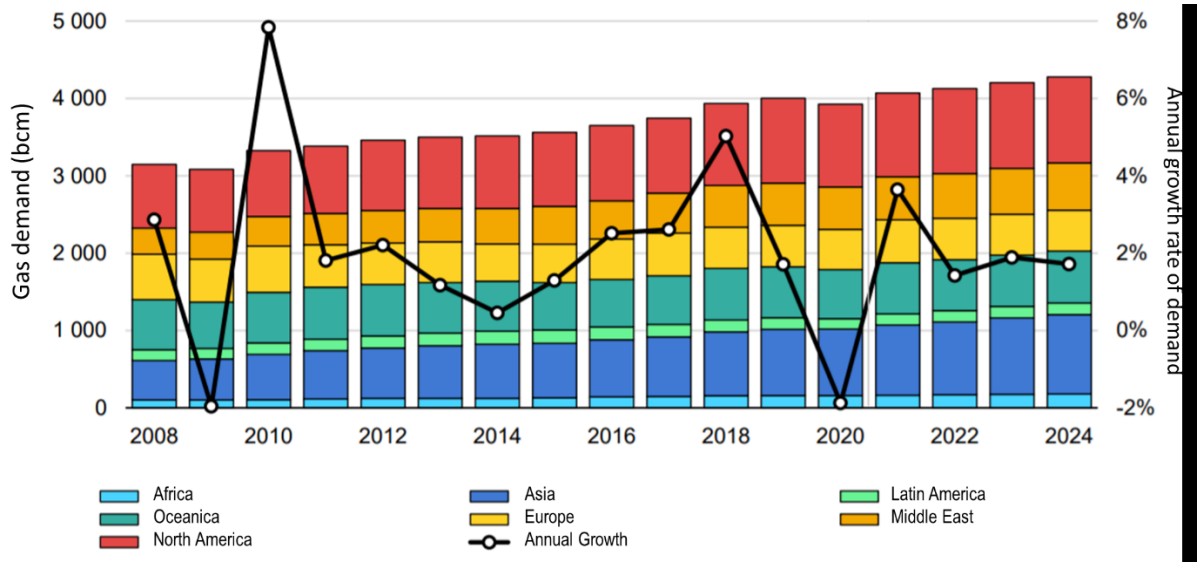

Figure 1. Global gas consumption and growth rate (Source: World Economic Forum)

In response to the global energy crisis, many countries adopted measures such as subsidizing coal and other polluting energy sources, reducing gas taxes, or lowering carbon-emissions costs (Bonakdari et al., 2025). While these short-term solutions reduced electricity bills, they contradicted efforts to limit global warming to 1.5°C, increasing the risk of a climate crisis (Gössling et al., 2023). European countries sought to boost gas imports from Algeria, Norway, and Azerbaijan, introduced gas storage commitments, and agreed on voluntary targets to cut

gas and electricity demand by 15% through efficiency measures, renewable energy, and improved productivity Taghipour et al., 2023). The UK entered into a long-term LNG supply agreement with Qatar. In 2021, a U.S. producer signed three long-term supply contracts with China's Sinopec for LNG, doubling China's imports of U.S. natural gas. Gas prices in Europe dropped by 12% after Gazprom announced increased supply following the filling of Russian storage by early November. Norway ramped up gas production, and lower coal prices in China also helped reduce natural gas costs. However, regulatory issues and speculation drove emission quota prices to spiral, thereby increasing electricity costs (Liu et al., 2021).

In Iran, the energy outlook is equally challenging. Despite holding the second-largest natural gas reserves and being the fourth-largest producer (Mohaghar et al., 2025)Iran's gas sector faces numerous challenges (Slocum and Gessel, 2022). In 2022, gas production increased from 840–850 million cubic meters per day to 4 billion cubic meters per day, while annual consumption averaged 250 billion cubic meters, or 685 million cubic meters per day. Although sufficient on paper, seasonal spikes in winter demand lead to shortages (Keskar et al., 2023). In 2021, Iran exported 17 billion cubic meters of natural gas, with daily exports to Iraq rising to 35 million cubic meters to meet growing energy needs. Turkey, Iran's second-largest export market, imported about 9 million cubic meters per day in 2021 (Abdolahinia et al., 2024). However, Iran now faces its worst energy crisis in four decades, with potential social unrest as temperatures drop (Hussain et al., 2023).

According to the National Iranian Gas Company (NIGC), 60-70% of the country's gas production is consumed by the residential and commercial sectors (Heidari et al., 2022). This high consumption has caused fuel shortages in major industries such as cement, steel, petrochemicals, and power generation, resulting in an estimated $20 billion in lost revenue (Tickner et al., 2021). To address this, measures such as daily inspections of 4,000 government offices, a 50% penalty on gas bills for high-consuming offices, revised household gas tariffs penalizing overconsumption, and efficiency improvements in boiler systems have been implemented. A daily color-coded consumption map highlights excessive residential gas use in northern provinces and regions such as West Azerbaijan and Kurdistan, where consumption exceeds allowable per-household limits. Provinces such as Hormozgan, Khuzestan, Bushehr, and Sistan and Baluchestan adhere best to consumption guidelines. Moderate overconsumption is observed in provinces marked in orange, whereas red indicates severe excess; Mazandaran, Gilan, and Golestan exceed the standard limit by more than twice.

To mitigate the crisis, the NIGC should implement targeted measures in high-consumption regions, such as prioritizing diesel for power plants or limiting gas supply to residential and industrial users in over-consumption provinces, to protect other provinces from the crisis. Decision-making appears centralized, sidelining participatory approaches (Nath et al., 2022). This study proposes a framework for participatory decision-making and policymaking in the energy sector, with a focus on the gas crisis.

The global energy crisis, coupled with the urgent need for sustainable solutions (Ehsanifar et al., 2023, Foukolaei et al., 2024, Ghaedi et al., 2024), highlights the importance of rethinking energy management frameworks (Ghaedi et al., 2024). Particularly in centralized energy systems, the lack of participatory decision-making and stakeholder engagement exacerbates inefficiencies and limits the potential for innovative, inclusive solutions. This research aims to address these gaps by proposing a comprehensive framework aligned with Society 5.0 principles, emphasizing technological integration, stakeholder collaboration, and sustainability. The framework leverages advanced methodologies, including Total Systems Intervention (TSI) (Torlak, 2001) and Decision-Making Trial and Evaluation Laboratory (DEMATEL)-based Analytical Network Process (DANP), to develop actionable strategies that balance technological innovation (Tang and Tsai, 2024), environmental preservation, and public participation.

The purpose of this study is to develop a participatory decision-making model that addresses systemic challenges in the energy sector while aligning with long-term sustainability goals. By integrating advanced tools such as GIS, AI, and data mining with stakeholder-centric approaches, this research seeks to enhance transparency, inclusiveness, and efficiency in energy governance. Specifically, it focuses on the context of Iran's gas energy sector, providing actionable insights and strategies to optimize resource utilization and promote the adoption of renewable energy (Khazaei et al., 2025a). The integrative framework enables both the identification of systemic weaknesses and the prioritization of participatory strategies through quantitative and qualitative analyses. It contributes to the literature by bridging systems thinking and participatory energy governance and by offering a replicable methodological framework for regions facing similar centralized energy challenges.

The remainder of the paper is structured as follows: the literature review explores existing research on participatory decision-making and energy management, identifying gaps and opportunities. The methodology section details the application of TSI and DANP in developing the proposed framework. The results and discussion sections outline the key findings,

highlighting the interconnectedness of strategies and their implications for sustainable energy management. Finally, the conclusion presents the study's contributions, practical implications, and directions for future research.

