DIGITAL TRANSFORMATION AND ADMINISTRATION INNOVATION

Citation: Esmaeili, M., Movahhedi, M. M., & Motamedi, M. (2025). Modeling the Improvement of the Technology Transfer Process in Iran's Petro-Refining Industry Using a System Dynamics Approach. *Digital Transformation and Administration Innovation,* 3(3), 1-13.

Received date: 2025-04-16 Revised date: 2025-06-14 Accepted date: 2025-06-28 Published date: 2025-07-08

Modeling the Improvement of the Technology Transfer Process in Iran's Petro-Refining Industry Using a System Dynamics Approach

Mansoureh Esmaeili[1], Mohammad Mehdi Movahhedi[2], Majid Motamedi[3*]

1. Department of Technology Management, Kish International Branch, Islamic Azad University, Kish Island, Iran
2. Department of Industrial Management, SR. C., Islamic Azad University, Tehran, Iran
3. Department of Industrial Management, Nos.C., Islamic Azad University, Noshahr, Iran

*Correspondence: majidmotamedi@iau.ac.ir

Abstract

The main objective of this research is to model the technology transfer process in Iran's petro-refining industry using the system dynamics method in order to improve this process. This analysis assists decision-makers in identifying critical success factors and designing optimization strategies for the technology transfer process. Following the system dynamics approach, this study investigates the dynamics of variables affecting the development and improvement of the technology transfer process in Iranian petro-refineries through a review of relevant studies and interviews with industry experts. Eight subsystems were identified in this study: organizational and environmental infrastructures, technology monitoring and selection, technology acquisition, technology learning and localization, knowledge management, innovation system, technology development and improvement, and technology dissemination. The causal loop diagrams associated with these subsystems were developed using Vensim software. Ultimately, the analysis of the causal loop diagrams indicates that the primary enabler for optimal technology transfer in Iranian petro-refineries is the existence of an organizational body dedicated to the leadership, coordination, and control of the technology transfer process. The absence of such an organization will hinder the optimal completion of the technology transfer process.

Keywords: System dynamics, technology transfer, petro-refinery.

1. Introduction

In the age of knowledge, it is knowledge-based technology that is utilized to produce goods, deliver services, and optimize the use of limited and valuable resources (Khalil, 2000). Technology is the golden key to competition in the world of work and business, a prerequisite for economic growth, and the primary weapon in corporate rivalry. In today's global environment, success is highly dependent on the use of technology. Therefore, technology is one of the most vital components of commercial and industrial organizations, and the importance of acquiring technology for organizational success is well recognized (Bagherzadeh & Meftahi, 2011).

Organizations are constantly striving to access new technologies to gain a competitive edge. One of the most important ways to acquire technology is through technology transfer. In general, companies, due to the high costs and risks involved in developing new technologies, often do not conduct independent research and development within their own centers. Instead, to bridge the technology gap and achieve industrial development, they employ a technology transfer approach to acquire technologies (Hafeez et al., 2020).

In developing countries, technology transfer is one of the main pathways to economic and industrial growth (Naghizadeh et al., 2017). However, the success of technology transfer is highly dependent on the selection of efficient technologies from effective sources. Conceptually, technology transfer includes the selection of appropriate technologies, transfer via selected methods, and obtaining proper feedback from the transferred technology to refine its application (Milani Tabrizi et al., 2022).

Iran, with its vast oil reserves, is considered an influential producer in the global oil market, and the production of petroleum derivatives plays a critical role in generating national revenue. In this context, the petrochemical industry is one of the country's main industrial sectors and a leader in creating added value from oil and gas resources. As the top contributor to non-oil exports, this industry plays a fundamental role in economic prosperity, sustainable development, and the localization of technology (Esmaili Pour Masouleh & Garshasbi, 2016).

Accordingly, this issue is emphasized in national policy documents, particularly the general policies of the Resistance Economy, which highlight the development of petro-refineries as a means to mitigate vulnerability in oil and gas revenues through value chain expansion and increased exports of these products (Bayat et al., 2022).

Technology is broadly defined as a collection of knowledge, processes, tools, methods, and systems utilized for the production of goods and delivery of services. It is essentially the means by which goals are achieved through structured application of technical capabilities (Khamseh & Azadi, 2011; Khamseh et al., 2023). Technology transfer, on the other hand, is the process of sharing advanced knowledge, tools, and procedures with the goal of enhancing economic and industrial competencies. When aligned with sustainable development policies and supported by investment in education, technology transfer can play a vital role in narrowing technological inequalities (Faghih et al., 2023; Fayyaz et al., 2020). The technology transfer process consists of a sequence of activities including identification and selection of technology, acquisition, adaptation, absorption, exploitation, development, and dissemination (Radfar & Khamseh, 2021). In analyzing complex systems such as technology transfer in industrial contexts, system dynamics emerges as a powerful methodology that models feedback structures and interactions among variables, enabling simulation-based scenario analysis to better understand systemic behaviors. Petro-refineries—integrated facilities combining refining and petrochemical production—are designed not only to produce fuels but also to supply feedstock to downstream chemical and polymer complexes. Their development increases profitability and enhances competitiveness in global oil markets, making them essential assets in advanced industrial economies (Moeini Jazani et al., 2020; Mohammadi, 2023).