2. Literature review

2.1. Energy participation decision-making

Research on energy participation decision-making has explored diverse frameworks to enhance stakeholder engagement and social acceptance in renewable energy projects. Estévez et al. (2021) analyzed the integration of social criteria into renewable energy decision-making, reviewing 184 articles and identifying 490 social impact indicators using Multi-Criteria Decision Analysis (MCDA). Their findings highlighted critical social factors, including employment, governance, and social acceptance, while identifying challenges in expert consultation and stakeholder engagement, particularly in Asia and Europe. Wahlund and Palm (2022) investigated the concepts of energy democracy and energy citizenship within participatory energy transitions. Through a thematic literature review, they emphasized the differences between institutional governance in energy democracy and behavioral change in energy citizenship. Despite a focus on decentralized systems in Europe and North America, the study identified a lack of research on centralized systems.

Galende-Sánchez and Sorman (2021) critically reviewed participatory climate and energy initiatives to assess the potential for co-production. Their systematic review of 183 records revealed that genuine co-production remains rare, with consultation predominating. They called for innovative methods and stronger science-policy synergies to achieve transformational outcomes in developed countries. Zhou and Lund (2023) explored peer-to-peer (P2P) energy sharing and decision-making in smart communities. Their review highlighted the role of blockchain technology in enhancing transparency, security, and automation, as well as the economic and environmental benefits of P2P energy trading.

Stober et al. (2021) conducted a comparative analysis of 25 participatory renewable energy projects across Europe, focusing on inclusiveness and participation levels. Their findings revealed advanced practices in Western Europe and highlighted the importance of broad inclusiveness and substantive rationales for increasing social acceptance of renewable energy projects. Spyridonidou et al. (2021) developed a participatory framework for siting large-scale wind and PV farms in Israel using GIS and AHP tools combined with public and expert consultations. The framework successfully identified socially and environmentally suitable

sites, showcasing the value of collaborative spatial planning. Stadelmann-Steffen and Dermont (2021) examined the role of political and economic participation in local renewable energy project acceptance. Their conjoint analysis revealed that while participation improves acceptance, its effectiveness varies by population group and mode of participation. Hanke et al. (2021) analyzed renewable energy communities (RECs) in Europe, finding that while RECs address energy justice, they often underrepresent vulnerable groups, emphasizing the need for broader inclusion.

2.2. Gas energy in iran

Iran's energy sector faces challenges in transitioning to a sustainable model while leveraging its vast natural gas resources. Tayebi et al. (2022) developed a decision support system (DSS) combining ANP, DEMATEL, and MULTIMOORA methods to prioritize air pollution control technologies in oil, gas, and petrochemical facilities. Their findings underscored the efficacy of technologies like electrostatic precipitators in supporting low-carbon policies. Pamučar et al. (2021) evaluated renewable energy potential in Iran's Caspian Sea coastline agriculture using MCDA techniques. Their analysis identified Mazandaran as the region with the highest bioenergy potential, informing sustainable energy strategies in agriculture.

Zahedi et al. (2022) explored strategic renewable energy policies in Iran, emphasizing wind energy for its economic and market advantages. They highlighted the potential for Iran to become a regional hub for renewable energy. Jamali et al. (2021) compared energy flow and greenhouse gas (GHG) emissions across irrigation systems in southern Iran. Their study demonstrated the superiority of sprinkler systems in reducing GHG emissions and improving energy efficiency compared to traditional methods. Taghvaee et al. (2022) analyzed energy efficiency improvements versus price policies in reducing fossil fuel consumption. Their dynamic modeling indicated that technology-driven efficiency improvements outperform price policies, yielding significant environmental and economic benefits. Noorollahi et al. (2021) modeled Iran's energy transition using the EnergyPLAN model. They found that efficiency improvements in thermal power plants and the expansion of renewable capacity significantly reduce CO2 emissions and enhance energy system sustainability. Solaymani (2021) assessed renewable energy trends and policies in Iran, identifying challenges in scaling renewable energy. His study highlighted the need for diversifying policies and biomass utilization to reduce dependence on fossil fuels and promote sustainability.

2.3. Research gaps and novelties

Despite extensive studies on participatory energy decision-making, several gaps remain in both theoretical development and practical implementation. First, existing research primarily focuses on decentralized energy systems in developed contexts, leaving a significant void in understanding how participatory frameworks can be applied within centralized systems such as those in the Middle East. Second, most participatory initiatives emphasize consultation rather than co-production, resulting in limited stakeholder empowerment and insufficient integration of community perspectives into policy outcomes. Third, vulnerable and marginalized groups often remain underrepresented in participatory processes, raising concerns regarding energy justice, inclusivity, and equitable access to decision-making. Fourth, while several studies have applied tools such as GIS, AHP, and MCDA to support participatory planning, the use of emerging technologies, such as artificial intelligence, blockchain, and data mining, for participatory governance remains largely unexplored. Finally, in the specific context of Iran's energy sector, few studies address the intersection of stakeholder engagement, sustainability, and system-level transformation, despite the country's growing dependence on natural gas and pressing sustainability challenges. Addressing these gaps is essential to developing innovative, technology-driven, and participatory frameworks that enhance transparency, efficiency, and long-term energy resilience.

Most previous studies have relied on three main types of indicators to evaluate participatory energy systems: social, technological, and environmental. Social indicators focus on participation levels, inclusiveness, and public acceptance. Technological indicators address the integration of renewable energy, transparency, and system efficiency. Environmental indicators emphasize emission reduction and resource conservation. However, these metrics are often treated separately rather than within a unified framework, and their interdependencies remain unclear. This study addresses this gap by integrating these indicator categories into a coherent analytical framework within the E-FLEX 5.0 model, linking stakeholder participation to technological and environmental performance outcomes.

3. Methodology

The research methodology comprises three main stages. First, TSI is utilized to identify stakeholders, diagnose systemic weaknesses, and propose actionable solutions (Midgley and Rajagopalan, 2020) aligned with Society 5.0 (Deguchi et al., 2020). TSI adopts a flexible, meta-methodological framework that integrates multiple systems methodologies to analyze complex

problems from diverse perspectives (Torlak, 2001). By systematically evaluating and revisiting methodologies, TSI ensures iterative refinement and adaptability to dynamic challenges, promoting a comprehensive understanding of systemic issues and opportunities (Nakamura and Kijima, 2011). Second, the DANP approach integrates DEMATEL and ANP techniques . This hybrid methodology leverages DEMATEL to establish causal relationships and ANP to prioritize criteria, eliminating the traditional need for pairwise comparisons. DANP's advanced approach addresses interdependencies among criteria, providing a robust framework for evaluating and selecting technology-driven solutions tailored to Society 5.0 requirements (Adel and Alani, 2024). Finally, a comprehensive development package for the gas supply system and fossil fuel management is formulated. This package consolidates findings from the TSI and DANP stages, offering a practical, participatory, and scalable roadmap. It emphasizes stakeholder engagement, technological innovation, and sustainability to address systemic inefficiencies and align with the goals of Society 5.0 (Ghobakhloo et al., 2024). The linguistic variables used in the fuzzy DEMATEL process were transformed into triangular fuzzy numbers as shown in Table 1, adapted from [49].

Table 1. Triangular fuzzy numbers for linguistic variables (Sorourkhah and Edalatpanah,2022)

Linguistic variable	Numerical scale	Triangular fuzzy numbers
No influence	0	(0, 0, 0.25)
Very low influence	1	(0, 0.25, 0.5)
Low influence	2	(0.25, 0.5, 0.75)
High influence	3	(0.5, 0.75, 1)
Very high influence	4	(0.75, 1, 1)

In this step, expert opinions are collected and averaged. Considering the input from P experts, P matrices (Z_1, Z_2, ..., Z_p) are obtained, where each element is represented by corresponding fuzzy numbers (Peng and Wang, 2018). To calculate the average matrix, the formula 1 is used.

$$Z_{ij} = \frac{Z^1 \oplus Z^2 \oplus \ldots Z^P}{P} \mathrm{z} \quad (1)$$

The resulting matrix is referred to as the "Initial Fuzzy Direct Relationship Matrix," where each element Zij of the matrix is expressed as a triangular fuzzy number (I_{ij}, m_{ij}, u_{ij}), representing the lower, middle, and upper values.

Step 3: Using equation 1, the standardization equation, the indicators' scales are transformed into comparable units. In the following equation, the matrix X is called the standardized direct relations fuzzy matrix (Wu et al., 2019):

$$a_{ij} = \left(\sum_{j=1}^{i} I_{ij}, \sum_{j=1}^{i} m_{ij}, \sum_{j=1}^{i} u_{ij}\right) \quad (2)$$

$$r = max_{1 \leqslant i \leqslant n} \left(\sum_{j=1}^{i} u_{ij}\right) \quad (3)$$

$$x_{ij} = \frac{Z_{ij}}{r} = \left(I'_{ij}, m'_{ij}, u'_{ij}\right) \quad (4)$$

Step 4: In this step, the fuzzy total relations matrix T is obtained. Each element x_{ij} of the matrix is represented as $(I'_{ij}, m'_{ij}, u'_{ij})$, where I', m', and u' correspond to the lower, middle, and upper values, respectively (Ardakani et al., 2024). These values are derived from the elements of the matrices X_u, X_m, X_I, which represent the lower, middle, and upper values in matrix X.

$$XI = \left[I''_{ij}\right], Xm = \left[m''_{ij}\right], Xu = \left[u''_{ij}\right] \quad (5)$$

Given that $t_{ij} = \left(I''_{ij}, m''_{ij}, u''_{ij}\right)$, we have:

$$\left[I''_{ij}\right] = X_I \times (I - X_I)^{-1} \quad (6)$$

$$\left[m''_{ij}\right] = X_m \times (I - X_m)^{-1} \quad (7)$$

$$\left[u''_{ij}\right] = X_u \times (I - X_u)^{-1} \quad (8)$$

This formula represents the identity matrix, while Xl, Xm, and Xu are n×n matrices, where the elements represent the lower, middle, and upper values of the triangular fuzzy numbers in matrix X, respectively (Ardakani et al., 2024).

Step 5: The row and column sums of matrix T are calculated using the specified formulas. These sums are critical for further steps in the analysis and help determine the relationships and influences among the criteria (Hasheminezhad et al., 2021).

$$\tilde{\mathrm{D}} = \left(\tilde{\mathrm{D}}_{\mathrm{i}}\right)_{\mathrm{n}\times 1} = \left[\sum_{\mathrm{j}=1}^{\mathrm{n}} \tilde{\mathrm{T}}_{\mathrm{ij}}\right]_{\mathrm{n}\times 1} \qquad \tilde{\mathrm{R}} = \left(\tilde{\mathrm{R}}_{\mathrm{i}}\right)_{1\times \mathrm{n}} = \left[\sum_{\mathrm{i}=1}^{\mathrm{n}} \tilde{\mathrm{T}}_{\mathrm{ij}}\right]_{1\times \mathrm{n}} \quad (9)$$

The matrices $\tilde{\mathrm{D}}$ and $\tilde{\mathrm{R}}$ represent n×1 and 1×n matrices, respectively.

Step 6: Determining the Importance of Indicators $(\tilde{D}_i + \tilde{R}_i)$ and Relationships Between Criteria $(\tilde{D}_i - \tilde{R}_i)$, If $\tilde{D}_i - \tilde{R}_i > 0$, the corresponding criterion is influential (impacting other criteria, If $\tilde{D}_i - \tilde{R}_i < 0$, the corresponding criterion is influenced (impacted by other criteria)

Step 7: Defuzzifying the Fuzzy Numbers $\tilde{D}_i + \tilde{R}_i$ and $\tilde{D}_i - \tilde{R}_i$

The fuzzy numbers obtained in the previous step are defuzzified using the following formula. In this formula, B represents the defuzzified value of a fuzzy number $\tilde{\mathrm{A}} = (a_1, a_2, a_3)$.

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$$B = \frac{l + m + n}{3} \tag{10}$$

The ANP is a generalization of the AHP, in which relationships are not strictly hierarchical but are represented as a network that encompasses more complex interconnections. In this method, the first step is to model the problem's network structure (Emrouznejad and Marra, 2017). For this purpose, the DEMATEL method and its resulting structure are employed. Once the network is established, it identifies which main criteria influence one another (external relationships) and which sub-criteria within a criterion influence one another (internal relationships) (Nasrollahi et al., 2023). In the next step, pairwise comparisons must be conducted for each relationship in the network. According to Saaty's research, this involves fixing one factor while comparing it with the others (Saaty, 2004), a process that is notably complex and time-consuming. To address this issue, Chen and Lin (2018) proposed the fuzzy DANP method. In this approach, the full influence matrix generated by the DEMATEL method serves as the supermatrix for pairwise comparisons, thereby eliminating the need for the traditional, labor-intensive pairwise comparison process.

Step 8: Using the DEMATEL method, a network structure is established among the criteria, and the complete influence matrix is calculated for both criteria and sub-criteria (Kadoić et al., 2019). This matrix reflects the relationships and mutual impacts within the system.

Step 9: This step is performed twice: once for the complete influence matrix among the criteria and once for the complete influence matrix among the sub-criteria. Let the complete influence matrix derived from the DEMATEL method be denoted as T. To obtain the unweighted supermatrix (T_c^{α}), the data within each block corresponding to the sub-criteria of a criterion are normalized. The final matrix is constructed by arranging the normalized blocks together, and its transpose is considered the unweighted supermatrix (Ju et al., 2015).

$$T = \begin{bmatrix} T^{11} & \cdots & T^{1j} & \cdots & T^{1m} \\ \vdots & & \vdots & & \vdots \\ T^{j1} & \cdots & T^{ij} & \cdots & T^{im} \\ \vdots & & \vdots & & \vdots \\ T^{m1} & \cdots & T^{mj} & \cdots & T^{mm} \end{bmatrix}, \qquad T^{11} = \begin{bmatrix} T_{11}^{11} & \cdots & T_{12}^{11} & \cdots & T_{1m_2}^{11} \\ \vdots & & \vdots & & \vdots \\ T_{21}^{11} & \cdots & T_{22}^{11} & \cdots & T_{2m_2}^{11} \\ \vdots & & \vdots & \ddots & \vdots \\ T_{m_1 1}^{11} & \cdots & T_{m_1 2}^{11} & \cdots & T_{m_1 m_2}^{11} \end{bmatrix},$$

By dividing the elements of each row in the matrix T^{ij} by the sum of the elements in the same row and arranging them together, the normalized matrix T^{α} is obtained. The unweighted supermatrix is then defined as the transpose of the matrix derived in this step (Hsu et al., 2013).

$T_c^{\alpha} = (T^{\alpha})'$

Step 10: The unweighted supermatrix is used. Each block of the supermatrix corresponding to the main criteria is multiplied by the elements of the block related to the sub-criteria. This process yields the weighted supermatrix (W).

Step 11: After forming the weighted supermatrix, the final weights are determined by calculating the limit of the supermatrix. This step ensures the convergence of the matrix, providing the final priorities for the criteria and sub-criteria (Gölcük and Baykasoğlu, 2016).

$$\lim_{k\to\infty} W^k$$

3.1. Analytical process

To enhance the clarity of the analytical process, the study employed a structured, sequential approach that linked qualitative insight generation with quantitative validation. Using TSI, stakeholders and systemic weaknesses were first identified, and critical problem boundaries were refined through CSH. Expert panels then evaluated the interrelationships among the identified strategies using fuzzy linguistic variables, which were transformed into triangular fuzzy numbers and processed by the fuzzy DEMATEL method to quantify causal relationships and determine influence weights. The resulting influence matrix was normalized and integrated into the DANP framework, generating both unweighted and weighted supermatrices. Iterative computations continued until convergence, producing the final priority rankings for environmental, technological, and participatory strategies. This sequence of analytical steps enabled a transparent and replicable process for deriving data-driven conclusions from expert knowledge.