Technology transfer is a strategic tool that enables access to and acquisition of advanced capabilities and plays a key role in facilitating national growth and development (Manjily & Taleghani, 2015, 2016). Various studies emphasize that the characteristics of the technology recipient significantly affect the success of transfer (Lavoie & Daim, 2020). The petrochemical industry is a pivotal sector in the global economy, contributing notably to gross domestic product (Esmaili Shahmirzadi, 2020; Hakkak & Hassanvand, 2020), with official statistics estimating that nearly 10% of global GDP originates from its value chain, while in Iran it contributes approximately 5% (Hakkak & Hassanvand, 2020). Successful technology transfer in this industry is considered a means of preserving competitive advantage, and scholars have proposed innovative frameworks for enhancing technology absorption capabilities (Fayyaz et al., 2020). Several researchers, including Manjili and Taleghani (2015), have identified key factors influencing transfer—such as the agent, medium, subject, and environment—with the subject of transfer exerting the greatest influence (Manjily & Taleghani, 2015). Cultural dynamics, including national and organizational culture, also affect transfer outcomes (Manteghi et al., 2015), while absorptive capacity and organizational competence contribute to technological development (Mokhtarzadeh & Rashidi Astaneh, 2016). Radfar and Khamseh (2021) delineate three main stages of transfer: selection and acquisition, installation, and maintenance, encompassing six subphases including adaptation and dissemination (Radfar & Khamseh, 2021). Horner et al. (2019) present a cohesive framework that incorporates sender and recipient features, transferable content, and methods of transfer (Horner et al., 2019). Min et al. (2019) underscore the need for active, collaborative partnerships to enhance learning and absorptive capacity (Min et al., 2019). Khamseh et al. (2023) add phases of learning and innovation to the transfer process, asserting that repeated transfers facilitate organizational learning (Khamseh et al., 2023). Furthermore, Fayyaz et al. (2020) proposed a Delphi-based model for public-private partnerships in downstream oil and gas sectors, while Gholamnejad et al. (2022) examined structural capital's role in facilitating technology transfer in petrochemical industries (Fayyaz et al., 2020). Sadeghi et al. (2022) employed a system dynamics approach to study technology transfer capacities in the polymer pipe sector, identifying international collaboration and institutional experience as central schema (Sadeghi Marznaki et al., 2022), while Moeini et al. applied system dynamics to simulate knowledge management strategies in the oil industry, suggesting combined policy approaches for successful implementation (Moeini Jazani et al., 2020). Overall, despite the acknowledged importance of technology transfer in Iran's petro-refining industry, a comprehensive model capturing its complex dynamics remains absent. The use of a system dynamics approach holds promise for filling this gap by offering a deeper understanding of key variable interactions.

Petro-refineries, as one of the most important industrial infrastructures of the country, play a key role in producing petroleum, gas, and petrochemical products. The process of technology transfer from international companies, universities, and research centers to the industry—especially in the petro-refining sector—is one of the most critical factors in a nation's industrial and economic development. Despite significant efforts, this process in Iran has yet to be properly implemented. Numerous barriers and challenges hinder the effective transfer of technology. Naturally, due to its heavy dependence on advanced technologies, this industry requires an efficient and sustainable technology transfer process. However, challenges such as the lack of indigenous technical knowledge, international constraints, and institutional capacity limitations have created serious obstacles to technology transfer in this sector. The central problem of this study is how to develop a model for optimizing the technology transfer process in petro-refineries using the system dynamics analysis tool.

2. Methods and Materials

This research, based on data collection from managers and experts in petro-refinery companies, is an applied and descriptive-survey study. The applied methodology is illustrated in Figure 1. The process begins with an analysis of the Iranian petro-refining industry, during which strategic challenges within the sector are identified. A review of the literature indicates that among the threats and opportunities in this industry, the most significant strategic bottleneck hindering development is the process of technology transfer.

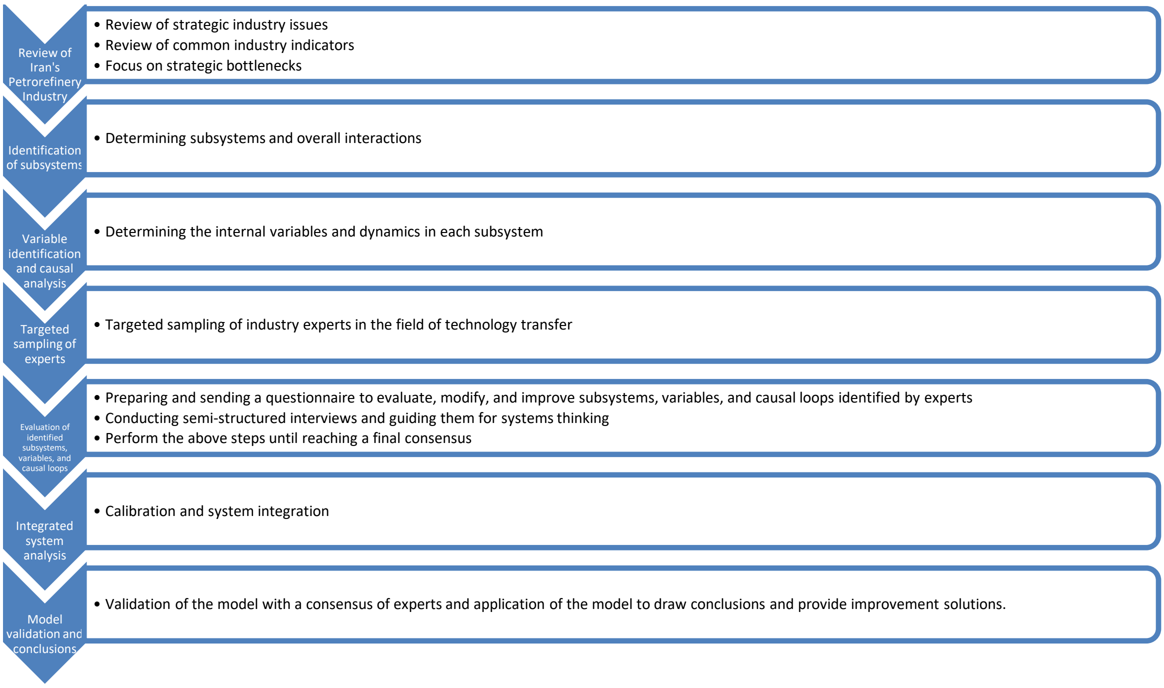

Figure 1. Stages of Research Methodology

Subsequently, based on library studies, subsystems and their interactions were identified. In the next steps, the variables and internal dynamics of each subsystem were defined, and industry experts were selected using purposive sampling. These individuals were required to possess not only high-level technical and managerial academic knowledge but also hands-on experience with technology transfer projects in petro-refineries, along with willingness and adequate time to collaborate with the research. Ultimately, 10 experts with 18 to 36 years of experience and at least a master's degree were selected.

In the following stages, the subsystems, variables, and causal loop diagrams identified by the experts were evaluated through a structured questionnaire until consensus was achieved. Finally, system calibration and integration were carried out, and the final model was validated using structural consistency tests, receiving expert confirmation and being used for deriving conclusions and improvement proposals. The developed model includes 8 subsystems and 93 key indicators and variables. Moreover, the study adopts a systems approach using VENSIM software.

3. Findings and Results

As previously described, the general stages of the technology transfer process can be outlined as follows:

1. **Technology Selection and Acquisition**: The process of choosing the most appropriate technology among available alternatives, followed by negotiation and contractual acquisition.
2. **Adaptation of Imported Technology**: The precise alignment of the acquired technology with the project's needs, national resources, and contextual conditions.
3. **Absorption of Imported Technology**: Full awareness and understanding by the recipient of all components of the acquired technology.
4. **Application of Transferred Technology**: Utilizing the acquired technology in operational contexts.
5. **Development of Imported Technology**: Leveraging the acquired technology, along with experience, skills, and internal research findings, to create improved and innovative processes and products.
6. **Dissemination of Imported Technology**: Deepening and expanding the technological components throughout the national context.

These steps are depicted in *Figure 2*.

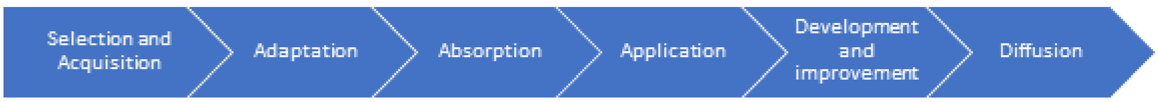

Figure 2. General Stages of Technology Transfer Process

In the present study, these stages are categorized into the following subsystems:

1. **Selection and Acquisition Stage**:
   - Technology Monitoring and Selection
   - Technology Acquisition

2. **Adaptation, Absorption, and Application Stages**:
   - Knowledge Management
   - Learning and Localization
3. **Development, Improvement, and Dissemination Stages**:
   - Innovation System
   - Technology Development and Improvement
   - Technology Dissemination

The causal loop diagrams of the subsystems represent the components that influence the improvement of the technology transfer process in Iran's petro-refining industry. *Figure 3* illustrates the identified subsystems, their variables, and interrelationships.

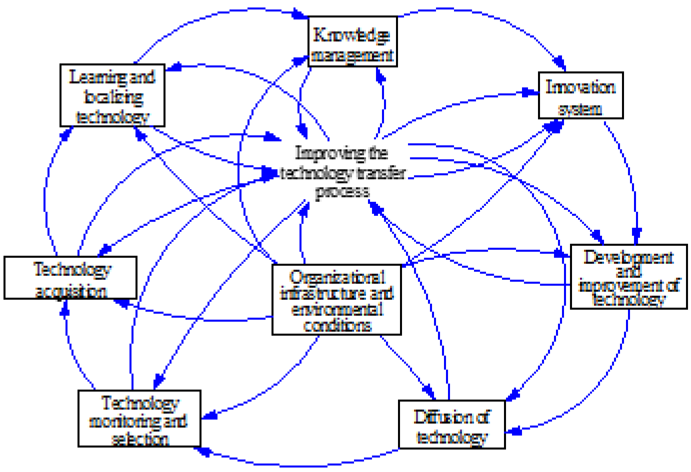

Figure 3: Subsystems Related to the Improvement of the Technology Transfer Process in the Iranian Petro-Refining Industry

It is also important to note that although the subsystem titled "Organizational Infrastructure and Environmental Conditions"—which encompasses organizational culture, resources, structure, and broader economic and social conditions—is not a direct part of the technology transfer process, it plays a critical role in improving this process, as it influences all other subsystems.

Following the identification of subsystems relevant to technology transfer improvement in Iran's petro-refining sector, the next step involves analyzing the impact of key variables by constructing their causal loop diagrams. As mentioned earlier, although organizational infrastructure and societal environmental conditions are not direct components of the technology transfer process, they provide the foundation for optimal implementation. Key elements of this subsystem include policy and procedures, organizational values and culture, suitable structures, systems and technologies, and an attractive economic and social environment for retaining specialized human resources. Based on expert consensus and the organizational infrastructure identified, causal loop diagrams for the subsystems were developed. These diagrams illustrate how influential variables are interconnected and reveal the dynamics that can enhance or diminish the quality of the technology transfer process.

Figure 4 presents the causal loop diagram related to technology monitoring in improving the technology transfer process within Iranian petro-refineries. It illustrates the relationships among the main variables in the form of eight reinforcing loops. For instance, the reinforcing loop *R1* indicates that the foundation of technology monitoring in petro-refineries is the existence of a dedicated technology development organization and supporting managerial infrastructure. This entity is responsible for overseeing and guiding activities within the technology monitoring subsystem according to the refinery's strategic goals. The organization’s key functions include promoting international collaborations, as illustrated in reinforcing loop *R2*, which mutually strengthens the development organization itself. Conversely, international sanctions weaken the effectiveness of this organization.

Reinforcing loop *R3* shows the positive impact of governmental support on the organization, which in turn can help attract further state backing for enhancing the technology transfer process. Additionally, factors such as the growing demand for petrochemical products, both domestic and global competition, and scientific and technological advancements exert reinforcing and reciprocal effects on the organization—represented by loops *R4*, *R5*, and *R6*. Finally, identifying critical technology domains is essential in the technology monitoring and scouting process.