Each methodological component in this hybrid framework played a complementary role in ensuring methodological depth and coherence. TSI structured the intervention and guided stakeholder identification, while CSH offered a critical and reflective dimension that revealed discrepancies between current and desired system states. DANP then transformed these insights into quantifiable interdependencies, linking the systemic and participatory analyses to prioritized decision outputs. Together, these methods provided a coherent transition from problem diagnosis to strategic evaluation. The integrated process culminated in the development of the E-FLEX 5.0 model, which translates qualitative stakeholder perspectives into quantifiable, evidence-based policy recommendations for sustainable and participatory energy governance.

3.2. Reliability and validity

To ensure the reliability and validity of the integrated approach, several validation steps were undertaken throughout the research process. First, methodological triangulation was applied by combining TSI, CSH, and DANP to cross-verify findings from qualitative and quantitative perspectives. The convergence of stakeholder insights (from TSI and CSH) with numerical prioritization (from DANP) provided internal validation for the proposed framework. Second, expert validation was conducted through iterative feedback sessions with 14 specialists representing academia, industry, and government. These experts reviewed intermediate outputs such as stakeholder maps, causal diagrams, and priority rankings to ensure conceptual coherence and practical relevance. Third, comparative validation was achieved by referencing the analytical sequence and outcomes against similar case studies in regional and international energy system research, ensuring consistency in methodological logic and interpretation of results.

Furthermore, sensitivity analysis within the DANP model was conducted by adjusting the fuzzy scales and re-evaluating the weight distributions to assess the robustness of the results under varying expert assumptions. The minimal variation in ranking outcomes confirmed the model's stability. Finally, the feasibility of the proposed strategies in the E-FLEX 5.0 package was examined through discussions with regional policymakers, thereby providing contextual validation and assessing the practicality of implementation. These multi-level validation measures ensured that the study's findings are both scientifically sound and contextually grounded.

4. Results

4.1. Case of khorasan razavi

The province of Khorasan Razavi, particularly its capital, Mashhad, is experiencing a severe energy and gas crisis. This stems from a combination of factors, including rapid population growth, harsh climatic conditions, and the province's strategic role as a hub for industrial and residential energy consumption. Residential gas consumption in the province has steadily increased over the years, with peak demand during the colder months of December, January, and February. In 2022 alone, residential and commercial sectors accounted for 60-70% of the province's gas production, creating a severe imbalance between supply and demand during the winter months. Consequently, energy-intensive industries such as cement, steel, and

petrochemicals have experienced significant shortages, resulting in an estimated $20 billion in annual revenue losses.

Mashhad, as a densely populated urban center and a hub for religious tourism, exacerbates this crisis. Its high energy demand is attributable to population growth, tourism-related activities, and infrastructure expansion. The industrial sector, primarily located in regions such as Sarakhs and Neyshabur, relies heavily on natural gas for production processes. However, inefficiencies in distribution networks and outdated infrastructure have resulted in excessive energy waste. For example, regions such as Sarakhs, known for their rich gas reserves, are unable to meet the growing local demand due to outdated extraction and distribution technologies. Additionally, the lack of renewable energy integration has further strained the province's gas reserves, which remain the primary energy source (Taghipour et al., 2024).

Efforts to address the crisis have included measures such as revised household tariffs, inspections of government facilities, and penalties for overconsumption. Despite these interventions, the 2022 winter gas shortages in Razavi Khorasan underscore the inefficiencies in centralized decision-making and the absence of participatory approaches. Seasonal spikes in demand and reliance on fossil fuels, coupled with insufficient investment in renewable energy, have left the province vulnerable to energy crises. A shift toward sustainable solutions such as solar and wind energy, particularly in areas such as Binalood and Khaf, could alleviate the crisis. However, implementation remains slow, hampered by bureaucratic and financial barriers, leaving the province in a precarious energy state.

4.2. Land administration and expert alignment

In the early stages of our research, we used the comprehensive land-planning data for Khorasan Razavi to align perspectives among a diverse group of experts. The goal was to establish a unified understanding of the region's challenges and opportunities, particularly with respect to energy consumption and infrastructure development. The experts, with diverse backgrounds in economics, industry, and environmental science, initially presented varied and sometimes conflicting viewpoints. By facilitating structured discussions, we harmonized these perspectives, ensuring that everyone worked toward common goals. This alignment was critical for advancing the stages of the TSI methodology effectively. Through the TSI process, it became evident that Critical Systems Heuristics (CSH) would be the most appropriate approach for addressing the province's complex energy issues (Dehghan Nayeri et al., 2020). We applied CSH to refine our analysis by posing critical questions that guided experts in systematically

evaluating the challenges and potential solutions (Khazaei et al., 2025b). These discussions not only clarified the objectives but also encouraged experts to adopt a holistic and collaborative perspective. The structured use of CSH helped us integrate diverse insights and foster a deeper understanding of the systemic issues at hand (Ramezani et al., 2021).

The panel of experts included individuals with experience ranging from 6 to 30 years in their respective fields, ensuring a blend of innovative and seasoned perspectives. Among the 14 participants, 50% held doctoral degrees in disciplines such as industrial management, environmental sciences, and chemical industries, while the others had advanced expertise in mechanical engineering, human resources, and project management. This group's diversity in age (29–55 years), gender balance (seven women and seven men), and professional backgrounds provided a rich pool of knowledge. Their collective expertise significantly contributed to the iterative refinement of our approach, enabling us to address the critical energy challenges in Khorasan Razavi with a comprehensive and forward-looking strategy.

4.3. CSH explorations

To gather in-depth insights into the systemic challenges and potential solutions for energy management in Khorasan Razavi Province, CSH was employed to structure expert interviews. This approach enabled the study to examine multiple dimensions of the energy crisis by engaging a diverse set of stakeholders, including energy experts, environmental scientists, and policy analysts. The interviews were designed around the twelve core CSH questions, which investigate stakeholders, purposes, measures of success, decision-makers, and broader contextual influences (Khazaei et al., 2025b). By focusing on both "as-is" and "ought-to-be" conditions, the interviews facilitated a critical comparison between the current energy system's limitations and its potential ideal state.

Table 2. Summary of CSH results from experts

CSH question	As Is	Ought to be
Who is the client or stakeholder in this system?	Ministry of Oil, Ministry of Energy, industries, and public	Ordinary individuals, organizations, the entire ecosystem, regulators, environmental organizations, and research centers
What is the purpose?	Public satisfaction, energy provision at any cost (e.g., fuel oil)	Provision of clean and sustainable energy, welfare, sustainability, and long-term goals
What is the measure of progress or success?	Expansion of gas and energy supply	Use of clean and renewable energy, sustainable development for all
Who is the decision-maker?	Government, Ministry of Energy, Ministry of Oil, Parliament	Expert groups comprising energy specialists and elite decision-makers
What resources are controlled by the decision-maker?	Fossil fuels and energy resources managed by the Ministry of Oil and Energy	Renewable resources such as wind and solar, laws, and sustainable energy resources

CSH question	As Is	Ought to be
What conditions exist outside the decision environment?	Oil and gas resources, potential environmental resources	International collaboration, technology transfer, and foreign investments
Who is the professional or expert in this system?	Energy experts, governmental specialists	GIS specialists, AI researchers, energy domain scholars
What expertise is required in this system?	Energy domain expertise, extraction, and utilization	Multidisciplinary expertise, AI and data mining, strategic management
Who guarantees the system's success?	Government, Ministry of Energy, and Ministry of Oil	Expert groups, elite professionals, and reliance on renewable resources
Who safeguards the interests of those affected?	Media, city governors, supervisory institutions	Regulatory and oversight organizations with a sustainable community approach
What prevents false promises?	Audit Court, oversight agencies	Transparency, openness, and preventive approaches
What is the defined worldview or vision?	Maximum energy (gas) development	Sustainable energy for all society, environmental protection for future generations

The findings in Table 2 highlight discrepancies between the current state ("As Is") and the desired state ("Ought to be") of the energy system in Khorasan Razavi. While the present framework prioritizes short-term goals such as expanding energy supply and fulfilling immediate needs, the ideal system emphasizes long-term sustainability, public welfare, and environmental preservation. This divergence underscores the need for systemic transformation through multidisciplinary collaboration, the adoption of clean energy technologies, and greater transparency in decision-making processes. One of the key insights from the CSH results is the shift in how stakeholders and clients are defined. The current system identifies government entities and industries as the primary stakeholders, whereas the "Ought to be" vision expands this scope to include individuals, environmental organizations, and research centers. This broader inclusion reflects a commitment to participatory governance and environmental accountability. Similarly, the purpose of the energy system has evolved from merely meeting energy demand to promoting sustainable development and societal well-being.