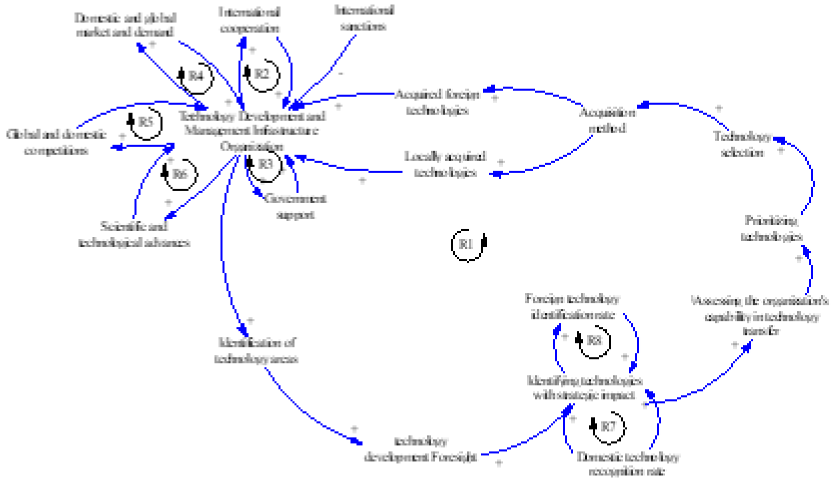

Figure 4. Causal Loop Diagram for Technology Monitoring and Selection in Technology Transfer Improvement

Understanding which technology domains are important to organizational managers and ensuring access to relevant databases are critical elements in the initial phase of technology monitoring. In the subsequent step, technology foresight becomes a significant focus within the monitoring process. This foresight is influenced by scientific and technological advancements, competitive pressures, and both domestic and international market demands, all of which stimulate greater motivation and activity in technology development forecasting.

Naturally, once technological foresight has been conducted, the next stage involves identifying technologies with strategic impact. This is shaped by reinforcing loops R7 and R8, representing the rates of identification of foreign and domestic technologies, respectively. As these rates increase, the system’s strategic focus is strengthened.

Organizational capability in acquiring technology is another crucial issue, as each organization must prioritize, select, and acquire technologies based on its absorptive capacity. Failing to do so may result in halting the technology exploitation process in its initial stages. Moreover, the method of acquisition plays a key role in the technology transfer process and should align with the technology’s maturity level, internal capabilities of the recipient organization, and strategic goals—ensuring a balance between transfer speed, cost, and absorption depth.

Figure 5 illustrates the relationships among variables in the causal loop diagram related to technology acquisition in improving the technology transfer process in Iranian petro-refineries. Three reinforcing loops (R9, R10, R11) and one balancing loop (B1) are depicted. The first step in technology acquisition is familiarity with legal frameworks and contractual issues, which play a pivotal role in finalizing technology transfer agreements.

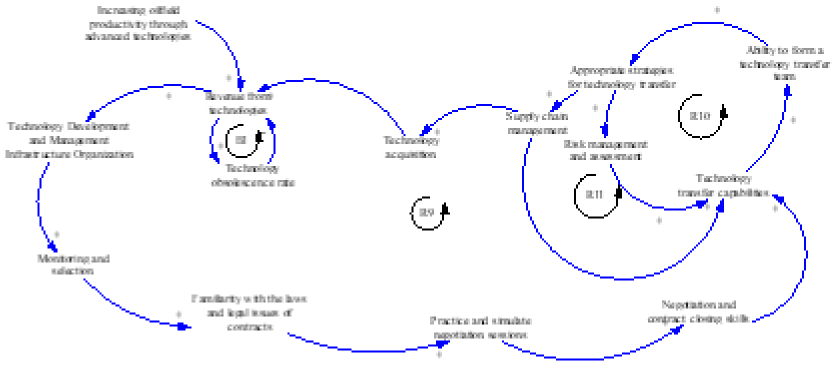

Figure 5. Causal Loop Diagram of Technology Acquisition in Petro-Refineries

On the other hand, technology transfer capabilities—represented in loops R10 and R11—play a critical role in successful acquisition. These include the ability to form technology transfer teams and adopt effective strategies for risk management, supply chain evaluation, and control. Such competencies are essential for completing the transfer process in petro-refining industries.

Balancing loop B1 illustrates that revenue derived from acquired technologies increases with stronger acquisition efforts. However, the obsolescence rate of technologies negatively impacts this revenue. Additionally, an increase in refinery feedstock, linked to enhanced oil field productivity through advanced technologies, will lead to higher technology-derived revenues.

The causal loop diagram on learning and localization of technology includes two reinforcing loops: R12 and R13. The Technology Development Organization plays a key role in strengthening these loops as it is responsible for guiding learning and localization and overseeing knowledge management. In R12, the number of technologies in active use in the petro-refining sector positively influences technical and specialized knowledge in the industry. This increase, in turn, strengthens the knowledge base of the Technology Development Organization and enhances learning and localization efforts.

In R13, knowledge management within the organization accelerates, improves, and refines the localization process. However, two balancing loops—B2 and B3—moderate these reinforcing effects. B2 addresses the total cost of localization projects; as learning and localization strengthen, costs decrease, which enables more projects to be initiated, further reinforcing the process. Therefore, a balance must be struck between costs and the number of localization projects.

Balancing loop B3 demonstrates that as learning and localization improve, the time needed to complete projects decreases. Conversely, extended project durations feed back into more extensive learning and localization. Ultimately, equilibrium must be achieved between duration and learning outcomes.

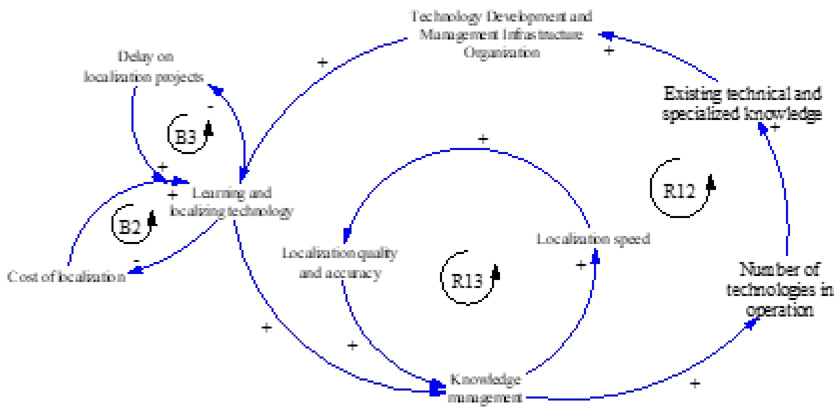

Figure 6. Causal Loop Diagram of Learning and Localization in Technology Transfer

The first step in institutionalizing knowledge management within an organization is establishing and promoting a knowledge-based organizational culture, represented by reinforcing loop R14. This cultural foundation fosters continuous learning, knowledge sharing, employee collaboration, and the formation of interdisciplinary teams—all of which facilitate the knowledge management system.

Effective knowledge management also depends on the budget allocated for documentation and IT infrastructure. The greater the number of documented technologies, the higher the budget tends to be, as illustrated by reinforcing loop R15. This budget also supports the implementation of knowledge management systems. The Technology Development Organization and its managerial infrastructure play a crucial role in managing knowledge. This organization acts as the planner, coordinator, and driver of all knowledge management activities in petro-refineries, a function emphasized by reinforcing loop R16.

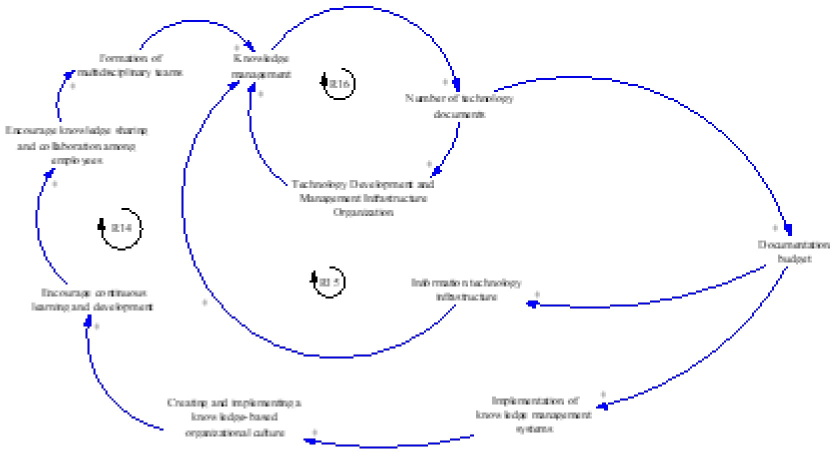

Figure 7. Causal Loop Diagram of Knowledge Management

This diagram includes three reinforcing loops (R17, R18, R19) and three balancing loops (B4, B5, B6). In R17, global technology trends and overarching governmental support policies stimulate motivation for technological independence. However, dependence on foreign technologies—while enhancing external acquisition obligations—negatively impacts the desire for independence, represented by balancing loop B4.

In R18, the drive for independence boosts a development-oriented rather than a project-based approach. Cost competitiveness and product diversification have positive reinforcing effects on this development-centered perspective.

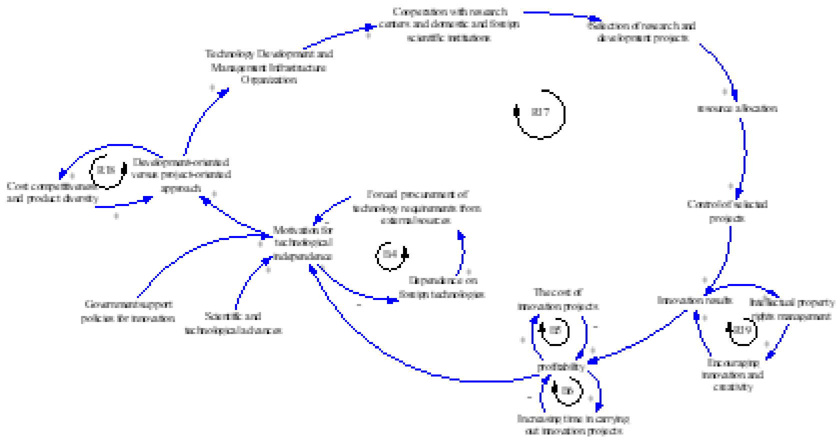

Figure 8. Causal Loop Diagram of the Innovation System

A development-focused approach encourages the creation of a Technology Development Organization and its corresponding managerial infrastructure. This organization enhances and facilitates causal mechanisms across all stages of the technology transfer process in petro-refineries. It positively affects collaboration with research centers and domestic and international scientific institutions. Additionally, the presence of skilled, experienced personnel strengthens the selection of suitable R&D projects, resource allocation, and oversight.

Proper management of R&D projects by the Technology Development Organization positively influences innovation outcomes in the petro-refining industry. Moreover, intellectual property management and the promotion of creativity and innovation reinforce these results, as depicted in R19. Naturally, improved innovation outcomes lead to increased refinery profitability. However, project cost and duration act as counterweights to this process, illustrated by balancing loops B5 and B6.

The presence of a Technology Development and Improvement Organization along with appropriate managerial infrastructures reinforces the area of technological enhancement and advancement within petro-refineries. This dynamic is represented by reinforcing loop **R20**. Strengthening this organizational function has a reinforcing impact on resource and process optimization, value chain completion, and the digitization and smartification of operational processes, depicted respectively by reinforcing loops **R21**, **R22**, and **R23**.

However, the increased duration of development and improvement projects, as well as their associated costs, exert a balancing effect on technological advancement in petro-refineries. These effects are shown by balancing loops **B7** and **B8**, which act to moderate excessive resource consumption and timeline extensions that may undermine overall performance improvement initiatives.