Table 3 presents actionable strategies to bridge these gaps, categorized into environmental, technological, and societal dimensions. Environmental recommendations, such as transitioning from fossil fuels to renewable energy (S1) and developing sustainable, long-term strategies (S3), align with the CSH vision of prioritizing clean energy and environmental preservation. Technological advancements, including investments in AI-driven optimization (IT2) and the development of clean energy infrastructure (IT3), are essential to achieving operational efficiency and future-proofing the energy sector. In the societal domain, fostering public participation (W2), enhancing energy awareness (W1), and promoting stakeholder collaboration (W3) are pivotal to creating an inclusive and equitable energy system. Strengthening regulatory frameworks (W8) and integrating scientific expertise into decision-

making (W7) further support the vision outlined in the CSH analysis. Together, these strategies provide a comprehensive roadmap to address existing shortcomings while paving the way for a sustainable and innovative energy future in Khorasan Razavi.

Table 3. . Strategic improvement options derived from interviews

Society 5.0 category	Code	Option name	Option description
Environmental	S1	Shift Focus from Fossil Fuels to Renewables	Replace fossil fuels with renewable energy sources such as solar and wind to protect the environment and ensure sustainability.
	S2	Increase Use of Renewable Energies	Expand the adoption of modern energy solutions in residential and industrial sectors to reduce environmental impacts.
	S3	Develop Long-term Sustainable Strategies	Focus on sustainable programs and proactive crisis prevention rather than temporary, isolated management.
	S4	Predict and Manage Environmental and Political Risks	Analyze and forecast environmental and political risks and plan for their management to enhance system sustainability.
Technological development	IT1	Invest in Advanced Technologies	Increase investment in advanced technologies to optimize energy production and consumption, reducing reliance on outdated methods.
	IT2	Use Data-driven and AI-based Methods	Leverage data mining and artificial intelligence to optimize energy consumption and forecast future demands.
	IT3	Develop Clean Energy Infrastructure	Build the necessary infrastructure for the production and distribution of renewable energy at the national level.
	IT4	Enhance Oversight Systems and Decision Transparency	Strengthen regulatory institutions and ensure transparency in decision-making processes to prevent systemic errors.
Consumption culture and public participation	W1	Promote Energy Awareness and Behavioral Change	Educate and raise public awareness about energy-efficient consumption and environmental consciousness.
	W2	Strengthen Public Participation Systems	Increase public and NGO involvement in energy and environmental decision-making processes.
	W3	Foster Collaboration Between Public and Private Sectors	Enhance collaboration among ministries, private companies, and academic institutions to improve energy resource utilization.
	W4	Broaden Stakeholders and Clients in the System	Include public participation, environmental organizations, and academic institutions as key stakeholders in the energy system.
	W5	Develop Multidisciplinary and Specialized Human Resources	Train and educate professionals in emerging fields such as AI, data mining, and renewable energy.
	W6	Upgrade Building Standards and Energy Efficiency	Establish new standards for building insulation and improve energy efficiency in industries.
	W7	Strengthen the Role of Scientific and Research Institutions	Enhance the involvement of scientific and research centers in decision-making and the development of innovative energy solutions.
	W8	Optimize Energy Laws and Regulations	Revise energy laws to support clean energy and optimize resource consumption.
	W9	Increased international interactions in the field of energy	Cooperation with leading countries in the field of renewable energy to exchange new knowledge and technologies

4.4. Implementing DANP

The analysis of fuzzy DEMATEL results highlights critical dynamics among the strategies employed for improving the energy system. The prominence measure, calculated as Di+Ri, identifies the most central strategies within the network. Strategies such as IT3 and W3 are most prominent, suggesting they play pivotal roles in achieving system-wide change. IT3, which involves the development of clean energy infrastructure, is particularly essential for transitioning to renewable energy sources and ensuring long-term sustainability. Similarly, W3, focused on fostering collaboration between public and private sectors, emerges as a linchpin for integrating diverse stakeholders into energy decision-making processes.

The net influence metric, Di-Ri, sheds light on the driving and dependent roles of various strategies. Positive values of Di−Ri indicate strategies that are primary drivers within the system. W1, which emphasizes promoting energy awareness and behavioral change, shows a notable driving effect. This strategy's influence underlines the importance of societal shifts in energy consumption patterns to support sustainable energy goals. Similarly, W3 not only shows high prominence but also acts as a driver, highlighting its dual role in shaping and stabilizing the energy system through robust collaboration frameworks. The results of both fuzzy and non-fuzzy DEMATEL analyses are summarized in Table 4. This table presents the computed prominence and relation values for each factor, enabling a comparative interpretation of the two approaches.

Table 4. Output table of fuzzy and non-fuzzy DEMATEL results

	Fuzzy Di			**Fuzzy Ri**			**Fuzzy Di+Ri**			**Fuzzy Di-Ri**			**Di+Ri**	**Di-Ri**
	l	***m***	***u***	***l***	***m***	***u***	***l***	***m***	***u***	***l***	***m***	***u***		
S1	0.5853	1.5899	5.9505	0.5913	1.5930	5.9365	1.1766	3.1829	11.8870	-5.3512	-0.0031	5.3592	4.5514	0.0035
S2	0.6116	1.6086	6.0001	0.5882	1.5971	5.9869	1.1998	3.2057	11.9870	-5.3753	0.0115	5.4119	4.5836	0.0158
S3	0.5504	1.5277	5.9043	0.5978	1.6205	6.0309	1.1482	3.1481	11.9352	-5.4804	-0.0928	5.3065	4.5319	-0.0724
S4	0.5873	1.6080	6.0113	0.6421	1.6861	6.1707	1.2294	3.2941	12.1820	-5.5834	-0.0781	5.3692	4.6743	-0.0697
IT1	0.6049	1.6288	6.0608	0.6387	1.6924	6.1802	1.2436	3.3212	12.2409	-5.5753	-0.0636	5.4221	4.7024	-0.0528
IT2	0.5640	1.5627	5.9159	0.5951	1.5990	5.9693	1.1591	3.1617	11.8852	-5.4053	-0.0364	5.3209	4.5350	-0.0283
IT3	0.6082	1.6403	6.0859	0.6253	1.6827	6.2082	1.2334	3.3230	12.2941	-5.6000	-0.0424	5.4607	4.7100	-0.0390
IT4	0.5987	1.6032	5.9706	0.6069	1.5978	5.9781	1.2056	3.2010	11.9487	-5.3795	0.0054	5.3636	4.5754	0.0049
W1	0.6510	1.7216	6.2234	0.5631	1.5810	5.9824	1.2141	3.3026	12.2058	-5.3314	0.1406	5.6603	4.6819	0.1290
W2	0.5907	1.5897	6.0260	0.5793	1.6071	6.0455	1.1700	3.1968	12.0715	-5.4548	-0.0174	5.4467	4.5867	-0.0067
W3	0.6181	1.6662	6.1934	0.4920	1.3943	5.5757	1.1101	3.0605	11.7691	-4.9576	0.2720	5.7015	4.4440	0.2627
W4	0.5885	1.5892	5.9761	0.5980	1.6345	6.1143	1.1866	3.2237	12.0905	-5.5258	-0.0454	5.3781	4.6094	-0.0421
W5	0.6046	1.6316	6.0983	0.5447	1.5251	5.8762	1.1493	3.1567	11.9745	-5.2715	0.1065	5.5536	4.5435	0.1037
W6	0.5767	1.5865	5.9443	0.6002	1.6064	5.9738	1.1769	3.1929	11.9181	-5.3972	-0.0199	5.3441	4.5628	-0.0146
W7	0.5969	1.5995	5.9418	0.5873	1.6018	6.0801	1.1842	3.2013	12.0219	-5.4833	-0.0023	5.3545	4.5841	-0.0155
W8	0.5889	1.6216	6.0697	0.5623	1.5273	5.8179	1.1512	3.1489	11.8876	-5.2290	0.0944	5.5074	4.5258	0.0966
W9	0.5383	1.4793	5.7416	0.6519	1.7082	6.1872	1.1902	3.1875	11.9289	-5.6490	-0.2289	5.0897	4.5619	-0.2036