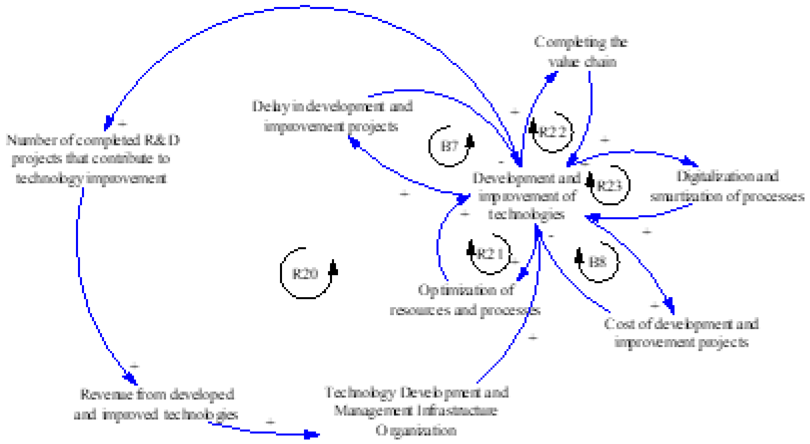

Figure 9. Causal Loop Diagram of Technology Development and Improvement

Given the necessity of specialized expertise for effective technology dissemination, the Technology Development Organization and its managerial infrastructure play a pivotal role in facilitating technology diffusion across the petro-refining industry. This is highlighted by reinforcing loop **R24**. Within this organizational structure, technological market needs are identified and assessed using market research and economic evaluation methods.

This organization strengthens negotiation skills and contract finalization capabilities. Moreover, due to the technical expertise embedded within the organization, it positively influences education and technology transfer processes—further enhanced by training programs and collaborations with universities.

With the presence of experts and industry elites within the Technology Development Organization and its managerial infrastructure, industrial implementation of disseminated technologies becomes feasible. This implementation includes on-site installation and performance monitoring, advancing technology dissemination to a more mature stage. The process is reinforced through continuous feedback and improvement cycles, involving data collection and technology updating.

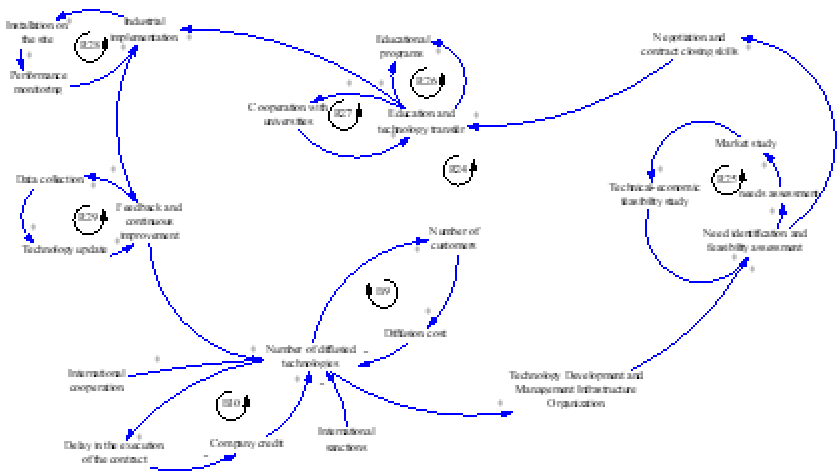

Figure 10. Causal Loop Diagram of Technology Dissemination

Naturally, international collaborations have a positive impact on the number of technologies disseminated. Although an increase in the number of disseminated technologies leads to a broader customer base, it is also associated with higher dissemination costs, forming a balancing loop on technology rollout. Additionally, delays in contract execution reduce the company's credibility from the customer's perspective and negatively affect technology dissemination. These effects are captured by balancing loops **B9** and **B10**, respectively.

4. Discussion and Conclusion

The findings of this study aimed at modeling and improving the technology transfer process in Iranian petro-refineries through a system dynamics approach reveal that the effective functioning of this process depends on the integration of eight interrelated subsystems: organizational and environmental infrastructure, technology monitoring and selection, technology acquisition, learning and localization, knowledge management, innovation system, technology development and improvement, and technology dissemination. The causal loop diagrams constructed for each subsystem illustrate the complex network of reinforcing and balancing feedback loops that shape the dynamics of technology transfer. These diagrams allow for a better understanding of how managerial and structural factors, external pressures, and internal capabilities interact to facilitate or hinder the optimization of technology transfer in the petro-refining context.

The analysis showed that the cornerstone of successful technology monitoring in Iranian petro-refineries lies in the existence of a dedicated technology development organization with adequate managerial infrastructure. This organization plays a vital role in identifying technology priorities, facilitating international cooperation, navigating sanctions, and aligning technology foresight activities with national and industrial goals. These findings are consistent with Sadeghi et al. (2022), who emphasized the significance of such entities in managing feedback loops related to technological prioritization, acquisition, and adaptation (Sadeghi Marznaki et al., 2022). Moreover, the study found that technology acquisition is influenced not only by legal familiarity and strategic negotiation skills but also by the organization's internal capacity for forming technology transfer teams and risk-managing supply chains. These insights align with Manjili and Taleghani (2015), who identified critical elements such as the transfer agent, medium, subject, and environment, and emphasized the strategic weight of the "subject of transfer." (Manjily & Taleghani, 2015).

The learning and localization subsystem is reinforced by the number of technologies actively used in the industry, which contributes to technical expertise and organizational knowledge. This is supported by Khamseh et al. (2023), who argued that repeated exposure to technology transfer processes leads to organizational learning and innovation. Additionally, the study confirms the role of knowledge management in accelerating and refining the localization process, where organizational culture and documentation infrastructure play central roles (Khamseh et al., 2023). Horner et al. (2019) similarly underscored the influence of organizational and managerial factors in enabling effective knowledge capture, sharing, and deployment during technology absorption (Horner et al., 2019). The balancing loops in this subsystem—specifically those related to cost and time—demonstrate the importance of establishing equilibrium in resource allocation, consistent with the arguments of Makhtarzadeh and Rashidi (2016), who found that absorptive capacity and cost control are determinants of successful technological adaptation.