Strategies with low or negative Di−Ri values, such as S3 and IT2, are more dependent on other strategies for their success. These strategies rely heavily on the enabling conditions

established by stronger drivers like W1 and IT3. For example, the success of IT2, which focuses on leveraging data-driven and AI-based methods, depends significantly on investments in infrastructure (IT3) and awareness campaigns (W1). The interplay between drivers and dependents demonstrates the interconnectedness of strategies and underscores the necessity of a coordinated approach to implementing the energy system transformation. This interconnectedness is further supported by Appendix A, which identifies significant relationships among strategies, highlighting the networked influence among them and emphasizing the need for integrated policy interventions.

Figure 2 presents a causal mapping of strategies by their prominence and influence within the system. The horizontal axis (Di+Ri) indicates the total prominence of a strategy, which combines its overall influence on the system and its dependence within the system. The vertical axis (Di-Ri) reflects the net influence, distinguishing whether a strategy is a driver (positive Di-Ri) or dependent (negative Di-Ri).

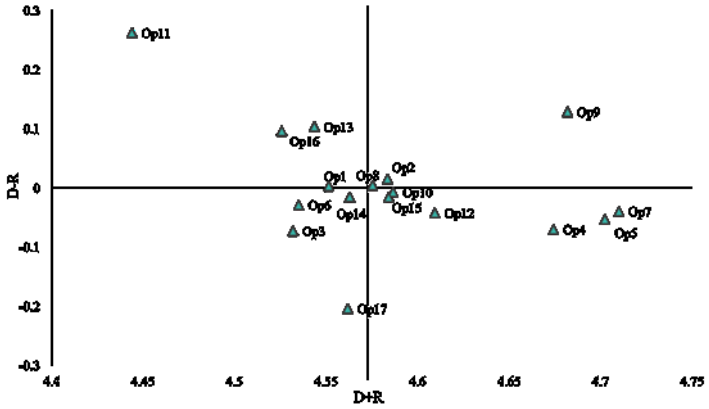

Figure 2. Final diagram of DEMATEL

In the first quadrant, where both prominence and influence are high, the strategies are key drivers of the system. These are the most critical actions to focus on, as they not only significantly impact the system but also have the potential to shape the dynamics of other strategies. They are essential for initiating systemic changes and should be prioritized in planning and resource allocation. The second quadrant, with high prominence but negative influence, includes strategies that are highly interconnected but primarily dependent on other elements. These strategies are vital to the system's functioning but require support from the drivers to be implemented effectively. Addressing these strategies is crucial to ensuring the system's overall stability and operational efficiency. In the third quadrant, where both prominence and influence are low, strategies are peripheral and play a minimal role in driving

systemic change. They are supportive and may not require immediate attention unless they enable higher-priority strategies. Meanwhile, the fourth quadrant, characterized by low prominence but positive influence, highlights fewer central strategies that act as influencers. These may not have a broad impact but can trigger specific changes or outcomes within targeted areas of the system. The distribution of strategies across the quadrants provides valuable insights for prioritizing actions and resources. By focusing on the drivers in the first quadrant while supporting dependent strategies in the second, decision-makers can maximize system-wide effectiveness and address key areas of improvement.

According to Table 5, in the environmental strategies category (S), four strategies (S1 to S4) were evaluated, focusing on assessing environmental impacts in the transition from fossil fuels to renewable energy and sustainable development. S2, with an overall score of 0.349158 and a weight of 0.307189, ranked first, highlighting the importance of expanding renewable energy use in environmental strategies. S4, with a score of 0.273584 and a weight of 0.240699, ranked second, emphasizing the management of environmental and political risks. S1 and S3, with weights of 0.232413 and 0.219699, ranked third and fourth, respectively.

Table 5. The weights obtained by DANP

Code	Final score	Rank	Local weight	Local rank
S1	0.264165	16	0.232413	3
S2	0.349158	9	0.307189	1
S3	0.249715	17	0.219699	4
S4	0.273584	15	0.240699	2
IT1	0.274128	14	0.222793	4
IT2	0.304184	12	0.247221	2
IT3	0.297851	13	0.242073	3
IT4	0.354253	6	0.287913	1
W1	0.318347	11	0.099266	9
W2	0.352652	8	0.109962	7
W3	0.358288	5	0.11172	5
W4	0.352843	7	0.110022	6
W5	0.367478	3	0.114586	3
W6	0.366385	4	0.114245	4
W7	0.374455	1	0.116761	1
W8	0.347384	10	0.10832	8
W9	0.369187	2	0.115119	2

In the technological development strategies category (IT), four strategies (IT1 to IT4) were assessed, focusing on investing in advanced technologies, artificial intelligence, and data mining, and developing clean energy infrastructure. IT4, with a score of 0.354253 and a weight of 0.287913, ranked first, underscoring the importance of transparency and the strengthening of monitoring systems for the success of energy systems. IT2, with a score of 0.304184 and a weight of 0.247221, ranked second, emphasizing the use of data-driven methods and artificial

intelligence. IT3 and IT1, with relatively similar weights, ranked third and fourth, underscoring the importance of infrastructure development and the optimization of new technologies in the energy sector .In the consumption culture and public participation strategies category (W), the largest category with nine strategies, efforts focus on promoting cultural awareness, strengthening inter-organizational cooperation, and enhancing public participation. W7, with a score of 0.374455 and a weight of 0.116761, ranked first, showing the critical importance of strengthening the role of scientific and research institutions in energy decision-making. W9 and W5, with weights of 0.115119 and 0.114586, ranked second and third, underscoring the importance of optimized laws and regulations in supporting clean energy. These findings indicate that strengthening legal and scientific frameworks is essential for achieving sustainable development. W3 and W4 are also important strategies for fostering interagency collaboration and promoting energy-efficient consumption .Overall, strategies W7, W9, and W5 have the highest scores and weights in this category, underscoring the pivotal role of cultural awareness and public participation, particularly in strengthening scientific institutions and improving regulations, in achieving sustainable development and enhancing energy systems. Additionally, strategies S2 and IT4 are key in their respective categories, focusing on renewable energy development and system transparency. In general, the weights derived from the DANP method highlight the central role of cultural and public participation strategies, particularly in reinforcing scientific institutions and legal improvements. Environmental and technological strategies also rank highly, contributing significantly to the optimization of energy consumption and production (Figure 3).