The innovation system was shown to be a function of both internal and external drivers, including global trends and national innovation policies. Reinforcing loops identified the motivational impact of striving for technological independence and transitioning from project-based to development-based models. These findings support the conclusions of Min et al. (2019), who noted that modern technology transfer mechanisms must go beyond inter-organizational collaboration and require active participation from all stakeholders to enhance mutual learning and absorptive capacity. Furthermore, the development and improvement subsystem emphasized the role of digitalization, value chain completion, and process optimization—all of which were positively impacted by the presence of a central innovation-oriented body. This corroborates the findings of Moeini et al., whose dynamic simulation of knowledge management policies revealed that combining documentation, training, and inter-organizational cooperation leads to superior R&D performance and technological advancement.

In the dissemination subsystem, the study found that identifying market needs and enhancing industrial implementation capabilities are pivotal. The Technology Development Organization facilitates training programs and university collaborations, enabling the rollout of technologies at scale. Gholamnejad et al. (2022) reached similar conclusions in their study of structural capital's role in petrochemical firms, where market-oriented dissemination mechanisms and technological maturity were central to success (Gholamnejad et al., 2022a, 2022b). The study also found that dissemination effectiveness is tempered by cost and contract delays, indicating the need for tighter project management and stronger client engagement. Bayat et al. (2022) stressed the importance of integrating dissemination strategies with broader economic and infrastructural development plans, especially under sanction-induced constraints (Bayat et al., 2022).

Overall, this study contributes a systems-based, holistic model of technology transfer tailored to the Iranian petro-refining sector. It goes beyond linear or static frameworks by offering dynamic, feedback-sensitive representations of how different managerial subsystems interact to shape technological capabilities. The research framework echoes the conceptual structure suggested by Radfar and Khamseh (2021), who outlined a multi-phase process model for technology transfer, including selection, acquisition, adaptation, exploitation, development, and dissemination (Radfar & Khamseh, 2021). Importantly, this study integrates those phases within a unified systemic architecture and quantifies their interdependencies through causal loop modeling.

This study, despite its strengths, faces several limitations. First, the model relies heavily on expert judgment, which—while valuable—introduces subjectivity and may be influenced by individual biases or experiences limited to specific organizations. Second, the study is context-specific to the Iranian petro-refining industry, which may reduce the generalizability of its findings to other sectors or geographic regions. Third, although system dynamics modeling enables simulation of complex interactions, the lack of empirical time-series data constrained the model's capacity for quantitative validation. Additionally, political and economic conditions such as international sanctions, which significantly influence technology access and transfer in Iran, were treated as external forces and not modeled in depth within the system.

Future research could explore several promising directions. One important avenue would be the integration of quantitative simulation into the causal loop model through the development of stock-and-flow diagrams and the use of real-world data. This would enhance model precision and allow for scenario-based policy analysis. Additionally, comparative studies across industries—such as pharmaceuticals, energy, or manufacturing—could test the model's robustness and adaptability. Researchers might also investigate the role of emerging technologies such as blockchain and artificial intelligence in enabling secure and efficient technology transfer processes. Furthermore, examining the influence of international legal frameworks, trade agreements, and intellectual property rights on technology transfer in similar economies would provide valuable insights for policy development.

To improve the effectiveness of technology transfer in Iranian petro-refineries, several practical steps are recommended. First, institutionalizing a Technology Development Organization with clearly defined mandates for coordination, training, and strategic planning is essential. Second, enhancing organizational capacity through investment in knowledge management systems, technical training, and documentation practices will support long-term learning and localization. Third, structured collaboration with universities, international technology providers, and research institutes can help bridge capability gaps and accelerate innovation. Finally, balancing cost, time, and performance in technology projects requires robust project management frameworks and performance monitoring systems that align operational decisions with strategic objectives.

Ethical Considerations

All procedures performed in this study were under the ethical standards.

Acknowledgments

Authors thank all who helped us through this study.

Conflict of Interest

The authors report no conflict of interest.

Funding/Financial Support

According to the authors, this article has no financial support.

References

Bagherzadeh, M., & Meftahi, J. (2011). Investigating Factors Affecting Successful Technology Transfer in Screw Compressor Industries of Iranian Companies. *Beyond Management*, *4*(16), 125-154. https://sanad.iau.ir/en/Article/976152

Bayat, A., Rahbar, F., Vatani, A., & Razavi, S. A. (2022). An Analysis of the Value Chains of the Petrochemical Industry with a Focus on the New Approach of the Petro-Refinery. *Petroleum Business Review*, *6*(4), 115-133. https://pbr.put.ac.ir/article_166828.html

Esmaili Pour Masouleh, E., & Garshasbi, A. (2016). Identifying Challenges and Presenting Solutions for Developing the Petrochemical Industry from the Perspective of Financial Integration of Listed Companies. *Commercial Reviews*, *80*. https://barresybazargani.itsr.ir/article_30539.html?lang=en

Esmaili Shahmirzadi, H. (2020). Appropriate Market Development Strategies for Iran's Petrochemical Industry. *Interdisciplinary Strategic Knowledge Quarterly*, *10*(40), 33-56. https://smsnds.sndu.ac.ir/article_1170.html?lang=en

Faghih, H. R., Ghazi Nouri, S. S., & Elyasi, M. (2023). Validation of Technology Acquisition Methods in Development Process of an Iranian Defense Industry. *Scientific Journal of Management Improvement*, *17*(2), 60-87. https://www.behboodmodiriat.ir/article_175905.html?lang=en

Fayyaz, S., Faghihi, A., & Sayad Shirakesh, S. (2020). Public-Private Partnership Model in Iran's Downstream Oil Industries. *Public Management Research*, *13*(50), 31-55. https://journal.iams.ir/article_351.html

Gholamnejad, M., Movahedi, M., Manteghi, M., & Aliyari, S. (2022a). Presenting a Model for Measuring Technology Transfer Success in Iran's Petrochemical Industries. *Technology Development Management Quarterly*, *9*(4). https://jtdm.irost.ir/article_1169.html

Gholamnejad, M., Movahedi, M., Manteghi, M., & Aliyari, S. (2022b). Presenting a Structural Capital Model Centered on Technology Transfer in Iran's Petrochemical Industries. *Innovation Management Journal*, *11*(2), 105-145. https://www.sid.ir/paper/1039715/en

Hafeez, A., Shamuddin, A. B., Saeed, B., Mehmood, A., & Andleeb, N. (2020). Exploring the impact of absorptive capacity on technology transfer effectiveness: A conceptual framework. *International Journal of Scientific & Technology Research*, *9*(3), 4779-4792. https://www.researchgate.net/publication/340162489_Exploring_the_Impact_of_Absorptive_Capacity_on_Technology_Transfer_Effectiveness_A_conceptual_Framework

Hakkak, M., & Hassanvand, J. (2020). Transformational Leadership, Creativity and Innovation in Petrochemical Industry: The Mediating Role of Productive Work Behaviors. *Transformation Management Research Journal*, *12*(23). https://tmj.um.ac.ir/article_30620.html?lang=en

Horner, S., Jayawarna, D., Giordano, B., & Jones, O. (2019). Strategic choice in universities: Managerial agency and effective technology transfer. *Research Policy*, *48*(5), 1297-1309. https://doi.org/10.1016/j.respol.2019.01.015

Khalil, T. M. (2000). *Management of Technology: The Key to Competitiveness and Wealth Creation*. McGraw-Hill. https://books.google.com/books/about/Management_of_Technology.html?id=0dWuAAAACAAJ

Khamseh, A., & Azadi, A. (2011). Evaluating Technology Transfer Success and Determining the Best Transfer Method Using AHP Model: Case Study of AzarAb Industries. *Technology Growth*, *7*(26), 3-13. https://www.magiran.com/paper/913804/

Khamseh, A., Farhanifar, F., & Forouzanmehr, M. (2023). *Technology Transfer Process Management*. Saraafraz Publications.

Lavoie, J. R., & Daim, T. (2020). Towards the assessment of technology transfer capabilities: An action research-enhanced HDM model. *Technology in Society*, *60*, 101-217. https://doi.org/10.1016/j.techsoc.2019.101217

Manjily, P., & Taleghani, M. (2015). Technology transfer strategy in the upstream oil industry (oil fields development) of the Islamic Republic of Iran has provided the effectiveness of technology transfer model. *International Journal of Operational Research*, *5*(4), 87-101. https://www.researchgate.net/publication/341070695_Technology_transfer_strategy_in_the_upstream_oil_industry_oil_fields_development_of_the_Islamic_Republic_of_Iran_has_provided_the_effectiveness_of_technology_transfer_model

Manjily, P., & Taleghani, M. (2016). Determine the Factors Affecting the Technology Transfer in the Development of Iranian Oil Fields by Using Contingent Effectiveness Model of Technology Transfer. *Kuwaiti Chapter of Arabian Journal of Business and Management*

Review, *5*(10). https://www.researchgate.net/publication/307869039_Determine_the_Factors_Affecting_the_Technology_Transfer_in_the_Development_of_Iranian_Oil_Fields_by_Using_Contingent_Effectiveness_Model_of_Technology_Transfer

Manteghi, M., Naghizadeh, M., Safardost, A., & Rozehsara, M. (2015). The role of organizational culture on the effectiveness of technology transfer projects in Iran. *Journal of Technology Development Management*, *3*(1), 9-30. https://jtdm.irost.ir/article_352.html?lang=en

Milani Tabrizi, M., Alamtabriz, A., Fallah, M., & Kazemipoor, H. (2022). Development of Main Success Factors in Technology Transfer: An Empirical Study of Iranian Oil Industry. *Journal of Industrial Engineering International*, *18*(4). https://sanad.iau.ir/Journal/jiei/Article/1039537

Min, J. W., Vonortas, N. S., & Kim, Y. (2019). Commercialization of transferred public technologies. *Technological Forecasting and Social Change*, *138*, 10-20. https://doi.org/10.1016/j.techfore.2018.10.003

Moeini Jazani, R., Kasraei, A. R., Aslizadeh, A., & Sohrabi, T. (2020). Developing a Dynamic Knowledge Management Model for Iran's Oil Industry Using System Dynamics (SD) Approach. *Strategic Management in Industrial Systems Quarterly*, *15*(52), 67-87. https://journals.iau.ir/article_675715.html?lang=en

Mohammadi, R. (2023). Legal Analysis of Smart Contracts in Oil, Gas and Petrochemical Sectors. *International Nations Research Journal*, *8*(87). https://ensani.ir/fa/article/534205/

Mokhtarzadeh, N., & Rashidi Astaneh, M. (2016). Investigating the Effect of Technological Sensemaking and Organizational Capability on Innovative Performance with Emphasis on Absorptive Capacity Mediating Role. *Technology Development Management Quarterly*, *3*(5), 9-39. https://jtdm.irost.ir/article_519.html?lang=en

Naghizadeh, M., Amini, R., & Nouri, S. (2017). A Context-Based Approach to Technology Transfer Challenges in International Commercial Contracts in Iran. *Innovation Management Journal*, *6*(1), 1-19. https://www.nowavari.ir/article_57421.html?lang=en

Radfar, R., & Khamseh, A. (2021). *Technology Management*. Scientific and Cultural Publishing.

Sadeghi Marznaki, Y., Khamseh, A., & Hosseini Shakib, M. (2022). A system dynamics approach for investigating technology transfer capacities in Iranian polymer pipe and fittings industry. *Technology Analysis & Strategic Management*. https://www.researchgate.net/publication/358829472_A_system_dynamics_approach_for_investigating_technology_transfer_capacities_in_Iranian_polymer_pipe_and_fittings_industry