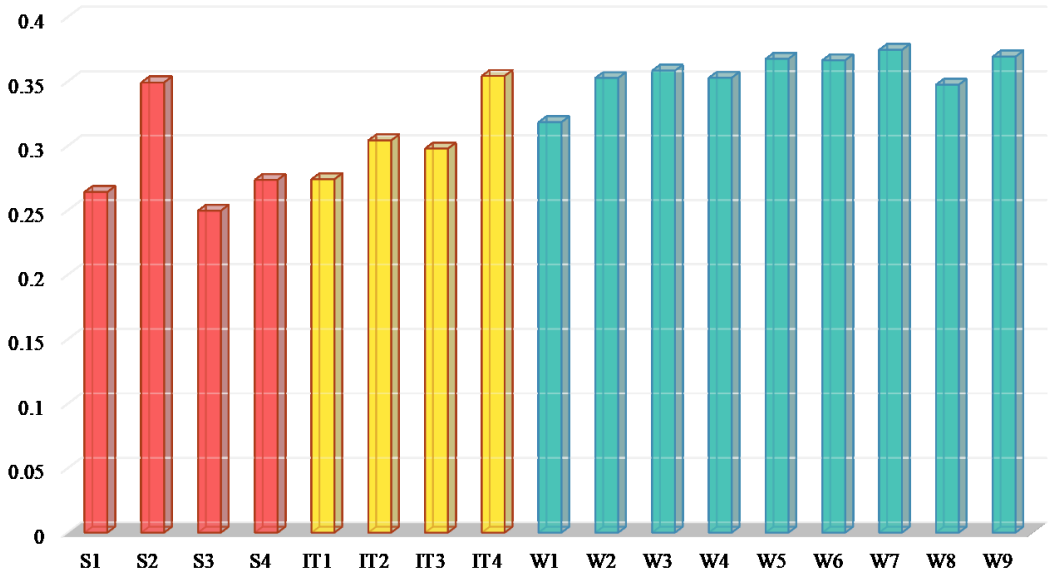

Figure 3. Diagram of society 5.0 strategies based on CSH

In the analysis of rankings within categories, the results indicate that strategies within each category are prioritized according to their specific importance. In the Environmental category, S2 ranks first with a weight of 0.307189, highlighting the importance of expanding renewable energy development. Additionally, S4, which focuses on managing environmental and political risks, ranks second with a weight of 0.240699, underscoring the importance of long-term planning and risk management for achieving a sustainable system. In the Technological Development category, IT4 ranks first with a weight of 0.287913, emphasizing the critical role of transparency and oversight. This strategy reflects the importance of optimizing and clarifying monitoring systems for managing and utilizing new technologies. Similarly, IT2, with a weight of 0.247221 and a second-place ranking, underscores the importance of leveraging data mining and artificial intelligence for energy consumption optimization.

In the Consumption Culture and Public Participation category, W7 ranks first with a weight of 0.116761, signifying the importance of strengthening scientific and research institutions in energy-related decision-making. W9, with a weight of 0.115119, and W5, with a weight of 0.114586, rank second and third, respectively, indicating the need to improve laws and regulations to promote clean energy consumption and optimize resource use. These rankings highlight that collaboration among governmental, private, and scientific entities, along with cultural promotion, is a key factor in enhancing the energy system and achieving sustainable energy consumption.

5. Discussion

The integration of TSI, CSH, and DANP established a comprehensive and structured framework for analyzing and improving the energy and environmental management system. TSI enabled the exploration of complex systemic challenges through a holistic lens, revealing coordination gaps, policy misalignments, and limited stakeholder participation in Iran's energy governance. It provided the foundation for identifying strategic weaknesses and proposing actionable pathways, especially in renewable energy adoption and environmental risk management. CSH added a reflective and ethical dimension by critically examining the roles, boundaries, and values influencing decision-making. This stage revealed the narrow scope of existing governance, dominated by the Ministry of Energy and the Ministry of Oil, and underscored the need to include scientific institutions, environmental organizations, and independent experts. CSH further redefined the perspective from "energy at any cost" toward "clean and sustainable energy," promoting long-term, knowledge-based, and participatory

governance reforms to enhance transparency and resilience in energy planning.

Building on these qualitative insights, the fuzzy DEMATEL–ANP analysis quantified the interrelations and priorities among identified strategies. The results highlighted the most influential factors driving sustainability and system transformation, such as strengthening scientific and research institutions (W7), optimizing energy laws and regulations (W9), enhancing multidisciplinary human resource development (W5), improving transparency and oversight systems (IT4), and expanding renewable energy adoption (S2). These high-ranking strategies formed the analytical foundation of the E-FLEX 5.0 model, confirming the pivotal role of research, regulation, and innovation in shaping a participatory and technologically adaptive energy transition. The findings underscore the importance of coordinated investment in clean energy infrastructure, stronger institutional collaboration, and the adoption of digital technologies such as AI and data mining to improve forecasting and policy integration. Overall, the results provide a clear, empirically grounded roadmap for implementing participatory, technology-driven, and sustainability-oriented energy governance.

5.1. The final E-FLEX 5.0 model

The E-FLEX 5.0 model serves as a comprehensive, flexible, and dynamic framework for policymaking and action research in the fields of energy and sustainable development (Figure 4). This model is built on a core participatory methodology, engaging various stakeholders across phases and employing systems thinking tools and modern methodologies. In the initial methodological phase, a collaborative effort with experts involves conducting statistical analyses and a comprehensive evaluation of the current situation, particularly from the perspective of territorial planning. This phase aims to thoroughly identify the existing conditions, challenges, and potential opportunities. Based on expert opinions and analyses, a detailed framework of fundamental issues and essential needs is developed, paving the way for subsequent phases. The second step of the E-FLEX 5.0 methodology core employs an action research approach. At this stage, systemic methodologies, such as TSI, and complementary methods, such as CSH, are applied. These approaches assist the implementation team in fully understanding complex organizational and societal issues and developing appropriate solutions. Active stakeholder engagement is fostered through the action research process, with CSH serving as the primary tool for critical analysis and issue clarification. This ensures that stakeholders gain a precise understanding of the topics addressed and the changes required to current systems.

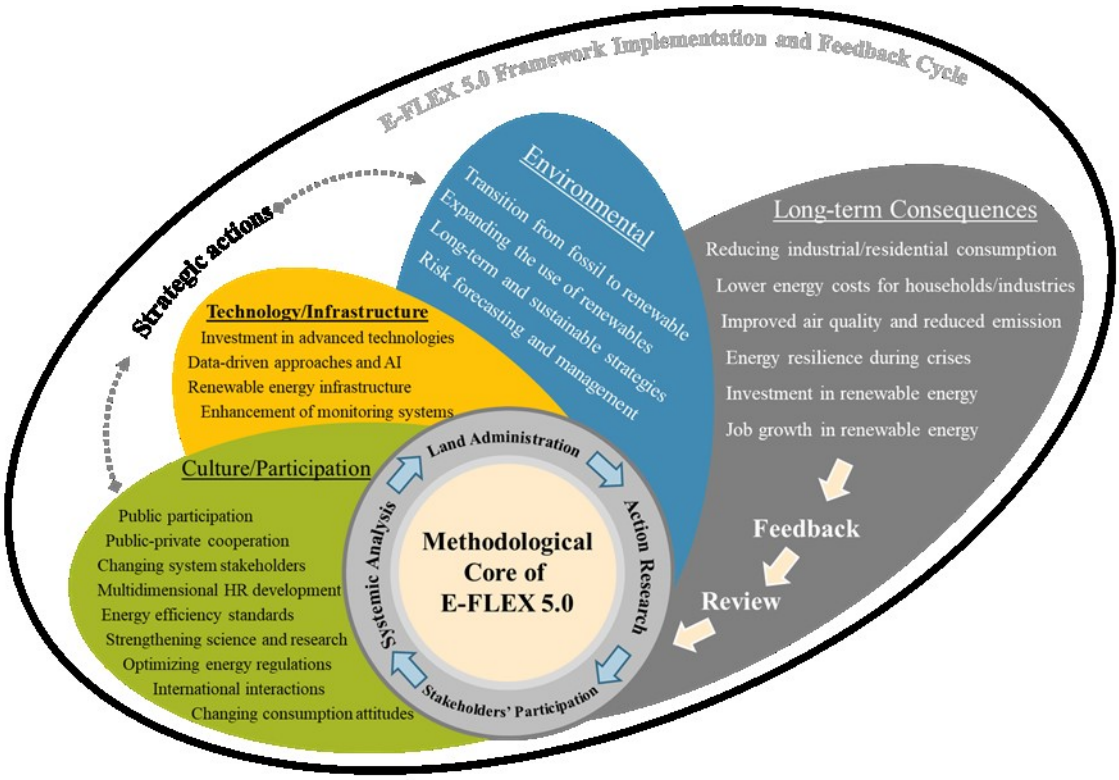

Figure 4. E-FLEX 5.0 model framework, methodological, and implementation core

The third and fourth steps of the EFLEX 5.0 model focus on ranking and prioritizing options. Following action research and a detailed stakeholder analysis, various options are evaluated with stakeholder participation. These options are ranked based on strategies such as sustainability, efficiency, and impact. This ranking helps the implementation team structure operational plans in a phased manner, aligned with strategic priorities. Analytical tools like DANP are employed for priority assessment, alongside critical insights and expertise from specialists, ensuring well-informed final decisions. The second phase includes implementing strategic actions categorized into three broad areas: environmental, technological and infrastructural, and public participation and cultural change. Environmental actions aim to enhance renewable energy use, manage natural resources, and reduce environmental impacts. Technological and infrastructural actions emphasize investing in advanced technologies, building clean energy infrastructure, and developing data-driven systems. Actions related to public participation and culture focus on changing societal attitudes toward energy consumption and fostering cooperation among the government, the private sector, and the public. Collectively, these strategies contribute to sustainable development and reduce dependence on fossil fuels.

Following the implementation of these strategic actions, the EFLEX 5.0 model enters its third phase, which involves assessing and reviewing outcomes. It is anticipated that these actions will

have tangible and long-term impacts on energy and sustainable development. Expected outcomes include improved quality of life, reduced environmental pollution, enhanced energy efficiency, and strengthened technological infrastructure. Regular, continuous evaluations will ensure that expected results are achieved and that necessary adjustments are made promptly. A key feature of the EFLEX 5.0 model is its emphasis on continuous review and improvement. Periodic assessments and feedback from different stages of implementation support optimization and alignment with environmental and social changes. Designed as a long-term participatory model, EFLEX 5.0 remains adaptable to future societal needs and can be redesigned with each implementation cycle to meet emerging challenges and conditions.

5.2. Predicted outcomes

Ultimately, EFLEX 5.0 serves as a dynamic framework for policymakers and decision-makers to systematically and strategically address complex energy and environmental challenges. By leveraging modern systemic methodologies, the model fosters innovation and continuous improvement, thereby enabling replication in other regions and countries. For energy consumption in Razavi Khorasan Province, six tangible outcomes are anticipated based on implementing renewable energy strategies and reducing reliance on fossil fuels:

- By shifting focus to renewable energies, the reliance on natural gas as the primary energy source in Razavi Khorasan Province will decrease, leading to reduced usage in both industrial and residential sectors.
- Data-driven and AI-based optimization methods will lower energy consumption, resulting in reduced gas costs, particularly benefiting gas-dependent industries.
- Increased adoption of renewable energies and reduced gas usage will significantly decrease pollution from fossil fuels, improving air quality in cities like Mashhad, which faces severe pollution issues.
- By replacing natural gas with renewable energy and managing risks, Razavi Khorasan Province will achieve greater energy security, reducing vulnerability to gas price fluctuations and crises.
- Investments in modern technologies and clean energy infrastructure will expand renewable energy projects, such as wind and solar, strengthening the province's new energy sector.
- Long-term sustainable energy strategies will create new employment opportunities in areas like installation and operation of renewable energy infrastructure, boosting the job market and reducing unemployment in Razavi Khorasan Province.

6. Conclusion

Before presenting the main findings, it is worth clarifying how the results were derived. The methodological process combined systemic diagnosis with quantitative prioritization. Expert input was systematically analyzed to identify causal links and assign weights to strategies under

the Society 5.0 framework. This integration of qualitative stakeholder assessment and quantitative modeling ensured that the results reflect both human-centered perspectives and data-driven rigor. The findings of this study highlight the importance of a participatory and systemic approach to addressing the energy challenges faced by Razavi Khorasan Province. By employing TSI, CSH, and the DANP method, this research provides a comprehensive framework for prioritizing strategies that balance environmental sustainability, technological advancements, and cultural shifts. The results emphasize the need to transition from fossil fuels to renewable energy, to invest in modern technologies such as AI and data-driven systems, and to strengthen the role of scientific and regulatory institutions. These strategies collectively enable sustainable development, reduce dependence on natural gas, and improve environmental outcomes.

The insights gained from this study are highly relevant to other regions and contexts, particularly those facing similar energy crises. The integration of systemic methodologies, such as TSI and CSH, enabled a deeper understanding of the complex interdependencies among stakeholders, resources, and strategies. Moreover, the DANP analysis demonstrated that prioritizing key strategies such as clean energy infrastructure (IT3) and public collaboration (W3) can have transformative effects. The study also underscored the importance of fostering inclusivity by engaging diverse stakeholders, ranging from policymakers to local communities, in the decision-making process. These findings highlight the critical need for a holistic approach to energy governance that aligns with both short-term needs and long-term sustainability goals.

Future implications of this research extend beyond the energy sector. The proposed E-FLEX 5.0 framework offers a replicable model for addressing systemic challenges across domains such as urban planning, water resource management, and climate change mitigation. The emphasis on stakeholder engagement and continuous evaluation ensures adaptability to evolving conditions and emerging technologies. As global energy transitions accelerate, the findings of this study can guide policymakers and practitioners in implementing participatory, data-driven, and sustainable solutions to address energy and environmental challenges in both regional and global contexts. By fostering innovation and collaboration, this research contributes to the development of resilient systems capable of meeting the demands of the Society 5.0 vision.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Appendices

Appendix A. Significant relationships between strategies (cells with values of 1)

	S1	S2	S3	S4	IT1	IT2	IT3	IT4	W1	W2	W3	W4	W5	W6	W7	W8	W9
S1	0	1	1	1	1	0	0	1	1	0	0	0	1	1	1	0	1
S2	1	0	1	1	0	1	1	0	1	1	0	1	0	1	1	0	1
S3	0	0	0	1	0	0	1	0	1	1	0	0	0	0	0	0	1
S4	1	0	1	0	1	0	1	1	1	1	0	0	0	0	0	0	1
IT1	1	1	0	1	0	1	1	1	1	1	0	1	1	1	0	1	1
IT2	1	1	0	1	1	0	1	0	0	1	0	1	0	0	0	1	1
IT3	1	0	1	1	1	1	0	1	0	0	0	1	1	0	0	1	1
IT4	1	1	1	0	1	1	1	0	0	1	0	1	0	0	1	1	1
W1	0	1	1	1	1	1	1	1	0	1	0	1	1	1	1	0	1
W2	0	1	1	1	1	1	0	0	1	0	0	1	1	1	1	0	1
W3	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1
W4	0	0	0	1	1	1	1	1	0	1	0	0	0	1	0	0	1
W5	0	1	0	1	1	1	1	1	0	1	0	1	0	1	1	0	1
W6	0	0	1	1	0	0	1	1	0	1	0	1	0	0	1	1	0
W7	1	1	1	1	1	1	1	0	0	1	0	1	0	1	0	0	1
W8	0	1	1	1	1	0	1	1	1	0	0	1	1	1	1	0	1
W9	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0

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